ISSN 2073–7599 (print)
ISSN 2618–6748 (online)

Agricultural MACHINERY and TECHNOLOGIES

SEL'SKOKHOZYAYSTVENNYE MASHINY I TEKHNOLOGII

Tom 12 N 4 2018

Vol. 12 N 4 2018

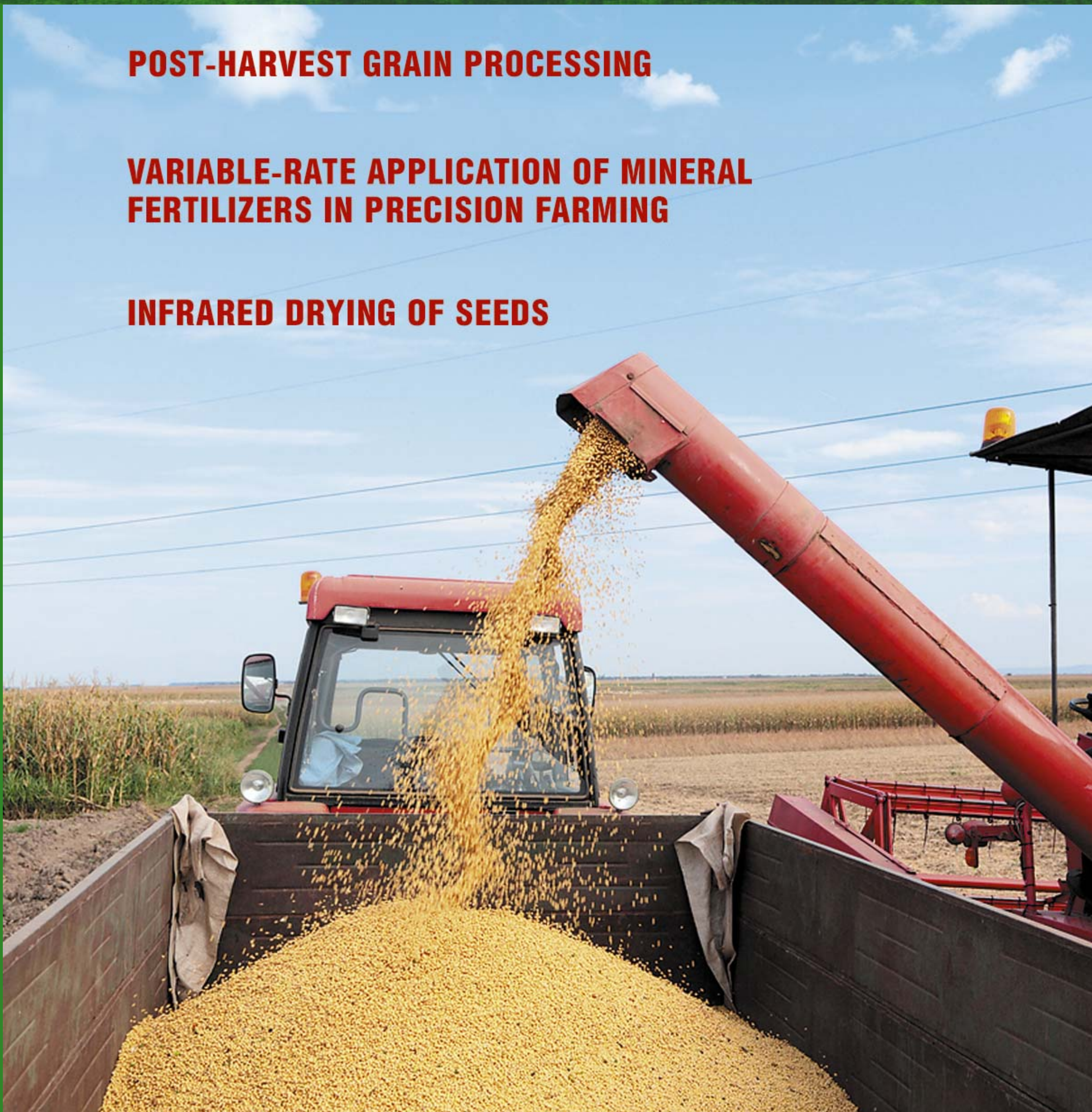
NAUCHNO-TEORETICHESKIY ZHURNAL

SCIENTIFIC-THEORETICAL JOURNAL

POST-HARVEST GRAIN PROCESSING

VARIABLE-RATE APPLICATION OF MINERAL FERTILIZERS IN PRECISION FARMING

INFRARED DRYING OF SEEDS



Agricultural MACHINERY and TECHNOLOGIES

Founder and publisher: Federal State Budgetary Scientific Institution "Federal Scientific Agroengineering Center VIM" of the Russian Academy of Science

SCIENTIFIC-TEORETICAL JOURNAL

The journal is registered by Federal Agency for Supervision of Legislation Observance of Mass Communications Sphere and Cultural Heritage Protection Certificate ПИ No. ФС77-68608 from February, 3, 2017

The journal is included in the Russian Index of Scientific Citation (RISC).

Full texts of papers are available on the website of electronic library: elibrary.ru

Protected by the Russian Federal Law RF №5351-1 "On Copyright and Related Rights" dated July 9, 1993. Content is distributed under Creative Commons Attribution 4.0 License. Violations are subject to prosecution.

EXECUTIVE EDITORS:
Gorelova L.A.,
Bizhaev V.V.,
Nurbagandova R.M.
Translation into English - Aleksei Alipichev

EDITORIAL OFFICE'S ADDRESS
109428, Moscow,
1st Institutskiy proezd, 5
Tel.: +7 (499) 174-88-11
+7 (499) 174-89-01
http://www.vimsmit.com
e-mail: smit@vim.ru

Printed by FSAC VIM
Russian Academy of Science
The format is 205 × 290 mm
The issue was submitted for printing on 15.08.2018
The circulation is 500 copies

EDITOR-IN-CHIEF

Andrey Yu. Izmaylov
Dr. Sc. (Eng.), Academician of the Russian Academy of Sciences, Academic Board Member of the Russian Academy of Sciences, Director of the Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

EDITORIAL BOARD

Viktor V. Al't
Dr.Sc.(Eng.), Professor, Academician of the Russian Academy of Sciences, Honoured Scientist of Russian Federation, Academician of NAS of Mongolia, Head of Scientific Division of Siberian Institute of Physics and Technology of Agrarian Problems, Novosibirsk, Russian Federation

Khristo I. Beloev
Dr. Sc. (Eng.), Professor, Corresponding Member of the Bulgarian Academy of Sciences, University of Ruse, Republic of Bulgaria

Mikhail N. Erokhin
Dr.Sc.(Eng.), Professor, Academician of the Russian Academy of Sciences, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Moscow, Russian Federation

Yuriy A. Ivanov
Dr.Sc.(Agr.), Academician of the Russian Academy of Sciences; Director of the All-Russian Scientific and Research Institute of Livestock Mechanization, Podolsk, Russian Federation

Yoshisuke Kishida
Academician, President Shin-Norinsha Co., LTD, Tokyo, Japan

Ivan M. Kulikov
Dr.Sc.(Econ.), Professor, Member of the Russian Academy of Sciences, Director of the All-Russian Horticultural Institute for Breeding, Agrotechnology and Nursery, Moscow, Russian Federation

Yakov P. Lobachevskiy
Dr.Sc.(Eng.), Professor, Corresponding Member of the Russian Academy of Sciences, First Deputy Director of the Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

Yuriy F. Lachuga
Dr.Sc.(Eng.), Professor, Academician of the Russian Academy of Sciences, Academician Secretary of Department of Agricultural Sciences at the Russian Academy of Sciences, Moscow, Russian Federation

Antonin Makhalek
Dr.Sc.(Eng.), Director of the Agricultural Machinery Research Institute, Prague, Czech Republic

Tadeush Pavlovsky
Dr.Sc.(Eng.), Professor, Director of the Industrial Institute of Agricultural Machines, Poznan, Poland

Vladimir D. Popov
Dr.Sc.(Eng.), Professor, Academician of the Russian Academy of Sciences, Head of the Research Direction of the Institute of Agroengineering and Environmental Problems of Agricultural Production, St.Peterburg, Russian Federation

Zharylkasyn S. Sadykov
Dr.Sc.(Eng.), Professor, Director of Research Institute of Agroengineering Problems and New Technologies, Kazakh National Agrarian University, Almaty, Republic of Kazakhstan

Dmitriy S. Strebkov
Dr.Sc.(Eng.), Professor, Academician of the Russian Academy of Sciences, Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

Yulia S. Tsench
Ph.D.(Ed.), Associate Professor, Head of Publishing Activity, Education and Technical information Department of the Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

Vyacheslav I. Chernoivanov
Dr.Sc.(Eng.), Professor, Academician of the Russian Academy of Sciences, Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

УДК 631.816.3

CC BY

DOI 10.22314/2073-7599-2018-12-4-4-9

Methods of Applying Fertilizers in Precision Agriculture

Gennady I. Lichman,
Dr.Sc.(Eng.), chief research associate,
e-mail: litchmangiv@yandex.ru;

Sergey A. Belykh,
Ph.D.(Eng.), senior research associate;
Aleksey N. Marchenko,
senior research associate

Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

Abstract. It is impossible to achieve the planned yields, product quality, and economic efficiency in agricultural production using only organic fertilizers. joint application of organic and solid mineral fertilizers solves the problem of replenishing the soil content of nitrogen, phosphorus and other elements used by plants. The authors have carried out the research of new methods of variable-rate application of mineral fertilizers in plant growing, allowing to increase the profitability of agricultural production. (*Research purpose*) is to develop new methods of variable-rate application of mineral fertilizers in crop production, which will allow increasing the profitability of crop production as compared with the conventional methods of applying fertilizers basing on average field indicators. (*Materials and methods*) The authors have developed a calculation technique implemented in the VBA Excel computer program for determining the main indicators: gross output, fertilizer saving, profit, etc. The main variable to change in the calculations is the planned yield based on average field parameters. At the end of the calculation process, the values of the best result for gross harvest output and profit are displayed on the screen. The research objects for the calculation were represented by elementary areas of crop areas of three farms Prodresurs, Agropoligon VIUA, and Murminskoye with different soil types: chernozem, loamy, and sandy-loam. (*Results and discussion*) The method of proportional variable-rate application of fertilizers on three types of soils gives a stable increase in profit as compared with the application of fertilizers basing on the average field indicators. (*Conclusions*) Calculations have shown that under the specified conditions and at the equal yield of 30 c/ha the application of organomineral fertilizers is the most effective, profitability has accounted for 40 percents – on mesopodzol sandy-loam soils; 8.7 percents – on sod-podzolic soils; and 1.3 percents – on black soils. The method of proportional variable-rate application of mineral fertilizers accompanied with variable-rate application of organic fertilizers makes it possible to reduce the amount of mineral fertilizers applied by half.

Keywords: variable-rate application of fertilizers, planned yield, gross harvest output, production processes.

For citation: Lichman G.I., Belykh S.A., Marchenko A.N. Methods of applying fertilizers in precision agriculture. *Sel'skokhozyaistvennye machiny i tekhnologii*. 2018. 12(4): 4-9. DOI 10.22314/2073-7599-2018-12-4-4-9. (In Russian)

Modern agricultural technologies consist of complex technological operations for managing farm crop production processes to achieve the planned yields, product quality, economic efficiency and environmental safety.

The use of only organic fertilizers contributes to the production of environmentally friendly products, but does not satisfy the emerging need in nutrients for plants. Joint local application of organic and solid mineral fertilizers helps to solve the problem of efficient use of resource-saving elements of precision farming technologies with obtaining a positive economic effect [5, 7]. To increase the soil fertility and ensure its conservation, it is necessary to introduce manure in rates inversely proportional to the content of soil nutrients or basing on the calculation of the planned yields in separate plots; to obtain an economic effect, mineral fertilizers should be introduced in proportion to the indicators of the natural soil fertility.

The research purpose is to study new methods of differentiated application of mineral fertilizers in crop production, which allow increasing profit from crop production as compared with average field input rates and [1-3]:

- proportional variable-rate application of solid mineral fertilizers;

- variable-rate application of solid mineral fertilizers taking into account three statistical intervals of soil nitrogen values as compared with other methods;

- introducing fertilizers according to average field indicators basing on the planned yield;

- variable-rate application of mineral fertilizers in separate areas basing on the planned yield; the total amount of nitrogen introduced should be equal to the amount of nitrogen introduced according the average field indicators.

Materials and methods. The authors have applied a method of calculating the introduced fertilizers taking account of three statistical intervals of soil nitrogen values (the method is described in the report «The program for determining optimal fertilizer rates taking into account the statistical parameters of soil nitrogen» in the proceedings of the International Scientific and Technical Conference «Intellectual machine technologies and technology for the implementation of the State Program for the Development of Agriculture» held in Moscow on September 15-16, 2015). The calculation methodology implemented in the computer program VBAExcel is developed to determine such main indicators as gross yield, fertilizer saving, profit, etc. [4-7].

The main variable in the calculations is the planned yield based on the average field indicators. Since the planned yields were calculated for nitrogen, a three-component ammonium nitrate phosphate fertilizer was used to compensate for the lack of nitrogen, potassium and phosphorus in soil [8, 9].

To determine the rate of nitrogen application, the proportionality factor for the fertilizers applied (КПР) is used for the planned yield:

$$K_{\text{ПР}} = \frac{У_{\text{ПЛ}}}{У_{\text{Б}}}, \qquad (1)$$

where $У_{\text{ПЛ}}$ – the planned yield;

$У_{\text{Б}}$ – planned yield based on the average field parameters without applying fertilizers.

The planned yield for separate plots is calculated using the formula:

$$У_{\text{ПNуч}} = K_{\text{ПР}} \cdot У_{\text{БNуч}}, \qquad (2)$$

where $У_{\text{БNуч}}$ – the yield of Nth site without applying fertilizers.

In the program, the following agrochemical parameters of the plots were used as initial data: acidity, phosphorus, potassium, according to which the fertilization rates were calculated.

Input data for calculations:

- organic fertilizers – manure content of 0.5%;
- mineral fertilizers – ammonium nitrate phosphate fertilizer (16% of nitrogen);
- the crop – winter wheat;
- the price of gross harvest – 12,500 rubles per ton;
- manure price – 475 rubles per ton;
- the price of mineral fertilizers – 25.8 rubles/kg;
- fuel price – 50 rubles per liter;
- fuel consumption – 50 l/ha;
- costs of obtaining information – 14,000 rubles/ha;
- costs of purchasing a GPS navigator for parallel driving – 140,000 rubles;
- costs of purchasing dosing devices with a controller – 300,000 rubles;

Calculations were carried out for field sections with a total area of 100 ha.

The following indicators were determined:

- planned yield based on the average field indicators, c/ha;
- an average yield per a plot, c/ha;
- a rate of nitrogen application in the active substance basing on average field parameters, kg/ha;
- an average rate of nitrogen application in the active substance in separate plots, kg/ha;
- the maximum rate of nitrogen application in the active substance in separate plots, kg/ha;
- the content of nitrogen in soil based on the average field parameters, mg/kg;
- planned yield based on the average nitrogen content in soil, t/ha;
- gross output, %;
- saved fertilizers, %;
- profit, %;
- profit per unit area according to average field indicators, thousand rubles / ha;
- average profit for separate plots, thousand rubles/ha;
- excess profit per total area, thousand rubles/ha.

Formulas for calculating profit basing on the average field indicators:

$$П_{\text{П}} = Ц_{\text{ур}} У_{\text{П}} S_{\text{П}} - D_{\text{вн}} Ц_{\text{уд}} S_{\text{П}} \frac{100}{A_{\%}} -$$

$$- Ц_{\text{гор}} P_{\text{гор}} S_{\text{П}} - З_{\text{инф}} S_{\text{П}} - Ц_{\text{пр}} - Ц_{\text{контр}}, \qquad (3)$$

for separate plots:

$$П_{\text{уч}} = \sum_{i=1}^{N} (Ц_{\text{ур}} У_{\text{iуч}} S_{\text{iуч}} - D_{\text{iвнуч}} Ц_{\text{уд}} S_{\text{iуч}} \frac{100}{A_{\%}} -$$

$$- Ц_{\text{гор}} P_{\text{гор}} S_{\text{iуч}} - З_{\text{инф}} S_{\text{iуч}}) - Ц_{\text{пр}} - Ц_{\text{контр}}, \qquad (4)$$

where $П_{\text{п}}$ – profit based on the average field indicators, rub.;

$П_{\text{уч}}$ – profits from separate plots, rub.;

$Ц_{\text{ур}}$ – the price of grain, rub./t;

$Ц_{\text{уд}}$ – the price of nitrogen fertilizers, rub./kg;

$A\%$ – nitrogen content in the ammonium nitrate phosphate fertilizer;

$Ц_{\text{гор}}$ – the price of fuel, rub/l;

$P_{\text{гор}}$ – fuel consumption, l/ha;

$З_{\text{инф}}$ – the costs of obtaining information, rub./ha;

$Ц_{\text{пр}}$ – the price of a GPS-navigator, rub.;

$Ц_{\text{контр}}$ – the price of a controller, rub.;

$У_{\text{пл}}$ – yield on soil nitrogen, t / ha;

$S_{\text{п}}$ – the field area, ha;

$S_{\text{iуч}}$ – the plot area, ha.

According to the acidity index of the plot (field), we can calculate nitrogen content in soil [7, 8]:

$$ln(У_{\text{pH}}) = 4{,}9801 \cdot ln(pH) - 6{,}713. \qquad (5)$$

According to the soil nitrogen and the amount of nitrogen fertilizers introduced, we can determine the yield:

$$ln(У_N) = ln(N_{pH}1,5 + N_{Вн}5,2)1,47454 - 1,385487, \quad (6)$$

where $У_N$ – planned yield based on soil nitrogen expressed through soil acidity;

N_{pH} – nitrogen content in soil expressed through soil acidity;

$N_{Вн}$ – active substance introduced with mineral nitrogen.

In the program, the input data is a variable parameter. At the end of the calculation, the values of the best result for gross harvest and profit are displayed on the screen. The form of the software interface is shown in *Fig. 1*.

The objects of research and calculation were elementary plots of crop areas of three farm enterprises – Prodresurs,

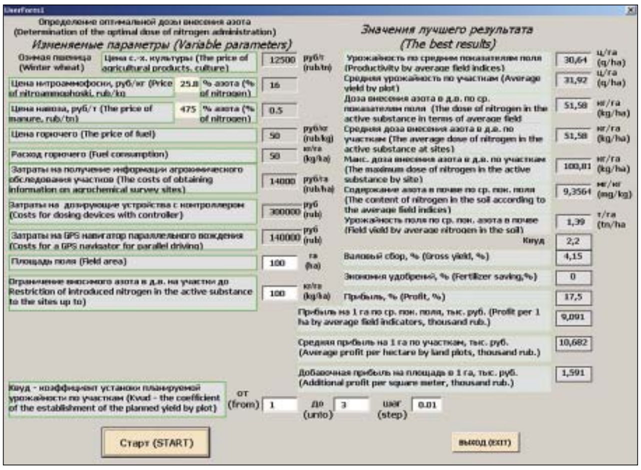


Fig. 1. Type of software interfrace

Agropoligon VIUA, and Murminskoye with different types of soil: chernozem, sod-podzolic loamy soil, and medium podzolic sandy loam soil.

The Prodresurs farm enterprise. The soil type is chernozem. The field area is 28 hectares. 56 plots. Average soil indicators: humus 6.4%; pH 6.3; phosphorus 9.5 mg/100 g; potassium 9.3 mg/100 g. All plots have an optimal and high content of soil nitrogen.

The Agropoligon of the Department of Long Field Experiments at VNIIA. The soil type is sod-podzolic loamy. The field area is 0,4 hectares. 400 plots. Average agrochemical indicators: humus 1.95%; pH 5.9; phosphorus 18.3 mg/100 g; Potassium 14.5 mg/100 g. All plots are divided according to the content of soil nitrogen into areas with a low, optimal and higher content.

The Murminskoye farm enterprise. The soil type is medium podzolic sandy loamy. The field area is 1832 hectares, 268 plots. Average agrochemical indicators: humus 1.1%; pH 5.5; phosphorus 19.1 mg/100 g; Potassium 8.1 mg/100 g. Half of the plots are characterized with low content of soil nitrogen.

Results and discussion. Tab. 1-3 show the calculations of gross harvest, profit, average and maximum fertilizer application per hectare, depending on the application method.

The Prodresurs farm enterprise. The calculations are based on the yield of 24.08 c/ha counted proceeding from the average field indicators. From *Tab. 1* it can be seen that a variable-rate application of fertilizers for the planned yield, we have an increase in the average and maximum fertilizer application per hectare.

Agropoligon VNIIA. In *Tab. 2*, the yields were calculated basing on the average field indicators of 23.9 c/ha.

The Murminskoye farm enterprise. In *Tab. 3*, the yields of 24 c/ha were calculated basing on the average field indicators.

With the uniform fertilizer application rate, the profit is obtained by means of increasing the gross harvest. With a variable-rate application for the planned yield, the average application of fertilizers is greater, because the gross harvest should be less than the planned yield. A comparison of the profit amounts for the three soil types in four ways is shown in *Fig. 2*.

From *Fig. 2* it follows that with a variable-rate application of fertilizers, taking into account the three statistical intervals of soil nitrogen values and proportional variable-rate application, the profit obtained is approximately the same; proportional variable-rate application of fertilizers on three soil types gives a stable excess of profit as compared with the application of fertilizers according to the average field indicators. Further, this method is used for joint application of mineral fertilizers and manure.

In proportional variable-rate application of mineral

Table 1

Calculations of gross harvest, profit, average and maximum application of fertilizers

Method of applying fertilizers	Gross harvest, centner/ha	Profit, ths. rub.	Average application of fertilizers, kg/ha	Maximum doses of fertilizer application, kg/ha
Application of fertilizers on average values of the field	24.8	7.34	11.55	11.55
Differentiated application of fertilizers to the planned yields	24.08	6.92	14.14	40.38
Proportional-differentiated application of fertilizers	24.31	7.63	11.55	16.26
The differentiated application of fertilizers to three statistical intervals of soil nitrogen	24.31	7.63	11.55	16.26

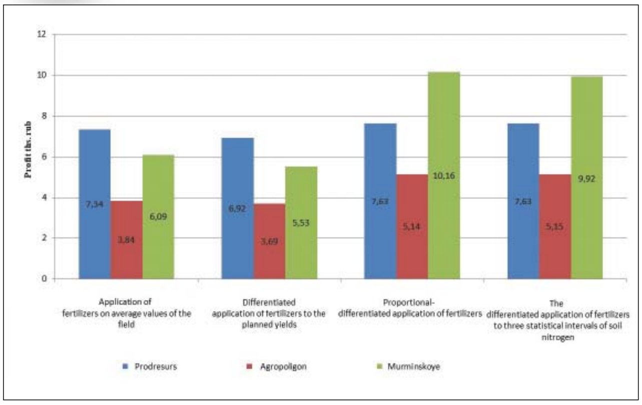


Fig. 2. Comparison of profits on three types of soils in four ways

VNIIA;

- 2.8 thousand rub./ha (or 40.6%) for the Murminskoye farm enterprise.

Conclusion. Calculations have shown that the application of organic and mineral fertilizers is most effective on medium podzolic sandy loamy soils, in this case the profit was 40.6%, with the application of nitrogen in the amount of 63 kg a.m./ha basing on the average field indicators. On sod-podzolic soils, the percentage of profit was equal to 8.7%, when nitrogen was applied in the amount of 51 kg a.m./ha basing on the average field parameters. On chernozems, the amount of profit is the smallest (1.3%), with the introduction of nitrogen in the amount of 29 kg a.m./ha basing on the average field parameters.

Table 2

Calculations of gross harvest, profit, average and maximum application of fertilizers

Method of applying fertilizers	Gross harvest, centner/ha	Profit, ths. rub.	Average application of fertilizers, kg/ha	Maximum doses of fertilizer application, kg/ha
Application of fertilizers on average values of the field	23.98	3.84	23.98	23.98
Differentiated application of fertilizers to the planned yields	23.98	3.69	33.42	99.90
Proportional-differentiated application of fertilizers	24.06	5.14	32.72	63.95
The differentiated application of fertilizers to three statistical intervals of soil nitrogen	25.04	5.15	32.50	56.78

Table 3

Calculations of gross harvest, profit, average and maximum application of fertilizers

Method of applying fertilizers	Gross harvest, centner/ha	Profit, ths. rub.	Average application of fertilizers, kg/ha	Maximum doses of fertilizer application, kg/ha
Application of fertilizers on average values of the field	24.06	6.09	44.67	44.67
Differentiated application of fertilizers to the planned yields	24.06	5.53	48.41	96.17
Proportional-differentiated application of fertilizers	27.60	10.16	44.67	129.24
The differentiated application of fertilizers to three statistical intervals of soil nitrogen	27.35	9.52	44.76	90.40

fertilizers together with variable-rate application of manure for the planned yield, the nitrogen rates are halved so that the total amount of nitrogen added is equal to the total amount of nitrogen introduced basing on the average field indicators. The amount of applied organic and mineral fertilizers was calculated for the planned yield of 30.5 c/ha [9, 10].

The profit accounted for:

- 0.17 thousand rub./ha (or 1.36%) for the Prodresurs farm enterprise;
- 1.56 thousand rub./ha (or 8,7%) for the Agropoligone

Among numerous calculations kept in the database there are also less profitable options. The method of complex joint variable-rate application of mineral and organic fertilizers for all three types of soils: (black earth, sod-podzolic loamy, and medium podzolic sandy loam) allows to reduce the amount of solid mineral fertilizers by half, increase the gross harvest output and obtain a positive economic effect.

REFERENCES

1. Izmaylov A.Yu., Lichman G.I., Marchenko N.M. Tochnoye zemledeliye: problemy i puti resheniya [Precision farming: problems and solutions] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2010. N5: 9-14. (In Russian)

2. Crowder D.W., Reganold J.P. Financial competitiveness of organic agriculture on a global scale. Proc Natl Acad Sci

USA. 2015. 112. 7611-7616. (In English)

3. Tsvetkov I., Atanassov A., Vlahova M., Carlier L., Christov N., Lefort F., Rusanov K., Badjakov I., Dincheva I., Tchamitchian M., Rakleova G., Georgieva L., Tamm L., Iantcheva A., Herforth-Rahm J., Paplomatas E., Atanassov I. Plant organic farming research – current status and opportunities for future development. *Biotechnology & Biotechnological Equipment*. 2018. 32. N2. 241-260. (In Russian)

4. Connor D.J. Organically grown crops do not a cropping system make and nor can organic agriculture nearly feed the world. Field Crop Res. 2013. 144. 145-147. (In English)

5. Tonfack L.B., Youmbi E., Amougou A., Bernadac A. Effect of Organic/ InorganicCation Balanced Fertilizers on Yield and Temporal Nutrient Allocation of Tomato Fruits under Andosol Soil Conditions in SubSaharan Africa International. *Journal of Agricultural and Food Research ISSN*. 2013. 2. N2. 27-37. (In English)

6. Šimon T., Czakó A. Influence of longterm application of organic and inorganic fertilizers on soil properties. *Plant Soil Environ*. 2014. Vol. 60, N7. 314-319. (In English)

7. Mulvaney R.L., Khan S.A., Ellsworth T.R. Synthetic nitrogen fertilizers deplete soil nitrogen: a global dilemma for sustainable cereal production. *J Environ Qual*. 2009. 38(6). 2295-2314. (In English)

8. Yeromin D.I., Kibuk Yu.P. Differentsirovannoye vneseniye udobreniy kak innovatsionnyy podkhod v sisteme tochnogo zemledeliya [Variable-rate fertilization as an innovative approach in the system of precision farming]. *Vestnik KrasGAU*. 2017. N8. 17-26. (In Russian)

9. Belykh S.A., Lichman G.I., Marchenko A.N. Metod sostavleniya kart-zadaniy dlya differentsirovannogo vneseniya organomineral'nykh udobreniy [Method of compiling maps for variable-rate application of organic-and-mineral fertilizers]. *Mezhdunarodnaya agroinzheneriya*. Almaty. 2016. Iss. 4. 14-19. (In Russian)

10. Yeromin D.I. Vliyaniye dlitel'nogo ispol'zovaniya organomineral'noy sistemy udobreniy zernovogo sevooborota na dinamiku podvizhnogo kaliya chernozema vyshchelochennogo [Influence of the prolonged use of the organic-and-mineral system of fertilizers of cereal crop rotation on the dynamics of mobile potassium in leached chernozem] // *Plodorodiye*. 2016. N2(89). 28-31. (In Russian)

The paper was submitted to the Editorial Office on 12.04.2018

The paper was accepted for publication on 09.08.2018

Conflict of interest. The authors declare no conflict of interest.

УДК 631.354.2
CC BY
DOI 10.22314/2073-7599-2018-12-4-10-15

Determining the Range of Combine Harvesters Used in Kazakhstan Regions

Vladimir L. Astafyiev[1],
Dr.Sc. (Eng), professor, director;

Vladimir A. Golikov[2],
Academician of Kazakhstan National Academy of Sciences, chief research engineer,
e-mail: kazniimech@yandex.kz

[1]Kostanay Branch of LLP “Kazakh Scientific Research Institute of Mechanization and Electrification in Agriculture”, Kostanay, Kazakhstan;
[2]LLP “Kazakh Scientific Research Institute of Mechanization and Electrification in Agriculture”, Almaty, Kazakhstan

Abstract. The fleet of combine harvesters in the Republic of Kazakhstan consists of 3-, 4-, 5- and 6-class harvesters, and 3- and 4- class harvesters make up for almost 82 percents of the fleet. According to the data provided by the Kazakhstan Ministry of Agriculture, 60 percents of grain harvesters have a lifespan of more than 10 years. (Research purpose) To determine the range of grain harvesters and headers for Kazakhstan regions in view of ongoing technical re-equipment. (Materials and methods) The range of grain harvesters should be determined according to the yield of harvested crops, the size of crop area on separate farms and in the region, the availability of machine operators as well as climatic conditions of the regions. (Results and discussions). The authors have analyzed the actual yield of grain crops in Kazakhstan regions, determined its possible expected level, and analyzed the number of machine operators required for available crop area, the number of small, medium and large-scale farms and climatic conditions during the harvest period in Kazakhstan regions. The efficiency of harvesters of different classes with headers of various operating width has been estimated taking into account the expected yield. Matching the obtained results to the yield data, organizational-and-economic and climatic conditions, and introducing appropriate limits, the authors have determined the range of grain harvesters for Kazakhstan regions. (Summary) It has been found that the harvesters of class 5, 6 and 4 are more effective under conditions of northern and central Kazakhstan regions provided they are equipped with wide-cut headers for direct harvesting. In southern, western and eastern Kazakhstan regions, where grain crops are cultivated on dry soils with an insufficient moisture content, combine harvesters of class 3 and 4 should be primarily used.
Keywords: combine harvesters, headers, range, regional conditions.

For citation: Astafyiev V.L., Golikov V.A. Determining the range of combine harvesters used in Kazakhstan regions. *Sel’skokhozyaystvennye mashiny i technologii*. 2018. 12(4): 10-15. DOI 10.22314/2073-7599-2018-12-4-10-15. (In Russian).

The fleet of grain combine harvesters in the Republic of Kazakhstan is represented by combine harvesters of class 3-6. According to the Ministry of Agriculture of the Republic of Kazakhstan as of 01.01.2015, there are 44.3 thousand grain combine harvesters currently available in the republic, including 18.7 thousand (42%) Enisey 1200 and Yenisei-950 Ruslan, 15 thousand (34%) – SK- 5A Niva, 2,5 thousand (5,7%) – Vektor, 1 thousand (2,2%) - Don-1500. Combines produced by far abroad manufacturers – 4.6 thousand available in 10 different brands. Thus, almost 82% of the fleet consists of combine harvesters of class 3 and 4. The fleet of grain harvesting equipment is mainly represented by combines coming from the following countries: Russian Federation (Rostselkhozmash, Krasnoyarsk Combine Plant, Promtraktor); the Republic of Belarus (Gomselmash, Agropromtehnika); the Republic of Kazakhstan (Agromashholding); USA (*JohnDeere*, *Challenger*, *MasseyFerquson*, *Case*, *NewHolland*), Germany (*Class*, *DeutzFahr*, *Fend*); Italy (*Laverda*); Finland (*Sampo*). According to the Kazakhstan Ministry of Agriculture, 60% of combine harvesters have a service life of more than 10 years, so the issue of technical re-equipment of the fleet of grain combine harvesters is very relevant. As organizational and economic conditions in the regions of Kazakhstan have changed significantly in recent years due to an increase in the share of peasant farms and the growing demand for machine operators, this issue cannot be solved by automatically replacing old harvesters with new ones of the same class.

The purpose of the present research is to determine the type of combine harvesters and headers in Kazakhstan regions in connection with the ongoing technical re-equipment.

Materials and methods. The determination of the range of combine harvester classes is made taking into account the yield amount of the harvested crops, the acreage of farms and in the region, the availability of machine operators, and weather conditions in separate regions [1-5]. When determining the range of combine harvesters, we have proceeded from the following methodological assumptions:

- in regions with high yield and a shortage of machine operators, higher-class combine harvesters should be used;
- the reduction in the crop area in farms leads to a reduction in seasonal load on combines and, as a result, a decrease in the class of a combine harvester used;
- in regions with high probability of precipitation, it is advisable to use combine harvesters with higher productivity to avoid produce losses due to unfavorable weather conditions;
- in regions with an average amount of yield, the full-load performance of a high-capacity combine harvester can be ensured by the use of wide-cut reapers and cutting headers, as well as for separate harvesting with picking up double swaths.

The productivity of a combine harvester of direct action is basically determined as follows: the width of the harvesting unit and the combine travel speed. The combine travel speed is subject to the full load of its thresher, was determined basing on the condition:

$$V = \frac{36}{BУ} q_з \leq V_д, \qquad (1)$$

where V is the combine travel speed, km/h;

V_d – allowable travel speed of combine harvester of class 3-6, km/h;

q_3 – zonal throughput capacity of grain mass at the grain weight-to-straw ratio 1:1.2, kg/s;

B – header width, m;

Y – yield of grain mass, t/ha.

The amount of threshing unit load for zonal grain yield has been determined using the formula:

$$C_з = \frac{B}{q_3}\frac{V}{36} У_з (1 + a_ф) 100\%, \qquad (2)$$

where C_3 is the threshing unit load;

$\alpha_ф$ is the straw content of grain mass (the straw-to-grain mass ratio), $\alpha_ф = 1.2$;

Y_3 – grain yield in zonal conditions, t/ha.

The cutting width of headers needed to increase the loading of grain harvesters by the throughput capacity for zonal grain yield has been determined from the condition:

$$B = \frac{36 q_3}{(1 + a_ф) V_d У_з} \leq [B], \qquad (3)$$

where [B] is the maximum possible cutting width of headers and cutting reapers to be attached with combine harvesters of class 3-6.

Results and discussion. Basing on the analysis of the yield level, organizational-economic and weather conditions in the regions of the Republic of Kazakhstan, we have determined a promising range of combine harvesters and headers by their classes for grain harvesting in Kazakhstan.

Combine harvesters are classified according to the throughput capacity (kg/s) as follows [6, 7]:

- Class 1 with a throughput capacity of 0.5-1.5 kg/s - selection combine harvesters;
- Class 2 with a throughput capacity of 2.5-3 kg/s, for small farms with an area of 70-100 hectares;
- Class 3 with a throughput capacity of 5.5-6 kg/s, for operating in fields with a yield of less than 25 c/ha;
- Class 4 with a throughput capacity of 7-8 kg/s, for operating in fields with a yield of 25-40 c/ha;
- Class 5 with a throughput capacity of 9-10 kg/s, for operating in fields with a yield of 40-55 c/ha;
- Class 6 with a throughput capacity of 11-12 kg/s, for operating in fields with a yield of 50-60 c/ha;
- Class 7 with a throughput capacity of 12-14 kg/s, for operating in fields with a yield of 60-100 c/ha.

Table 1

Wheat yield in separate regions of the Republic of Kazakhstan

Region	Average wheat yield, c/ha		Maximum wheat yield, c/ha	
	actual	potential	actual	potential
Southern	16.5	20.6	20.9	25.0
Eastern	12.3	15.4	14.2	18.0
Western	5.6	7.0	8.4	10.0
Northern	10.6	13.5	15.3	19.0
Central	10.5	13.1	11.0	14.0

Table 1 shows the wheat yield differentiated by Kazakhstan regions, and the average wheat yield obtained over a period of five years (2009-2014) for the country is 11.5 c/ha.

The average and maximum wheat yield obtained over a period of five years is the largest in the southern region, which is mainly due to the presence of irrigated land there, where winter wheat is cultivated and the yield is 40 c/ha and higher. However, the cultivation of winter wheat on irrigated land has been declining in the southern region in recent years, as priorities have been given to other crops. It should be noted that grain combine harvesters are used to harvest rice in the republic, the yield of which in yielding years is 45 c/ha or higher, and corn to be used for grain seed production, the average yield of which is 45 c/ha, and the maximum yield is 70 c/ha. To harvest these crops, high capacity combines of class 5 and 6 are required. According to the Kazakhstan Ministry of Agriculture, due to worn-out equipment, the loss of yield is currently estimated at 25%, as minimum. The range of combine harvesters can be determined taking into account a possibility of obtaining expected yields without planning for these losses.

Table 2
Crop areas in separate regions of the Republic of Kazakhstan

Region	Crop area	
	thousand ha	%
Southern	2528	11.6
Eastern	1358	6.3
Western	1105	5.1
Northern	15521	71.8
Central	1119	5.2

Table 2 shows the size of crop areas in separate regions of the Republic of Kazakhstan.

The largest share of crop areas belongs to the northern region. This region is characterized by the presence of farms of various categories (family farms, medium and large farm enterprises) with crop areas of 300-3000 ha; 3000-10000; and more than 10000 hectares, respectively. Moreover, large and medium-size farms in the region account for more than 20% and operate 71% of the crop area. The beginning of the harvest period (the third decade of August) is usually dry, but in September, as a rule, it begins to rain.

In the eastern and southern regions there is an overwhelming majority (more than 90%) of small farms with a crop area amounting to 25-500 hectares. The sizes of agricultural enterprises of these regions range from 130 to 7000 hectares [8]. In the central region, as well as in the north, large and medium-size agricultural enterprises are more typical, and in the western part, small farms account for the largest part (over 80%). Autumn in the southern, central and western regions is usually dry.

The structure of the combine harvester fleet in the republic is comprised of combines of class 3 – 77.6%; class 4 – 11.2%; class 5 – 7,8%, and class 6 – 3,4%. However, the distribution by regions is not equal. So, in the southern region, combine harvesters of class 3 make up for 90.6%; class 4 – 4.4%; class 5 – 3%; class 6 – 2%. In the northern region, combines of class 3 make up for 70.7%, class 4 – 14.6%; class 5 – 8.2%, class 6 – 5.8%.

Thus, in the northern region with the largest grain areas of relatively high yields, the share of high-performance combines of class 4, 5 and 6 is about 30%, while in the southern region – 9.4%, and in the whole in the republic – 22.4%. The increase in the share of high-class combines in the northern region is due to the limited periods of favorable weather in the autumn period and the strive of agricultural producers to maximize the productivity of machines in the harvesting process accompanied by a shortage of machine operators.

Our task is to determine the productivity and the degree of loading of threshing unit of different combine classes with different grain yields. The recommended travel speed of a direct combining harvester is 4-8 km/h [9, 10]. However, according to the test results of combine harvesters of class 3-6 in the KazNIIMESKH in the conditions of Kazakhstan regions at low grain yields for 3-4 class harvesters $V_д \leq 8$ km/h, for 5 class combines $V_д \leq 9$ km/h and for 6 class combine harvesters – $V_д \leq 10$ km/h.

Combine harvesters of class 3-4 are not fully loaded in harvesting at yields of 12 c/ha (*Table 3*). To increase their loading, it is necessary to use headers with a larger operating width. However, wide-cutting headers can be effectively used in steppe areas, but in foothill areas their use disrupts the movement stability of the harvester. The use of an *ACROS-530* 5-class harvester with a harvesting width (B) of 11 m for grain harvesting at yields of 12, 15 and 17 c/ha in the northern region of the Republic makes it possible to increase the actual feed (and productivity) by 1.7-2.5 times, as compared with 3-class harvesters. At the same time, the average load of the threshing unit in 5-class harvester is 64% at a yield of 12 c/ha, 80% at a yield of 15 c/ha, and 80% at a yield of 17 c/ha. In the first case, the combine harvester is underloaded by about a third, and in the latter case it is loaded almost completely. With the use of combine harvesters of 6 class with a cutting width of 12 m, the specific (per hectare) performance is even higher, as these combines operate at a yield of 12-17 c/ha with permissible losses at speeds of up to 10 km/h. Thus, the use of 6-class harvesters with wide-cutting headers can raise specific (per hectare) performance in grain harvesting at a yield of 12-17 c/ha as compared with 3- and 4-class harvesters.

The conformity of the harvesting width to the type of combine harvesters has been determined by Formula 3. At present, the harvesting width of direct combining headers attached to combine harvesters of class 3 is 5-6 m; class 4 – 6-9 m; class 5 – 6-12 m; and class 6 –- 9-12 m. To increase the load of the thresher and the harvesting efficiency of the combine harvesters of class 3, 4, 5 and 6, the harvesting width of a direct combining harvester must be increased to the upper limits in all Kazakhstan regions, except for foothill areas and watered fields.

The performed analysis, as well as the experience of advanced farms in the northern region, which is the main grain production area, has made it possible to

Table 3

Performance of combine harvesters per 1 hour of operation depending on work load in harvesting grain crops of different yield level

	Harvester class and make	Initial conditions					
		Grain yield, ql/ha	Thresher capacity, kg/s	Working width, m	Velocity, km/h	Actual feeding rate, kg/s	Loading rate, %
3 class	SK-5M-1 "Niva"	12	5.5	6	8	4.8	64
	SK-5ME-1 "Niva-Eff."	15	5.5	6	8	4.8	80
		17	5.5	5	8	4.0	91
		20	5.5	5	7	3.5	93
	Enisey-1200-1NM	12	6.3	7	8	5.6	65
		15	6.3	7	8	5.6	81
4 class	RSM-101 "Vektor"	12	8	7	8	5.6	51
		15	8	7	8	5.6	64
		17	8	7	8	5.6	73
	Palesse GS 07 (KZS-7)	12	8	9	8	7.2	66
		15	8	9	8	7.2	83
		17	8	9	8	7.2	93
5 class	ACROS-530	12	10	11	8	8.8	65
		15	10	11	8	8.8	81
		17	10	11	8	8.8	83
		40	10	6	6.1	3.7	90
6 class	Palesse GS 12 (KZS-1218)	12	12	12	10	12.0	63
		15	12	12	10	12.0	92
		17	12	12	9	10.8	93
		40	12	6	8	4,.8	88

identify a promising type of combine harvesters in the Republic: combine harvesters of class 4, 5 and 6 (*Table 4*).

Table 4

Perspective range of grain combine harvesters

Combine harvester class	Regions					For Kazakhstan as a whole
	northern	southern	central	eastern	western	
3	–	+	+	+	+	+
4	+	+	+	+	+	+
5	+	+	+	+	+	+
6	+	+	+	–	–	+

In the southern region, where winter wheat, rice, and maize are cultivated on irrigated lands to obtain high-yield grain, combine harvesters of class 5 and 6 will be effectively used (*Table 4*).

However, due to a large share of small farms, the combine harvester range will be basically made up of 3-class harvesters. In the western and eastern regions of the Republic, where grain crops are cultivated on rainfed lands with moisture deficiency, it is preferable to use 3- and 4-class harvesters. This is due to a large share of small farms, as well as low grain yields (the western region). Combine harvesters of a higher class are advisable to apply in the central and western regions in large and medium-sized agricultural enterprises that are characterized with a shortage of machine operators, and in the eastern region that feature high grain yields. Thus, in the northern region, where grain crop yields are higher and the share of large and medium-size farms is large with a pronounced shortage of machine operators, combine harvesters of class 5 and 6 are the most effective solution, provided they are equipped with wide-cut headers for direct and separate harvesting. On smaller farms, 4-class combines can also be used if equipped with wide-cut headers. Calculations have shown that when switching to a promising type of combine harvesters and headers and operating the required number of these machines, it is possible to ensure the harvesting operations to be done in the required periods.

Conclusions

1. It has been established that in the conditions of the main grain producing (northern and central) regions of Kazakhstan, characterized by a significant share of large and medium-size farms with a pronounced shortage of machine operators, combine harvesters of class 5, 6 and 4 are the most effective solutions if they are equipped with wide-cut headers for direct and separate harvesting.

2. In the southern region, due to a large share of small farms, the combine harvester range will be made up of 3-class harvesters. Harvesters of class 5 and 6 can be used in areas, where winter wheat, rice, and corn for grain with high yields are cultivated in irrigated fields.

3. In the western and eastern regions of the Republic, where grain crops are cultivated on rainfed lands with a moisture deficit, 3- and 4-class harvesters are predominantly used. This is due to a large share of small farms and low grain yields (the western region).

REFERENCES

1. Chepurin G.Ye., Ivanov N.M., Kuznetsov A.V. et al. Uborka i posle-uborochnaya obrabotka zernovykh kul'tur v ekstremal'nykh usloviyakh Sibiri: Rekomendatsii [Harvesting and post-harvest treatment of grain crops under extreme conditions of Siberia: Recommendations]. M.: Rosinformagrotekh. 2011. 175. (In Russian)
2. Zhalnin E.V. Metodologicheskiye aspekty mekhanizatsii proizvodstva zerna v Rossii [Methodological aspects of grain production mechanization in Russia]. M.: Poligraf-servis. 2012. 368. (In Russian)
3. Astaf'yev V.L. Kak tekhniku podgotovish', tak i uberesh' [Machinery readiness determines the efficiency of harvesting] // *Zapchasti*. KZ. 2014. N9. 24-25. (In Russian)
4. Faiffer A. Uchest' vse faktory [Taking all factors into account] // *Novoye sel'skoye khozyaystvo*. 2015. N1. 38-40. (In Russian)
5. Vorovkin G.P. Neravnomernost' sozrevaniya i uborka zernovykh kul'tur v nepogodu [Uneven ripening and harvesting of crops in bad weather]: Omsk: VPO "OmGAU". 2005. 132. (In Russian)
6. Lachuga Yu.F., Gorbachev I.V., Ezhevskii A.A., Izmailov A.Yu., Kriazhkov V.M., Antyshev N.M., Babchenko V.D., Beilis V.M., Golubkovich A.V., Grishin A.P., EvtushenkovN.E., Zhalnin E.V., Zhuk A.F., KolesnikovaV.A., Levina N.S., Lichman G.I., Marchenko N.M., Marchenko L.A., Marchenko O.S., Mikheev V.V. и др. Sistema mashin i tekhnologiy dlya kompleksnoy mekhanizatsii i avtomatizatsii sel'skokhozyaystvennogo proizvodstva na period do 2020 goda [System of machines and technologies for integrated mechanization and automation of agricultural production for the period until 2020]. Vol. 1. Rasteniyevodstvo [Crop cultivation]. M.: VIM. 2012. 303. (In Russian)
7. Zhalnin Ye.V. Tipazh kombaynov: kakoy yest' i kakoy nuzhen [Range of combines: actually available and required] // *Sel'skiy mekhanizator*. 2012. N8. 6-8. (In Russian)
8. Golikov V.A., Usmanov A.S., Astaf'yev V.L. et al. Sistema tekhnologiy i mashin dlya kompleksnoy mekhanizatsii rasteniyevodstva v Kazakhstane na period do 2021 goda: Rekomendatsii [A system of technologies and machines for integrated mechanization of plant growing in Kazakhstan for the period up to 2021: Recommendations]. Almaty. 2017. 128. (In Russian)
9. Bawatharani R., Jayatissa D.N., Dharmasena D.A.N., Bandara M.H.M.A. Impact of Reel Index on Header Losses of Paddy and Performance of Combine Harvesters // *Tropical Agricultural Research*. 2013. Vol. 25. 3-16. (In English)
10. Metodika opredeleniya ekonomicheskoy effektivnosti tekhnologiy i sel'skokhozyaystvennoy tekhniki, chast' II. Normativno-spravochnyy material [Methodology for determining the economic efficiency of farm production technologies and machinery, Part II. Regulations and reference material]. M.: 1998. 251. (In Russian)
11. Zhalnin E.V., Tsench Yu.S., P'yanov V.S. Analysis method of combine harvesters technical level by functional and structural parameters // *Sel'skokhozyaystvennye mashiny i technologii*. 2018. 12(2). 4-8. (In Russian)

The paper was submitted to the Editorial Office on 13.06.2018

The paper was accepted for publication on 06.08.2018

Conflict of interest.
The authors declare no conflict of interest.

УДК 631. 353

CC BY

DOI 10.22314/2073-7599-2018-12-4-16-21

Fractional Technology and Tools for Post-Harvest Grain Treatment and Processing with Crushing

Peter A. Savinykh,
Dr.Sc.(Eng.), chief research associate,
e-mail: peter.savinyh@mail.ru;

Yury V. Sychugov,
Dr.Sc.(Eng.), chief research associate;
Vladimir A. Kazakov,
Ph.D.(Eng.), senior research associate

Federal Agricultural Scientific Center of North-East named after N.V. Rudnitskiy (North East FASC), Kirov, Russian Federation

Abstract. The use of fractional technologies for post-harvest treatment and processing of grain heap delivered from field with further special purpose use of grain fractions leads to a significant increase in grain production efficiency. (*Research purpose*) Developing a fractional technology for post-harvest treatment and processing of grain with crushing and preservation of feed grain fraction and designing a technological line and machines for it. (*Materials and methods*) The authors have analyzed the technological level and developed a fractional technology for grain post-harvest treatment and processing by crushing with subsequent preservation of the feed grain fraction. They have offered a technological line and presented the design and technological parameters of the corresponding technical means (МЗУ-20Д - grain cleaning universal machine, МПО-30ДФ - preliminary grain cleaning machine with fractionation, ПЗД-3,1, ПЗД-10 – two-stage grain crusher). (*Results and discussion*) The authors have designed, manufactured and tested a universal grain-cleaning machine МЗУ-20Д. It efficiently cleans grain material coming from the field after its threshing by combine harvesters, and divides it into fractions: seed and feed grain – 60-70 percent, waste material - up to 10 percent, grain fodder - up to 40 percent. Further on, the grain is sent for crushing (for wet grain), followed by preservation and hermetic storage of the products obtained before their feeding to animals. Tests have shown that the developed feed preparation machine efficiently performs the technological process. The authors have developed a two-stage grain crusher (ПЗД-3,1), performing the crushing of grain material in two stages by three rollers, followed by preservation (for wet grain) of the feed grain fraction. (*Conclusions*) It has been established that the use of the new fractional technology and equipment contributes to an increase in grain cleaning productivity by 30-40 percent, and the estimated annual economic effect of the renovation is 400,000 rubles. The estimated annual economic effect of the use of the two-stage grain crusher (ПЗД-3,1) has proved to be more than 60 thousand rubles, and the level of production intensification has increased by 26 percent as compared to the MURSKA crusher produced in Finland.

Keywords: grain, fractionation, technology, preservation, foreign matter, crushing, cleaning.

For citation: Savinykh P.A., Sychugov Yu.V., Kazakov V.A. Fractional technology and tools for grain post-harvest treatment and processing with crushing. *Sel'skokhozyaistvennye machiny i tekhnologii*. 2018. 12(4): 16-21. DOI 10.22314/2073-7599-2018-12-4-16-21. (In Russian)

The use of fractional technology for post-harvest processing (or a technology for the special-purpose (targeted) use of products) of a grain heap coming from the field after combine harvesting to post-harvest grain processing stations with further targeted use of grain fractions and the production of finished products from them contributes to a significant increase in the efficiency of the entire grain production sector. In this respect, the reconstruction of grain cleaning and drying facilities, their technological lines and corresponding technical means is one of the important tasks of farm production modernization. To solve this problem, the designers of FASC together with those from North-East Farming Research Institute have been developing new technologies and technological lines, for example, fractional technology of post-harvest grain processing and technology for processing feed grain for the production of final products (ready-made animal feed) – crushed preserved wet grain, as well as technical means for the implementation of these processes - fractional grain cleaning machines and a grain crusher.

The study purpose is the development of fractional technology for crushing and preserving of feed grain, the technological line and technical means for its implementation; development of a machine for grain material fractionation with its cleaning from impurities and a two-stage conditioner for dry and wet grain.

Materials and methods. Existing stations and facilities of post-harvest grain processing do not provide the required deep processing, which is necessary in particular for the production of concentrated (grain) feeds for livestock that are directly suitable for feeding [1, 2]. In FASC North-East, a constructive technological scheme for fractional processing and treatment of grain material (heap) has been developed, with the feed fraction being separated and its subsequent crushing and preserving (*Fig. 1*) [3-5]. It operates as follows. The grain heap is fed from a pit (ЗЯ) or an air duct into the grain pre-treatment machine (МПО), where it is cleaned from impurities by the air flow and on the grate mills, and is also divided into the main (seed and food grains, 60-70%), feed fraction (up to 40%) and waste material (5%). The main fraction – pure grain - is transported through grain lines to the hopper of the wet grain storage (БРВЗ), where it is further processed with common technologies. The cleaned feed fraction is fed to the wet feed grain hopper (БВФЗ).

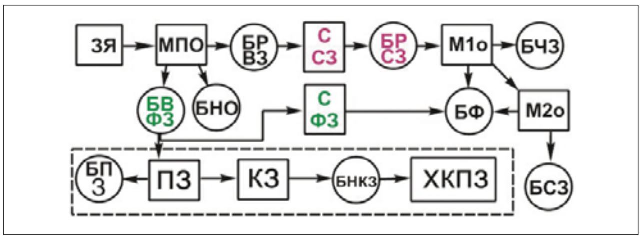


Fig. 1. Scheme of fractional technology of grain processing with its subsequent crushing: ЗЯ – dammed pit; МПО – grain cleaning machine; ССЗ, СФЗ – grain driers; М1о, М2о – dry grain cleaning machines; ПЗ – grain crusher; КЗ – grain preservation; БНО, БРВЗ, БРСЗ, БФ, БЧЗ, БСЗ, БПЗ, БНКЗ – grain hoppers; ХКПЗ – crushed grain storage

In accordance with the common technologies for post-harvest processing of grain heaps, wet feed grain is fed to a feed grain dryer (СФЗ) with a rigid drying mode or is preserved [4]. Waste material separated by МПО from grain material are sent to the unused waste hopper (БНО). The amount of feed grain received in the БВФЗ hopper makes up for 30-40% of the total amount coming from the field, and its quality must satisfy the livestock breeding requirements for the technology of preparation of concentrated forages and meet the requirements of GOST 9267-68, GOST 9268-90, GOST 18221-72.

In the proposed (new) technology, the feed grain fraction extracted from the impurities by the grain cleaning machine is fed through grain lines from the БВФЗ hopper for crushing, which is provided by a machine for preparing concentrated feeds – the grain crushing unit (ПЗ), and the feed products (crushed grain) produced by it must meet the requirements of TU 8-22-39-88. The obtained crushed grain is fed to the hopper-storage unit БПЗ, from which it comes as a full-value concentrated feed either for feeding animals or for preserving (КЗ). Crushed preserved grain is fed to the storage hopper БКПЗ, from which it is taken for storage.

Results and discussion. Increasing the efficiency of post-harvest grain processing requires the reconstruction of grain cleaning and drying lines of grain post-harvest processing facilities with a possibility of applying grain-crushing technologies [6]. To solve this problem, the designers of the North-East Farming Research Institute have developed a technological line (*Fig. 2*) installed at the grain processing facility in farm enterprise «Zarya», the Nagorsk district of the Kirov region.

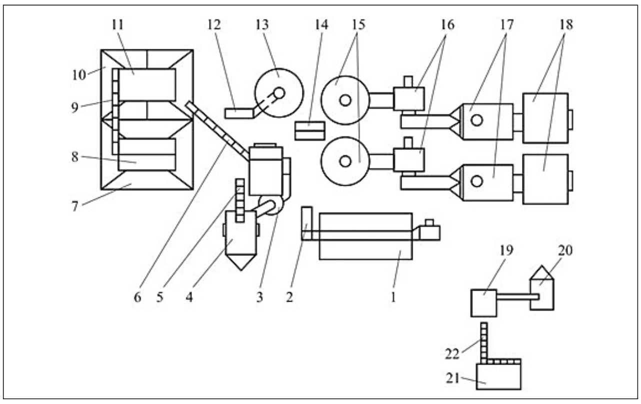


Fig. 2. Technological scheme of seed-cleaning and drying of complex post-harvest grain processing in the Zarya farm enterprise, the Nagorsk district of the Kirov region:
1 – air slide; 2, 12, 14 – cup-type elevators; 3 – grain pre-cleaning machine with fractionation (optional) МПО-30ДФ; 4 – waste material hopper; 5, 6, 9, 22 – transporters; 7, 10 – a pack of grain bins; 8 – screening separator; 11 – secondary cleaning machine; 13 – grain binning hopper; 15 – drying bin; 16, 17, 18 – dry grain processing machine; 19 – crusher; 20 – trailer; 21 – intake hopper

The technological process of the facility is a sequence of certain operations. The wet grain pile is unloaded into the receiving device with an air duct, from where it flows to the cup-type elevator, which feeds it to the grain pre-treater with a possibility of fractionation МПО-30ДФ. The cleaned grain is also fed by a scraper conveyor to the hopper of the wet grain section or gravity feed to one of the cup-type elevator sections that loads the drying hoppers. Further, the dried grain discharged into the second section of the cup-type elevator is sent to the hoppers for cooling and resting, and then fed by the cup-type elevator into the secondary cleaning machine. The separated grain is sent by the transporter to the screening cleaning and then to the pure grain hopper, from where it enters the storage area of finished products.

Feed waste from the screening unit and the secondary cleaning machine МВО-8Д are loaded into the dry feed grain section of the hopper. Grain material that enters the hopper section of wet grain is unloaded into vehicles and transported under a canopy to the receiving hopper and then fed into the crusher via a scraper conveyor. The preservative-treated crushed grain is loaded with a conditioner auger into the trailer and sent for storage or used for animal feed. It is also possible to crush dry feed grain from the hopper.

The use of the new fractional technology and equipment in the reconstruction of the grain cleaning and drying facilities located in the «Zarya» farm enterprise, the Nagorsk district of the Kirov region, has contributed to an increase in its productivity of up to 30-40%, and the estimated annual economic effect from the renovation of the considered facilities has accounted for 400 thousand rubles.

To increase the efficiency of agricultural technologies for post-harvest (including fractional) treatment and grain processing, the experts of the North-East Farming Research Institute have developed grain cleaning machines and grain crushers and started their production [7-10].

Taking into account the results of experimental studies of the post-harvest grain treatment and processing, as well as the analysis and monitoring of key indicators and corresponding technical means, the universal grain cleaner МЗУ-20Д (patents N2513391 RU, N2371262 RU) has been developed. The device is intended for fractionation of grain and seeds of different crops, their primary and secondary cleaning from impurities and can be used in practically all agricultural zones of the Russian Federation.

The operating principle of the technological scheme (*Fig. 3*) of the offered grain-cleaning machine is as follows. The grain mixture is fed through the grain line into the feeder, being evenly distributed by the scraping screw along the machine width, and then fed to the first pneumatic separating channel where the airflow from the cereal mixture carries away light impurities (chaff, straw particles, weed seeds, and dust). After cleaning in the first pneumatic channel, the material enters the upper screen of the screening mill, which separates larger impurities leaving the machine, while cleaned grain enters the middle grating sieve. The middle sieve separates large-sized pure grain (a fraction of seed and food grain), which falls into the second pneumatic separating channel, where light impurities are separated. On the lower sieve small impurities are separated and pass through the lower sieve and the bottom of the lower sieve mill and are discharged from the machine through the tray. Grain (the fraction of feed grain) going overtail is fed into the third pneumatic duct, cleaned rom impurities, and afterwards taken out and sent to the crushing unit. The air stream with light impurities from the first pneumatic channel is sequentially fed to the first dust-settling chamber, then to the second one and is fed by the diametric fan into the sediment chamber of the dust collector. The impurities trapped in the chambers are discharged by the screws outside the machine. Thus, the grain-cleaning machine МЗУ-20Д provides the output of the cleaned feed grain fraction (going overtail from the lower sieve) for its subsequent crushing and preserving (for wet grain).

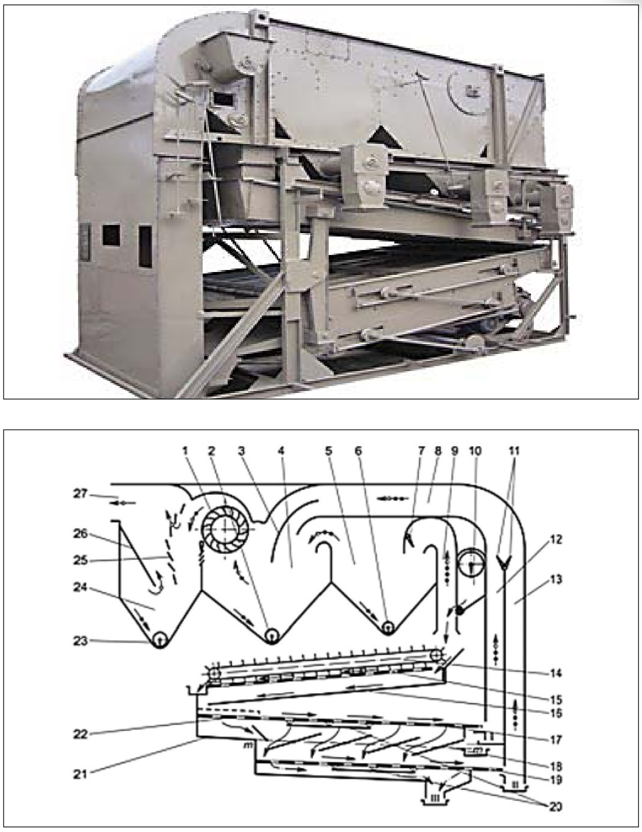


Fig. 3. Flow chart and general view of the universal grain cleaning machine (МЗУ-20Д):
1 – feeding device; 2 – first pneumatic separating channel; 3 – upper sieve; 4 – upper grating; 5 – average dividing sieve; 6 – second pneumatic separating channel; 7 – the bottom part of the lower grating mill; 8, 9 – first and second dust chamber; 10 – diametral fan; 11 – sedimentary chamber of the dust collector

An experimental model of the universal grain cleaning machine МЗУ-20Д has been made. Specialists of the Kirov machine testing station have conducted preliminary tests of the machine in the «Rassvet» farm enterprise of the Nema district of the Kirov region. According to their results, it has been established that this model qualitatively implements the technological process of grain material cleaning from light, large and small impurities, and its design and technological parameters comply with the requirements of technical design specification and ND, in particular, in terms of its designation, energy estimate and design safety. The machine meets the requirements of the technology of post-harvest processing of grain and seeds and can be successfully used in agricultural enterprises. The Kirov machine testing station recommends that the grain-cleaning machine МЗУ-20Д should be subjected to acceptance testing.

For the production of crushed grain feed, including feed grain fraction extracted from the grain heap coming from combine threshing and cleaned from impurities by the aforementioned grain cleaning machines, a two-step grain conditioner (ПЗД-3.1) with

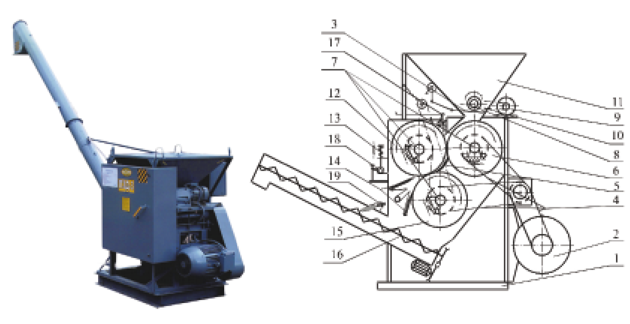


Fig. 4. General view and scheme of ПЗД-3,1 grain crusher: 1 – frame; 2, 9 – electric motor; 3 – flap; 4 – belt drive; 5 – cleaning knife; 6 – upper shaft; 7 – supports; 8 – feeder; 10 – chain drive; 11 – feed hopper; 12-side shaft; 13 – protective device; 14 – cleaning knives; 15 – lower shaft; 16 – discharge conveyor; 17, 18 – gap regulators; 19 – nozzle

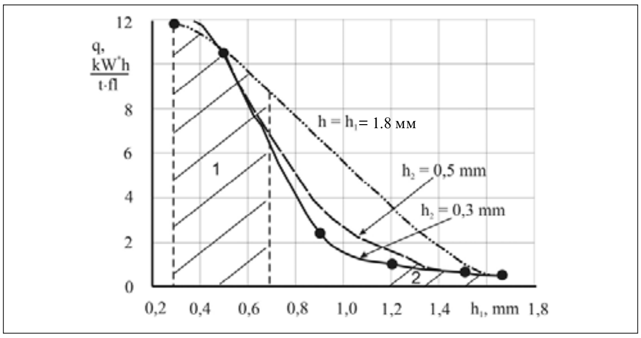


Fig. 5. Dependence of specific energy consumption change q on the input flange clearance h_1 of the first stage of crushing

a productivity of 3 t/h, a general view and a technological design scheme of which are presented in *Fig. 4*.

To determine a two-stage working process of producing crushed feed grain, experiments have been carried out for single- and two-stage grain crushing, which has made it possible to determine the influence of various design and technological factors on the throughput capacity, the power consumption of the roller machine (grain conditioner-crusher) and the quality of the finished product. This allows assessing the application feasibility of two-stage crushing as compared with the single-stage one.

Basing on the results of the experimental studies, graphs of the dependence of the change in the specific energy consumption q on the input interval face gap h1 of the first stage for single-stage and two-stage crushing have been plotted (*Fig. 5*).

Fig. 5 shows zone 1 for single-stage crushing and zone 2 for two-stage crushing, which determine the range of using the finished product that corresponds to the livestock breeding requirements, based on the output inter-roller gap. The analysis of these zones shows that the use of two-stage crushing as compared to the single-stage one reduces the specific energy consumption in several times (the difference in the areas of zones 1 and 2). In addition, the use of two-stage crushing allows the grain to be crushed by rollers with a smooth working surface of a larger capacity, with a lower energy intensity of the process, with the output of flakes meeting the livestock breeding requirements, which indicates the high efficiency of its application.

Taking into account these studies, a prototype of the grain crusher ПЗД-3.1 has been developed, manufactured and tested in production conditions. The authors provide the economic estimation of technical means for crushing grain of various crops with simultaneous application of preservatives. The analogue for the calculation of economic efficiency is a single-stage grain harvester with two grooved rollers with a possibility of simultaneous application of the MURSKA-350S preservative. According to the calculations, the annual economic effect of the use of a technical means for grain crushing with simultaneous application of preservatives ПЗД-3.1 (with an annual load of 1000 tons on the conditioner) is ЭГ = 60,833 rubles, and the level of intensification of agricultural production for ПЗД-3.1 has amounted to 26% as compared with MURSKA-350S crusher manufactured in Finland.

Conclusions. The task of increasing the efficiency of post-harvest treatment and grain processing is solved by the method of reconstructing grain cleaning and drying facilities. This will allow, for example, to use the fractional technology of crushing and preserving wet feed grain, to increase the productivity of the whole complex by 30-40%, and to obtain a crushed grain feed directly at the points of production and processing of raw materials.

The use of new air-screening machines in the post-harvest grain processing lines allows the efficient fractionation of the grain heap coming in for processing, and the obtained grain fractions are used for their technological purpose: obtaining seeds and food from high-grade grain and ready-made crushed feed for various groups of farm animals from forage grain. The use of a machine for producing crushed feed – a two-stage grain crusher (ПЗД-3.1) significantly reduces the cost of feed production, for example, the estimated annual economic effect of using a two-stage grain crusher (ПЗД-3.1) instead of MURSKA-350S amount to ЭГ = 60,833 rubles, and the level of intensification is expected to reach 26%.

REFERENCES

1. Sysuyev V.A., Syrovatka V.I., Popov V.D. et al. Rekomendatsii po zagotovke i ispol'zovaniyu vysokovlazhnogo furazhnogo zerna [Recommendations for obtaining and use of high-moisture feed grain]. M.: Rossel'khozakademiya. 2006. 130. (In Russian)

2. Sysuyev V.A., Rusakov R.V. et al. Sposob podgotovki zerna ozimoy rzhi v kormlenii krupnogo rogatogo skota i ptitsy. Rekomendatsii [A method for preparing winter wheat rye for feeding cattle and poultry. Recommendations]. Kirov: NIISKh Severo-Vostoka. 2012. 31. (In Russian)

3. Sysuyev V.A., Savinykh P.A., Kazakov V.A. Tekhnologiya dvukhstupenchatogo plyushcheniya furazhnogo zerna [Technology of two-stage crushing of feed grain] // *Dostizheniya nauki i tekhniki APK*. 2012. 6. 70-72. (In Russian).

4. Sychugov N.P., Sychugov Yu.V., Isupov V.I. Mekhanizatsiya posleuborochnoy obrabotki zerna i semyan trav [Mechanization of post-harvest processing of grain and grass seeds]. Kirov: FGUIPP "Vyatka". 2003. 368. (In Russian)

5. Sysuev V., Semjons I., Savinyh P., Kazakov V. The movement and transformation of grain in a two-stage crusher // In: Engineering for Rural Development, Proceedings. 14. Jelgava. 22-27.

6. Romaliyskiy V.S. Plyushchilka dlya vlazhnogo zerna [Wet grain crusher] // *Kombikorma*. 2004. N2. 23-25. (In Russian).

7. Sebestuen E.J. Grinding of animal feeding stuffs // *Journal of Flaut and Animal Feed Milling*. 1974. Mau. 128. (In English)

8. Izmaylov A.Yu. Tekhnologii i tekhnicheskiye resheniya po povysheniyu effektivnosti transportnykh sistem APK [Technologies and technical solutions aimed at improving the efficiency of transport systems used in farm enterprises]. M.: Rosifnormagrotekh. 2007. 197. (In Russian)

9. Izmaylov A.Yu. Povysheniye urovnya ispol'zovaniya transporta v sel'skom khozyaystve [Increasing the level of using transport in agriculture] // *Tekhnika v sel'skom khozyaystve*. 2006. N2. 8-10. (In Russian)

The paper was submitted to the Editorial Office on 06.04.2018

The paper was accepted for publication on 20.07.2018

Conflict of interest.
The authors declare no conflict of interest.

УДК 633.11:631.53
CC BY
DOI 10.22314/2073-7599-2018-12-4-22-28

Pre-sowing Treatment of Sunflower, Soybean and Maize Seeds with Low-Frequency Electromagnetic Radiation

Nelly S. Levina,
senior expert;
Yulia V. Tertyshnaya,
PhD(Chem), senior researcher,
e-mail: moraxella@bk.ru;

Irina A. Bidey,
laboratory assistant-research engineer;
Olga V. Elizarova,
laboratory assistant-research engineer

Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation

Abstract. Pre-sowing seed treatment by various energy methods is used as an effective way of stimulating the seed material. (Research purpose) The authors have studied the effect of a low-frequency electromagnetic field on the seed properties of sunflower (Helianthus), soybean (Glycine max) and maize (Zea mays L.) seeds. (Materials and methods) Parameters of the electromagnetic field: induction of 16 mT, pulse repetition rate of 16 Hertz I; exposure time of 15 and 20 minutes. The experiment has been conducted in two stages. The first stage is the determination of the germination and germination energy of irradiated and non-irradiated seeds, as well as the biometric characteristics of seedlings: the mass of stems and leaves, the length and mass of the root system. The second stage is the phenological observations of the growth and development of plants according to the phases of their development in the VIM climatic chamber. (Results and discussion) It has been shown that the sowing qualities of maize seeds after 15 min of irradiation are higher than the control ones. It has been determined that germination energy has increased by 10 percent as compared to the control sample, germination by 8 percent, seedling weight by 6.4 percent, weight of stems and leaves by 16, root system by 3.4 and stem height by 30 percent. It has been found that there is no influence of low-frequency electromagnetic radiation on the germination of soybeans both in the laboratory and in the climate chamber. It has been found that at the end of the growing season, the mass of plants irradiated for 20 minutes has turned out to be greater than the control values by 20 percents, the root mass by 25 percents, and the root length by 16 percents. The authors have determined that the treatment of sunflower seeds (Helianthus) with a low-frequency electromagnetic field has no stimulating effect on germination energy and germination capacity, but contributes to an increase in the mass of plants when they are grown in a phytotron. It has been calculated that a 15-minute irradiation of sunflower seeds before sowing resulted in an increase in the mass of plants by 34.9 percents; the mass of the root system – by 22 percents; length of roots – by 3.65 percents; the head (anthodium) diameter – by 5.3 percents and their weights – by 25.3 percents. (Conclusions) The response of plants to the energy impact depends on the type of crop. It has been determined that low-frequency magnetic radiation without changing the sowing properties of seeds can positively influence the growth and development of plants.
Keywords: sunflower seeds, soybean and corn seeds, germination energy, germination, low-frequency electromagnetic radiation, biometric indicators.

For citation: Levina N.S., Tertyshnaya Yu.V., Bidey I.A., Elizarova O.V. Pre-sowing treatment of sunflower, soybean and maize seeds with low-frequency electromagnetic radiation. *Selskokhozaistvennye mashiny i tekhnologii*. 2018. 12(4): 22-28. DOI 10.22314/2073-7599-2018-12-4-22-28. (In Russian).

Improving the quality of seed material and, as a reasult, increasing yields is the most important task of Russian farm industry. For many years, new methods and technologies for cultivating, processing and preserving crops have been developed [1-3].

Since during the storage of seeds, their bioenergetic capacity is depleted, it is recommended to use various energy effects for effective awakening of seed material, healthy growth and development of plants [4-6].

In recent years, the intensification of crop production in farm practices began to actively introduce electrophysical methods of affecting plants and seeds of cereals, vegetables, and legumes [7, 8]. There are physical methods of influencing the seed material, such as the electromagnetic field of various ranges, γ-radiation, ultraviolet, infrared, laser radiation, electric field of the corona discharge, and ultrasonic effect [9, 10]. In many works their effect on the improvement of the sowing qualities of cereals and vegetable crops is shown, as well as an increase in the preservation of the yield of fruit-bearing crops [11-15]. Despite the positive results of the exposure to various types of radiation and long-term studies in this field, there is no unequivocal opinion on this matter. Several mechanisms of action are proposed: the stress response of the system, the effect on photosynthetic activity and the porphyrin response, and the change in the water structure.

The present work discusses the study results on the influence of an effective method of irradiation - low-frequency electromagnetic field. The value of the work is grounded by the complex study of the sowing qualities of maize, soybean and sunflower seeds both in laboratory conditions and phenological observations in the phytotron.

The research purpose is to determine the sowing properties of sunflower (*Helianthus*), soybean (*Glycine max*) and maize (*Zea mays L.*), as well as biometric parameters of plant morphological organs after their exposure to low-frequency electromagnetic radiation.

Materials and methods. For the experimental purpose, selection material included the seeds of soybean variety «Slavia», a maize hybrid «Krasnodar 291-AMV» developed by Krasnodar Research Institute for Agriculture named after P.P. Lukyanenko, and sunflower variety «Dobrynya». The seeds were exposed to a low-frequency electromagnetic field with an induction of 16 mT and a pulse repetition rate of 16 Hz for 15 and 20 min.

Non-irradiated seed samples were used as control ones. Seed processing was carried out two weeks before the beginning of experimental studies to assess the effect of low-frequency electromagnetic radiation on planting properties, growth and the development of plants.

The studies were carried out in two stages. At the first stage, the researchers evaluated the viability and germination of irradiated and non-irradiated seeds, as well as the biometric characteristics of seedlings: the mass of stems and leaves, the length and mass of the root system.

The second stage included phenological observations of the growth and development of plants in their development phases in the VIM climatic chamber. In the chamber there were installed containers of 40×60×45 mm filled with soil. During the vegetation of plants in the climatic chamber daily observations were made of their growth and development.

Sowing parameters of the seeds were determined in accordance with the methodology set out in GOST 12038-84. Germination of seeds of large-seed crops (soybean, corn, sunflower), was carried out in the propagators filled with moistened sand. The number of seeds in the sample was 50 pieces, with four replicates. Seed viability was determined on the 5th day, germination – on the 8th day after sowing. Biometric indicators of seedlings (germination phase) were determined in 10 plants, in the harvesting phase – for all remaining plants.

At the end of the vegetation period, the plants were carefully removed from the containers along with the root system and their heights, masses of the aerial parts of plants and root systems were measured.

The tables show the arithmetic mean values of the indicators. The relative error did not exceed 3%.

Results and discussion. Corn. The results of laboratory studies on the evaluation of the influence of a low-frequency electromagnetic field on the sowing properties of the seeds of the maize hybrid «Krasnodar 291-AMV» and biometric indices of seedlings are given in *Tab. 1.*

Table 1

The response of biosystems of maize seeds and their seedlings to the effect of electromagnetic radiation

Controlled parameter	Time of irradiation of seeds (τ), min		
	0 (Control)	15	20
Energy germinations, %	85.0	95.0	95.0
Germination, %	90.0	98.0	100.0
Weight of seedling, g	1.266	1.347	1.181
Green mass, g	0.308	0.357	0.290
Mass of roots, g	0.958	0.991	0.891
Height of plants, sm	9.8	12.85	11.35
Dry content in the seedling, %	86.29	86.93	86.82

The analysis of the data obtained showed that pre-sowing treatment of maize seeds with a low-frequency electromagnetic field for 15 and 20 min had a positive effect on the process of yielding seeds from the state of rest. The values of seed viability and germination of maize seeds during their treatment for 15 and 20 min. increased by 10% as compared with the control values.

The highest seedling weight, its green mass (stem and leaves), the root system, and the dry matter content were obtained by treating the seeds for 15 minutes. Increasing pre-sowing effect time on corn seeds up to 20 min led to a significant decrease in biometric indicators of seedlings as compared with the control samples.

At the second stage, the effect of a low-frequency electromagnetic field on the growth and development of maize plants in a climatic chamber was evaluated.

During corn vegetation in the climatic chamber, daily observations were made of the growth and development of plants (*Fig. 1*). The first seedlings appeared in 8 days after sowing.

At the end of the vegetation period, measurements were taken of the height and weight of plants with a root system; the mass of the aboveground part of the plants, and the length and mass of the roots.

Biometric indices of plants grown from seeds irradiated with a low-frequency electromagnetic field within 15 minutes were significantly higher than similar

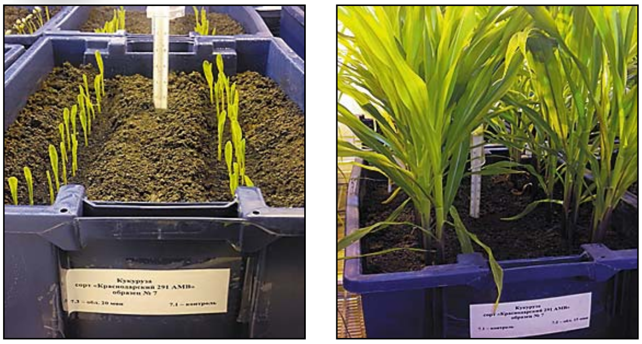


Fig. 1. The process of growing maize plants (Zea mays L) in the VIM climatic chamber

data obtained with a 20-minute irradiation. The height of the aerial part of the plants was 4% higher than the control value, the weight of the aerial part – by 8.8%, the length of the roots – by 17.2% and the mass of the roots by 13.6%.

Table 2

Biometric indicators of morphological parts of plants grown in a climatic chamber

Controlled parameter	Time of irradiation of seeds (τ), min		
	0 (Control)	15	20
Height of the aerial part plants, sm	78.33	81.46	74.66
Mass of the aerial part plants, g	18.47	20.09	14.31
Length of the roots, sm	17.55	20.56	14.44
Mass of the roots, g	0.66	0.75	0.57

Biometric indices of plants grown from seeds irradiated with a low-frequency electromagnetic field within 15 minutes were significantly higher than similar data obtained with a 20-minute irradiation. The height of the aerial part of the plants was 4% higher than the control value, the weight of the aerial part – by 8.8%, the length of the roots – by 17.2% and the mass of the roots by 13.6%.

Sunflower. Analysis of the data obtained under laboratory conditions showed that the treatment of the seeds for 15 and 20 min had no stimulating effect on their seed germination and the biometric characteristics of seedlings (*Tab. 3*). Thus, in seeds irradiated for 15 min, a decrease in germination by 10% was observed, in case of a 20-min treatment, the seed germination was practically unchanged as compared to the control values. When the seeds are irradiated for 15 min, the magnitude of the deviation of the controlled parameters from the control values was slightly lower as compared with similar data obtained with a 20-minute seed irradiation.

A comparison of the morphological characteristics of the plant parts obtained from the treated seeds with the control samples showed that a 15-minute irradiation of the seeds before sowing resulted in an increase in

Table 3

Sowing properties of seeds and biometric indicators of seedlings and sunflower plants

Controlled parameter	Time of irradiation of seeds (τ), min		
	0 (Control)	15	20
The phase of germination (laboratory conditions)			
Germination energy, %	63.0	65.0	70.0
Germination, %	95.0	85.0	95.0
Weight of seedling, g	1.483	1.423	1.357
Mass of the aerial part plants, g	0.977	1.049	1.026
Mass of the root, g	0.513	0.374	0.331
Height of a plant, sm	9.8	12.85	11.35
Dry content in the seedling, %	81.76	81.84	82.13
Harvesting phase (climate chamber)			
Weight of a plant, g	28.05	37,83	31.15
Height of a plant, sm	108.5	108.33	114.67
Mass of the root, g	2.11	2.58	2.26
Length of the root, sm	11.5	11.92	13.17
Diameter of flower heads, sm	5.08	5.35	6.34
Weight of flower heads, sm	16.61	20.85	15.07

Fig. 2. Morphological parts of sunflower plants and seeds after harvesting

the mass of plants by 34.9%, the root system weight by 22%, the root length by 3.65%, the head (anthodium) diameter – by 5.3% and their weight – by 25.3% (*Fig. 2, Tab. 3*). Biometric indicators of plant parts grown from seeds irradiated for 20 min. were significantly lower than the control samples. It should be noted that seeds in the heads of all harvested plants were immature.

Thus, the treatment with a low-frequency electromagnetic field for 15 minutes was the preferred method for sunflower seeds of the «Dobrynya» variety.

Soybeans. «Slavia» is a highly productive early soybean variety for grain producion, with a vegetation period of 95-105 days. The average weight of 1000 seeds is 172 g. The seeds accumulate up to 42% protein and up to 23% oil.

The viability of soybean seeds is determined in laboratory conditions, their germination in laboratory conditions and in a climatic chamber (*Tab. 4*).

Table 4

Determination of sowing indicators of soybean seeds of the «Slavia» variety

Conditions cultivations	Characteristic	Time of irradiation of seeds (τ), min		
		0 (Control)	15	20
Petri dish	Germination energy, %	95	85	88
	Germination, %	95	92	95
Climatic chamber	Germination, %	85	70	75

As a result of seed treatment, the aforementioned electromagnetic field has reduced their sowing indices, both in the laboratory and in the climatic chamber. The energy of seed germination when irradiated for 15 min. as compared to the control samples decreased by 10%, germination – by 3%. With a 20-minute irradiation, the laboratory energy of seed germination decreased by 7%. Germination of seeds in the climate chamber decreased by 15 and 10%, respectively.

Nevertheless, a positive trend of the influence of irradiation with an electromagnetic field was observed during the growth of soybean in the phytotron. A gradual increase was noticed in the aboveground mass of plants according to the variants of the experiment, the development of the root system, the intensity of flowering and fruit formation. However, externally, plants formed from seeds irradiated for 15 min., were slightly lower in height than the control samples and plants with 20-minute irradiation.

As a result of low-quality electromagnetic influence on soybean seeds, the biometric parameters of seed plants have changed, as well as qualitative indicators obtained after the growing season (*Tab. 5*)

Table 5

Biometric indicators of morphological parts of soybean plants under different irradiation modes

Controlled parameter	Time of irradiation of seeds (τ), min		
	0 (Control)	15	20
Weight of a plant, g	2.33	2.89	2.80
Mass of the aerial part plants, g	1.81	2.26	2.15
Mass of root, g	0.52	0.63	0.65
Height of a plant, sm	49.1	44.5	57.7
Height of a stem, sm	33.2	29.7	39.3
Length of a root, sm	15.85	14.8	18.4
The mass of 1000 seeds', g	153.0	166.0	164.0
Thickness of the stem, mm	2.06	2.06	2.17

An increase in the weight of plants and the mass of 100 seeds was observed both at 15 and at 20 minutes of low-frequency electromagnetic action, and at τ = 15 min this index was higher. However, the remaining indices were significantly lower than those after irradiation, τ = 20 min. After 20 minutes of irradiation, the root system of the plants was more developed featuring the longer root length and mass.

Conclusions

1. Pre-sowing treatment of maize seeds with low-quality electromagnetic radiation had an ambiguous effect on their sowing qualities and the formation of plants grown from them. Irradiation of seeds for 15 min. led to an increase in germination energy as compared to the control values by 10%, germination – 8%, seedling mass – 6.4%, stems and leaves – 16%, root system – 3.4%, stem height – 30%. At 20 minute seed irradiation, although there was some increase in germination (10%), however, the biometric indices of seedlings obtained in laboratory conditions and plants grown under phytotron conditions were lower as compared with the control samples.

2. Low-frequency electromagnetic radiation did not have a stimulating effect on the soybean's sowing quality, 20 minutes of seed irradiation led to an increase in the mass of plants at the end of the growing season by 20%, the root mass by 25%, and their length by 16%.

3. The exposure of sunflower seeds to a low-frequency electromagnetic field did not have a stimulating effect on seed viability and germination, but yielded a positive

result in the harvesting phase of plants. A comparison of the morphological characteristics of plant parts obtained from irradiated seeds and grown under the phytotron conditions with control indices showed that a 15 minute irradiation of the seeds before sowing resulted in an increase in the mass of plants by 34.9%; the mass of the root system – by 22%; the length of roots – by 3.6%5; the head (anthodium) diameter – by 5.3% and their weight – by 25.3%; biometric indicators of plant parts grown from seeds irradiated for 20 minutes were significantly lower than those of the control values.

REFERENCES

1. Lachuga Yu.F., Izmaylov A.Yu., Zyulin A.N. Razrabotka i vnedreniye vysokoeffektivnykh, resurso- i energosberegayushchikh tekhnologiy i tekhnicheskikh sredstv posleuborochnoy obrabotki zerna i podgotovki semyan [Development and introduction of highly effective, resource and energy-saving technologies and technical means of post-harvest grain processing and seed preparation] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2009. N1. 2-9. (In Russian)

2. Yakushev V.P., Mikhailenko I.M., Dragavtsev V.A. Reserves of agrotechnologies and breeding for cereal yield increasing in the Russian Federation // *Agricultural Biology*. 2015. 50. N5. 550-560. (In English)

3. Izmaylov A. Yu., Evtushenko N. E., Kurbanov R. K. Modernizatsiya tekhnologiy transportirovaniya selektsionnogo urozhaya [Modernization of technologies for transporting harvested selection crops] // *Vestnik sel'skokhozyaystvennoy nauki*. 2017. N2. 6-8. (In Russian)

4. Pavlov S. A., Dadyco A. N. Osobennosti syshki zerna pri ispolzovanii topochnyh blokov na tverdom toplive [Features of grain drying when using combustion blocks on solid fuel] // *Sel'skokhozyaystvennye mashiny i tekhnologii*. 2017. N4. 9-13. (In Russian)

5. Tertyshnaya Yu. V., Levina N. S., Elizarova O. V. Vozdeystvie ultrafioletovogo izlucheniya na vshozhest' I rostovie protsessy semyan pshenitsy [Influence of ultraviolet radiation on the germination and growth processes of wheat seeds] // *Sel'skokhozyaystvennye mashiny i tekhnologii*. 2016. N5. 24-29. (In Russian)

6. Tertyshnaya Yu.V., Levina N.S. Vliyanie spektralnogo sostava sveta na razvitie selskokhozyaystvennyh kultur [Influence of spectral composition of light on the development of farm crops] // *Sel'skokhozyaystvennye mashiny i tekhnologii*. 2016. N5. 24-29. (In Russian)

7. Kutyrov A.I., Khort D.O., Filippov R.A., Tsench Yr.S. Magnitno-impul'snaya obrabotka semyan zemlyaniki sadovoy [Magnetic-pulse treatment of strawberry seeds] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2017. N5. 9-15. (In Russian)

8. Rakosy-Tican L., Aurori C.M., Morariu V.V. Influence of near null magnetic field on in vitro growth of potato and wild Solanum species. // Bioelectromagnetics. 2005. 26. 548-557. (In English)

9. Sahebjamei H., Abdolmaleki P., Ghanati F. Effects of magnetic field on the antioxidant enzyme activities of suspension-cultured tobacco cells // Bioelectromagnetics. 2007. 24. 42-47. (In English)

10. Abdolmaleki P., Ghanati F., Sahebjamei H., Sarvestani A.S. Peroxidase activity, lignification and promotion of cell death in tobacco cells exposed to static magnetic field // *Environmentalist*. 2007. 27. 435-440. (In English)

11. Egorova I. V., Kondratenko E. P., Soboleva O. M., Verbitskaya N. B. Vliyanie obrabotok zerna pshenitsy elektromagnitnym polem na soderzhanie vodorastvorimyh vitaminov [Influence of wheat grain processing with an electromagnetic field on the content of water-soluble vitamins] // *Razionalnoe pitanie, pischevie dobavki I biostimulyatory*. 2014. N1. 22-23. (In Russian)

12. Hirota N., Nakagawa J., Koichi K. Effects of a magnetic field on the germination of Plants. J. Appl. Phys. 1999. 85. 5717-5719. (In English)

13. Levina N.S., Tertyshnaya Yu.V., Bidey I.A., Yelizarova O.V., Shibryayeva L.S. Posevnyye kachestva semyan myagkoy yarovoy pshenitsy (Triticum aestivum L.) pri raznykh rezhimakh vozdeystviya nizkochastotnym magnitnym polem [Sowing qualities of seeds of soft spring wheat (Triticum aestivum L.) under different exposure modes to a low-frequency magnetic field] // *Sel'skokhozyaystvennaya biologiya*. 2017. 52. N3. 580-587. (In Russian)

14. Syrovatka V.I., Ivanov Yu.A., Kononov V.P., Popov V.D. Rekomendatsii po zagotovke i ispol'zovaniyu vysokovlazhnogo furazhnogo zerna [Recommendations on harvesting and use of high-moisture feed grain]. Moscow: Rossel'khozakademiya, 2006. 130. (In Russian)

15. Alicamanoglu S., Sen A. Stimulation of growth and some biochemical parameters by magnetic field in wheat (Triticum aestivum L.) tissue cultures. // *Afr. J. Biotechn.* 2011. 53. 10957-10963. (In English)

The paper was submitted to the Editorial Office on 27.04.2018

The paper was accepted for publication on 07.06.2018

Conflict of interest.
The authors declare no conflict of interest.

УДК 66.047 CC BY DOI 10.22314/2073-7599-2018-12-4-29-34

Study of Grain Drying in the Automated Grain Drying Unit

Sergey A. Pavlov[1],
Ph.D.(Eng), key research engineer,
e-mail: sapavlov777@mail.ru;

Tatiana F. Frolova[2],
key research engineer

[1]Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation;
[2]LLC "Special Design Bureau ror Heat Generators", Bryansk, Russian Federation

Abstract. Mine and column grain dryers are a fairly complex object of control in the production line. The process of grain drying is characterized by a large number of parameters, quantitatively and qualitatively characterizing the dryer operation. First of all, this includes the criteria of maximum performance and minimum deviations of the moisture content of the dried grain from the standard values. These criteria, as studies show, are interconnected with each other: an increase in the performance П of the dryer leads to an increase in the moisture content of the grain coming out of it, and, conversely, an attempt to reduce the moisture content of grain causes the need to reduce the performance П. (*Research purpose*) The research purpose is to develop the expression for the transfer functions of the of grain flow control depending on perturbations of the initial moisture content and the maximum grain temperature, as well as to conduct experimental studies. (*Materials and methods*) The authors have developed simplified mathematical models of moisture perturbation compensation of grain coming in for drying and its heating temperature in a drying chamber by changing the dryer performance on the basis of theoretical-and-experimental studies. (*Results and discussion*). The authors have obtained expressions to control the process performance when the current humidity and temperature change through the dryer performance parameters as a function of grain moisture flow and heat used to grain heating up to an acceptable temperature. Farm tests of developed transition management functions have been implemented for dryer SZT-16 controlled by PLC S7-1200 Siemens and operating in an automatic mode. Tests have been conducted on the "Babachev" farm, Karachev district of the Bryansk region in the process of drying food wheat grain. (*Conclusion*) It has been confirmed that the dryer performance is determined not only by the rated capacity but also by the deviation of the current moisture content of grain from the specified values and by the ratio of the amount of heat used for evaporating and heating. The dryer performance at constant initial humidity is determined by its rated performance, the maximum specified difference of grain temperatures, as well as the ratio of the amounts of heat used for evaporating and heating.
Keywords: grain, drying, automation, control algorithms.

For citation: Pavlov S.A., Frolova T.F. Study of grain drying in the automated grain drying unit. *Sel'skokhozyaystvennye mashiny i technologii*. 2018. 12(4): 0-0. DOI 10.22314/2073-7599-2018-12-4-0-0. (In Russian)

Automatic control of grain drying processes opens up wide prospects for increasing its efficiency, reducing labor costs and improving the product quality.

Shaft and column grain dryers are quite a complex control object in the production line. The process of grain drying is characterized by a large number of parameters that quantitatively and qualitatively affect the dryer performance. Among these parameters the are the moisture content of grain at the dryer inlet and outlet, the dryer performance, the temperature of grain heating and the drying agent supplied to and spent in the dryer [1-6].

From this set of particular criteria, those relating to the dryer include, first of all, the criteria for maximum productivity and minimum deviations in the moisture of the dried grain from the standard values. These criteria, as studies show, are related to each other: an increase in the dryer performance *П* reduces the moisture content of grain coming out of it, and, conversely, an attempt to reduce the moisture content of grain causes the need for a reduction in the performance *П*. Since grain and seed processing enterprises should meet the requirements of standards, the moisture content of the obtained grain and seeds should not exceed the standard value, so the criterion *min W* becomes a restriction of the form $W \leq W_{\text{con}}$. In addition, the drying process of seed grain should meet the requirement of impermissibility of reducing the seed quality of finished products. This requirement, when applied to grain dryers, is to prevent grain overheating, i.e., the temperature θ of the grain should not exceed the permissible value $\theta_{\text{доп}}$ [7, 8].

Thus, the optimal control function is often expressed in the form:

$$max\ П = f(\theta, W, t), \tag{1}$$

where *П* – performance, t/h; θ – temperature of grain, °C;

W – moisture content of grain, %; t – temperature of the drying agent, °C.

With restrictions:

$$W \leq W_{кон} \text{ и } \theta \leq \theta_{доп}. \quad (2)$$

To describe the drying process in shaft and column dryers, a number of mathematical models have been developed, both based on differential equations and found empirically, but in the latter case, a number of parameters must be determined experimentally for each particular object, which is rather difficult [9, 10].

The task is to develop, on the basis of theoretical and experimental studies, simplified mathematical models for compensating the humidity disturbances of grain entering the drying stage and the temperature of its heating in the drying chamber by changing its performance.

The purpose of the present research is to develop expressions of the transfer functions of controlling the amount of grain dried, depending on the disturbances of the initial moisture and the maximum grain temperature, and also to carry out an experimental test.

Materials and methods. The dryer capacity by the mass of evaporated moisture can be presented as:

$$\Pi = \frac{G(U_1 - U_2)}{\tau\eta}, \text{ kg moist./h}, \quad (3)$$

where Π – rated performance of the dryer, t/h; G – grain mass in the dryer, kg; U_1, U_2 – moisture content of the initial and conditioned grain, kg moist./kg dry mat.; τ – duration of drying, h; η – the fraction of heat used to evaporate moisture.

Changing the dryer performance with deviations in the initial moisture content of the grain can be presented as:

$$\Pi_m = \frac{G(U_0 - U_1)}{\tau\eta}, \text{ kg moist./h},$$

where U_0 – the current moisture content of grain, kg moist./kg dry mat.; finally, the current performance looks like:

$$\Pi_m = \Pi\frac{(U_0 - U_1)\eta}{(U_1 - U_2)\eta_1}, \text{ t/h}, \quad (4)$$

where η_1 – the fraction of heat used to evaporate moisture in the case of humidity deviations.

The amount of heat used to evaporate moisture equals:

$$\eta = \frac{\Delta U\, r}{\Delta U\, r + \Delta\theta\, c},$$

where ΔU – the difference in moisture content, kg moist./kg dry mat.; $\Delta\theta$ – temperature difference at grain drying, °C; c – heat capacity of grain, kJ/kg. evap. moist.; specific heat of moisture evaporation, kJ/kg.

At a significant excess of the current humidity U_0 above the standard moisture (more than 1-1.5%), the dryer is transferred from the stream to the circulation mode, so grain rate ceases, and the expected circulation time can be determined by the expression:

$$\tau_ц = \tau\frac{U_0 - U_2}{U_1 - U_2}, \text{ h}, \quad (5)$$

where τ – drying time, h.

The value of τ is calculated from the known U_1, U_2 and the temperature mode of drying in order to estimate the time for transferring the operation of the dryer from the circulation to flow mode [11].

The main parameters characterizing the thermal mode of a grain dryer are the temperature of the coolant supplied to the drying chamber and the temperature of grain heating. On the one hand, the drying process must be carried out in such a way as not to exceed the permissible temperature of grain heating, but on the other hand, drying is most effective at the heating temperature limits. The desire to intensify the drying process led to the development of various systems of automatic regulation (stabilization) of the grain heating temperature, in which the control of the fuel supply and drying exposure (by varying the performance) were used as control actions. These systems allow maintaining the specified moisture content of grain, but do not prevent its drying or excess moisture of the output grain.

Let us consider a particular problem of changing the grain temperature with a constant initial moisture content. The dryer capacity for the heat used for drying can be presented as follows:

$$\Pi = \frac{G\,c(\theta_к - \theta_н)\eta_1}{\tau}, \text{ kJ/h}, \quad (6)$$

where $\theta_к$, $\theta_н$ – the final and initial temperature of grain, °C.

With temperature perturbations, the heat output varies according to the expression:

$$\Pi_0 = \frac{G\,c(\theta'_к - \theta_к)\eta_2}{\tau}, \text{ kJ/h}, \quad (7)$$

where $\theta'_к$ – the current grain temperature, °C.

The current capacity of the dryer is:

$$\Pi_0 = \Pi\frac{(\theta'_к - \theta_к)\eta_2}{(\theta_к - \theta_н)\eta_1}, \text{ t/h}. \quad (8)$$

When calculating $\theta'_к$ it is necessary to take into account the location of the temperature sensors and the inertia of grain heating.

Assuming that the temperature increases linearly along the shaft length and its maximum value is reached at the mine outlet, it is advisable to control the grain temperature in the upper regions of the column, for example, to place a thermal sensor at the entrance of the last drying section and determine $\theta_{к0}$ and $\theta'_{к0}$, decreasing their values by:

$$\Delta\theta = \frac{\theta_{\text{к}} - \theta_{\text{н}}(n-1)}{n};$$

$$\theta_{\text{к}0} = \theta_{\text{к}} - \Delta\theta \text{ и } \theta'_{\text{к}0} = \theta'_{\text{к}} - \Delta\theta, \qquad (9)$$

where n – the number of drying sections.

The economic checking-up of the developed transmission control functions was carried out during testing of the NWT-16 grain dryer, controlled by the S7-1200 Siemens logic controller and operating in an automatic mode. The tests were carried out in the «Baibashev» peasant farm, Karachev district of the Bryansk region, in the process of drying food wheat grain.

The controller was programmed for a specific 13 crops, including rapeseed, soybean, and corn. According to empirical relationships, the moisture content of grain at the inlet and outlet was measured by the Mikroradar-113 moisture meter. The grain temperature was measured by resistance thermometers. The grain dryer is controlled by changing the rotational speed of the rotor-type unloading device, for which a frequency converter is installed on its drive.

The technological scheme of the dryer is shown in *Fig. 1.*

The device operates as follows. The wet grain is fed through the first stream of the grain elevator through a valve that is set to flow or circulated into the moisture meter of wet grain (at the dryer inlet), then to the dryer, dried and cooled grain is discharged by the rotors, the drive of which is set to the specified flow rate and through a discharge the device is fed to the moisture meter at the outlet by the second stream of the grain elevator and is withdrawn from the dryer. The drying agent is prepared in a furnace and fed through a diffuser into the dryer.

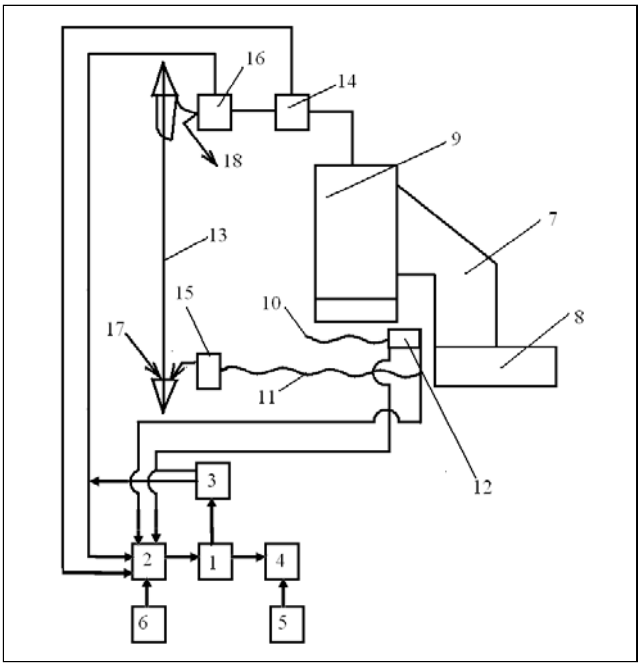


Fig. 1. Technological scheme of the dryer:
1 – contains microprocessor; 2 – meter; 3 – correction unit; 4 – sensor; 5 – grain crop selection unit; 6 – pause correction unit; 7 – dryer diffuser; 8 – furnace; 9 – dryer; 10 – discharge rotors; 11 – discharge device; 12 – rotor drive; 13 – grain elevator; 14 – moisture meter at the dryer inlet to the; 15 – moisture meter at the dryer outlet; 16 – transfer valve from the circulation to flow mode. Also shown in the diagram are directions of move-ment of wet grain 17 and dried grain 18

Sensor *4* is set for the crop name, the initial and final moisture of grain, the device is actuated in the humidity measurement mode of the set crop from moisture meter *15*, correction unit *3* is provided to compensate for external factors, in block *6*, the grain rate is automatically set according to the expression $V_i = K \cdot (W_i - W_{min})$, where V_i – a current value of the analog signal, V; K is the conversion coefficient of the moisture humidity index to the analog signal; W_i – current moisture value of the measured crop, %; W_{min} – the minimum value of humidity,%, there is a change in the rate of grain depending on its humidity at the dryer outlet.

When the moisture content of grain is relatively higher than the standard one, the grain rate decreases due to the rotational speed of the rotors, and then, if the moisture content of the grain does not reach the standard one, a pause is made.

At the end of the pause of at least *3* analog signals from moisture meter *15*, which is necessary to compensate for the current unevenness of grain in terms of humidity, grain unloading stops and the device enters the circulation mode. When the standard moisture ia achieved, the circulation stops, and the grain unloading resumes.

Two experiments were carried out with automatic correction of the rotor speed without grain circulation during the pause (*Fig. 2*) and with periodic circulation (*Fig. 3*).

The speed of rotors is determined basing on the condition that Π = 32 t/h at P=100%. The main indicators of the dryer are given in *Tab. 1.*

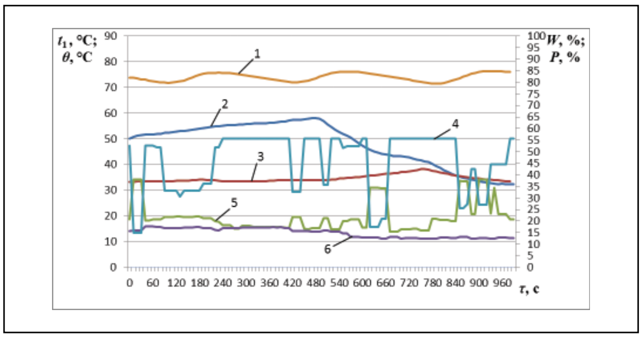


Fig. 2. Dependence of temperature (t, θ), rotor speed (P) and grain moisture W from time τ for dryer SZT-16 with controller
1 – drying agent temperature; 2 – grain temperature after drying; 3 – before drying; 4 – rotation speed of the unloading rotor; 5 – initial grain moisture; 6 – final grain moisture

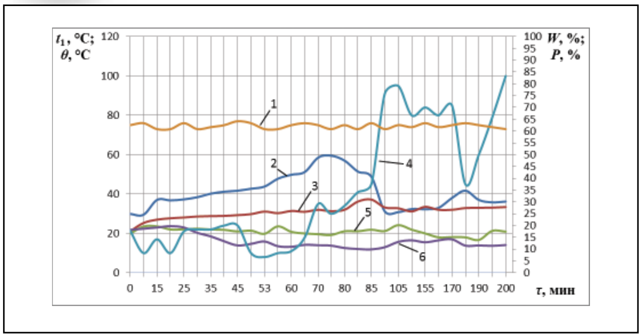


Fig 3. Dependence of temperature (t, θ), rotor speed (P) and grain moisture W from time τ for the automated dryer SZT-16: 1 – drying agent temperature; 2 – grain temperature after drying; 3 – before drying; 4 – rotation speed of the unloading rotor; 5 – initial grain moisture; 6 – final grain moisture

or the maximum grain temperature *θ*, correspond to the experimental data (with an error of not more than 15-20%).

Simplified analytical expressions have been developed for automatic control of the dryer's performance with respect to the initial and maximum moisture content of grain, which do not require specifying additional parameters. Comparison is made of a signal coming from moisture meters at the inlet and outlet of the dryer with the values of the initial and final moisture content of grain and the amount of heat used to evaporate moisture that are set in the control program. It is possible to stabilize the temperature mode of drying by varying the dryer performance, depending on the change in the grain heating temperature at W = const.

Periodic grain circulation is used when the current humidity value is higher than the standard one and it contributes to increased performance.

Table

THE MAIN PERFORMANCE INDICATORS OF THE DRYER SZT-16 (WHEAT PROCESSING)

Performance indicators	Indicators values	
	Flow-line mode, background 1	With periodic circulation, background 2
Performance, tons/h	14.2	14.7
Grain moisture, %		
– before drying	19.7	21.4
– after drying	13.4	13.8
Temperature, °C:		
– coolant	74	74.6
– grain at the dryer inlet	25	20
– grain in the maximum heating zone	48	48
– cooled grain	34	32
– external air	25	19
Fuel consumption (natural gas), m^3/h	78	80.5
Coolant consumption, m^3/h	35000	35000
Relative heat consumption, kJ/kg evap. moist.	2560	2472
Temperature of flue gases, °C	207	-
Heat productivity, MW	0.6	0.622

RESULTS AND DISCUSSION. In the first experiment, grain was dried with correction of its flow rate according to the expression $V_i = K(W_i - W_{min})$ set in the dryer control program. When the humidity deviated from the standard value, the circulation of grain was not used [9]. In the second experiment, when the final humidity deviated from the standard value, the circulation was used, which led to a higher performance of the dryer.

The experimental data obtained were compared with those calculated from expressions (4) and (8), developed for a simplified control system for the dryer by humidity and grain temperature. It has been established that the calculation results of the performance, depending on the change in the initial moisture content

Conclusions. The dryer performance is determined by its rated performance, the deviation of the current moisture content of grain from the specified values and from the ratio of the amount of heat used for evaporation and heating.

If the initial moisture content is constant, the dryer performance is determined by its rated performance, maximum set difference of grain temperatures, and the amount of heat used for evaporation and heating.

REFERENCES

1. Afon'kina V.A., Zakhakhatov V.I., Mayorov V.I., Popov V.M. K voprosu upravleniya kombinirovannoy sushki zerna [On the issue of controlling combined grain drying] // *Vestnik Mordovskogo universiteta*. 2016. Vol. 26. 32-39. (In Russian)
2. Steinberg Sh.E., Khvilevetskiy L.O., Yastrebenetskiy M.A. Promyshlennyye avtomaticheskiye regulyatory [Industrial automatic controllers]. Moscow: Energiya, 1973. 568. (In Russian)
3. Industrial programmable controller systems IPC– 300 (USA). 1985. (In English)
4. Gulyayev G.A. Avtomatizatsii protsessov posleuborochnoy obrabotki i khranenii zerna. [Automation of post-harvest processing and storage of grain] Moscow: VO "Agropromizdat", 1990. 68-71. (In Russian)
5. Aniskin V.I., Rybaruk V.A. Teoriya i tekhnologoya sushki i vremennoy konservatsii zerna aktivnym ventilirovaniyem [Theory and technology of drying and temporary preservation of grain by active ventilation]. Moscow: Kolos. 1972. 200. (In Russian)
6. Sekanov Yu.P., Elizarov V.P., Levina N.S. Regulirovaniye vlazhnosti zerna po kosvennomu parametru [Regulation of grain moisture by an indirect parameter] // *Mekhanizatsiya i elektrifikatsiya sotsialisticheskogo sel'skogo khozyaystva*. 1972. 5. 24-26. (In Russian)
7. Gulyayev G.A. Optimizatsiya upravleniya shakhtnoy zernosushilkoy [Optimization of the management of mining dryer] // NTB «VIM». 1986. Iss. 63. 21-25. (In Russian).
8. Sagar V.R., Kumar P. Suresh. Recent advances in drying and dehydration of fruits and vegetables: a review // *J Food Sci Techol*. 2010. 47(1). 15-26. (In English)
9. Voronov A.A., Kondrat'yev G.A., Chistyakov Yu.V. Teoreticheskiye osnovy postroyeniya avtomatizirovannykh sistem upravleniya [Theoretical bases of designing automated control systems]. Moscow: Nauka. 1977. 231. (In Russian)
10. Krausp V.R. Avtomatizatsiya posleuborochnoy obrabotki zerna [Post-harvest grain processing automation]. Moscow: Mashgiz. 1975. 277. (In Russian)
11. Sazhin B.S. Osnovy tekhniki sushki [Basics of drying techniques]. Moscow: Khimiya. 1984. 79. (In Russian)

The paper was submitted to the Editorial Office on 13.03.2018

The paper was accepted for publication on 25.07.2018

Конфликт интересов.
Авторы заявляют об отсутствии конфликта интересов.

Conflict of interest.
The authors declare no conflict of interest.

УДК 658.512:677.21.051

CC BY

DOI 10.22314/2073-7599-2018-12-4-35-40

Analysis of Economic Indicators for Oil Flax Processing

Eduard V. Novikov[1,2],
Ph.D.(Econ.), head of the laboratory processing,
associate professor,
e-mail: edik1@kmtn.ru;

Natalia V. Basova[1],
research associate;
Aleksandr V. Bezbabchenko[1],
senior research associate

[1]All-Russian Scientific Research Institute of Flax Cultivation Mechanization, Tver, Russian Federation;
[2]Kostroma State University, Kostroma, Russian Federation

Abstract. Oil flax grows in many countries of the world. Fibre production on its basis can significantly increase the profitability of flax-growing farms. At the present stage, taking into account the real possibilities of the national economy, for its effective development it is necessary to introduce advanced technologies. Cur-rently, processing enterprises may choose among different technological equipment lines to process oil flax into fibre and thus get additional profit. (*Research purpose*) The determination of a technologically and economical-ly effective line for oil flax processing. (*Materials and methods*) The main materials for calculation were represent-ed by the indicators of production capacity, the average annual value of fixed as-sets, the amount of money spent on salaries and wages, etc. The main research method is the balance method that allows making a plan in the form of a balance sheet that takes into account the sources of inputs and the requirements for these inputs. (*Results and discussions*) The authors have considered low-cost lines for oil flax processing into short fibre on the basis of disintegrators of various brands (from domestic and foreign producers), offered characteristics of the fibre obtained in the lines, and analyzed technical and economic indicators of various technologi-cal lines under different conditions, and the payback period of capital expenditures for different oil flax acreages. (*Conclusions*) The authors have determined that the most effective is the pro-cessing of oil flax from an area of at least 1000 hectares, with a throughput capaci-ty of raw materials of at least 1000 kilogram per hour and a distance of the transportation of straw rolls to a processing site of 50 kilometer. They have also obtained technological and economic data that can be used in the organization of oil flax processing into marketable fibre.

Keywords: oil flax, fibre, acreage, profitability, production lines, payback, production cost, efficiency.

For citation: Novikov E.V., Basova N.V., Bazbabchenko A.V. Analysis of economic indicators for oil flax processing // *Sel'skohozyajstvennye mashiny i tekhnologii*. 2018. 12(4): 35-40. DOI 10.22314/2073-7599-2018-12-4-35-40. (In Russian)

Oil flax is cultivated both in the southern and northern regions in many countries of the world [1]. Both fibre and seeds can be obtained from it simultane-ously [2]. The use of fibre from oil flax straw or retted stalks can significantly in-crease the profitability of a flax-growing farm, increase employment in rural areas, and expand the range of manufacturing enterprises for the processing of fibrous raw materials [3, 4].

In 2017, the flax acreage in the Russian Federation amounted to 565.2 thou-sand hectares, which, with a yield of 1000 kg per hectare, results in a gross yield of 565.2 thousand tons of flax straw (stalk mass), which can be processed into fibre. Additional profit from the sale of stalk fibre may amount to 2 thousand rubles/ha [5]. As a rule, not traditional flax factories, but small private enterprises in coopera-tion with research centers are interested in flax straw processing. For example, the All-Russian Research Institute of Flax Cultivation Mechanization and Kostroma State University are developing resource-saving technologies for oil flax straw pro-cessing into fibre of wide industrial use.

Among the most famous foreign companies and organizations involved in the development and sale of processing equipment for oil flax are *Charle & Co* (Belgium), *Laroche* (France), *DiloTemafa* (Germany) and the *Roman Research Center IPZS* (Italy)). These firms offer equipment and technologies for processing flax stalks into paper, and German manufacturers - for the production of geotex-tiles, nonwoven and composite materials, but this is a kind of deep processing [6]. At the initial stage, the primary processing is carried out, the purpose of which is the isolation of short fibre from the stalk mass of oil flax. As a rule, foreign techno-logical lines for primary processing are metal- and energy-intensive and expensive, and it is difficult to predict whether they will be profitable in Russia.

In Russia today, a significant problem is the considerable wear and tear of the material and technical facilities [7]. At the present stage, taking into account the real capabilities of the domestic economy, it is necessary to introduce progressive technologies for effective development [8]. Earlier, in the works of the All-Russian Research Institute of Flax Cultivation Mechanization, equipment for primary pro-cessing of oil flax based on a disintegrator was described [9, 10]. At present, one of the lines based on the disintegrator is the simplest, low-cost and efficient option. It consists of a straw roll cutter, two disintegrators (D) and two shakers (T), which can be presented as a straw roll cutter + Д + Д + + T + T [10]. This equipment is produced in Russia and Belarus. For example, at present, several types of disinte-grators are produced: ДЛВ-2М and ОКВ-1 (Russia), МДТ-1000 (Belarus) and ТН-112 (Russia), ТГВ-14 (Belarus). Obviously, processing enterprises may choose among the lines of technological equipment to process oil flax straw or ret-ted stalks into fibre and thereby gain additional profit.

The purpose of this research is to determine the technologically and economically efficient line for the processing of oil flax.

Materials and methods – the main materials for calculation were represented by the indicators of production capacity, the average annual value of fixed as-sets, the output and quality of fibre from retted stalks, the average annual number of industrial and production personnel (the number of employees), and the amount of money spent on salaries and wages. The main research method is the balance method that allows drawing a plan in the form of a balance sheet that takes into ac-count the sources of inputs and the requirements for these inputs.

To calculate specific values of technical and economic indicators, use has been made of direct calculation methods, factor-based calculation, and mathemati-cal modeling.

Results and discussion. Some enterprises employ the following technologi-cal lines:

- *Line 1* (from Russian manufacturers): straw roll unwinding machine РЛР-1500 + disintegrator ДЛВ-2М + fibre unloader ВУЛ + shaking machine ТН-112 (2 pcs.) + fibre separating machine ВОМ-2;

- *Line 2* (from Belarus manufacturers): straw roll unwinding machine МР-1400 + retted stalk crushing machine МДТ-1000 (disintegrator) + fibre unloader КНИИЛП + shaking machine ТГВ-14 (2 pcs.) + ВОМ-2;

- Combined *Line 3* (joint production of Belarus + Russia): carver of rolls KUHN (or similar) + MDT-1000 (2 pcs.) + unloader KNIILP + TGV-14 (2 pcs.) + VOM-2;

- Combined *Line 4* (joint production of Russia + Belarus + Belgium): МР-1400 + breaking machine М-110Л1 + МДТ-1000 + fibre unloader КНИИЛП + ТГВ14 + shaking machine (*Charle & Co*, Belgium) + scutching drum «*Charle & Co*», Belgium) + shaking machine (2 pcs., «*Charle & Co*», Belgium) + ВОМ-2.

Our previous production experiments have shown the following fibre quality on the lines (*Tab. 1*).

Table 1
Characteristics of the fibre of retted flax stalks obtained from different lines for primary processing*

Indicator	Line			
	1	2	3	4
Mass share of chaff and weed, %	35-45	35-45	25-30	20-25
Average mass-length of fibre, mm	70-90	70-90	60-80	50-70
Average linear density of fibre, tex	6-8	6-8	6-7	6-7
Breaking load, kgs	0-11			

*Throughput capacity of the lines is almost the same and depending on the feedstock amounts to 500 and 1000 kg/h

Since the price of the Belarusian МДТ-1000 disintegrator is much lower than that of its Russian analogue ДЛВ-2М, it is possible to assemble a relatively inex-pensive line from machines produced in these two countries, for example, *Line 3*. Of interest is also the Combined *Line 4*, which can produce a higher quality fibre.

The authors have carried out a comparative analysis of the technical and eco-nomic indicators (hereinafter referred to as TEI) of the flax plant, which processes the oil flax straw (retted stalks) into short fibre on the four considered lines.

The TEI of these lines for oil flax have been calculated for flax acreage of 700, 1000 and 1500 hectares, with a distance of straw roll transportation to the processing site of 50 and 100 km, the capacity of equipment of 500 and 1000 kg/h. The calculation includes the cost of

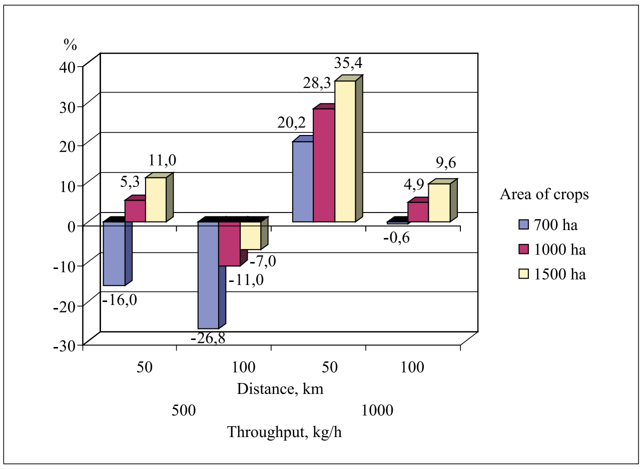


Fig. 1. The profitability of oilseed flax processing with Line 1

Table 2

Initial data for the calculation of TEI of processing lines

Indicator	Line			
	1	2	3	4
Throughput capacity of the line for raw material, kg/h	500 и 1000	500 и 1000	500 и 1000	500 и 1000
Fibre output, %	30	30	28	25
Sale price of fibre, rub/kg	29	29	31	33
Electric power of equipment, kW	70	68.4	103	83.6
Capital expenditures*, thousand rubles	14411.4	11025.6	11441.4	17240.9

* the price of new equipment

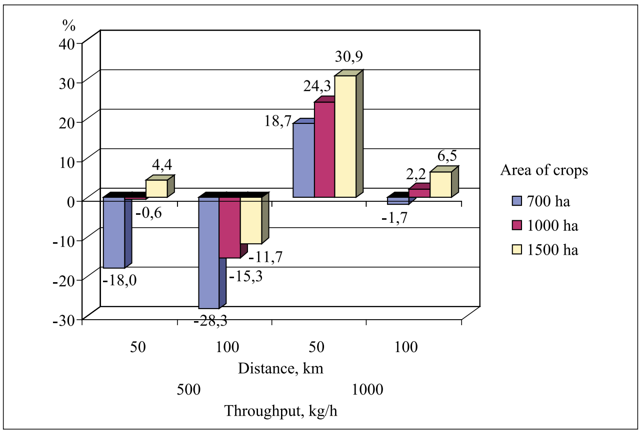


Fig. 3. The profitability of oilseed flax processing with Line 3

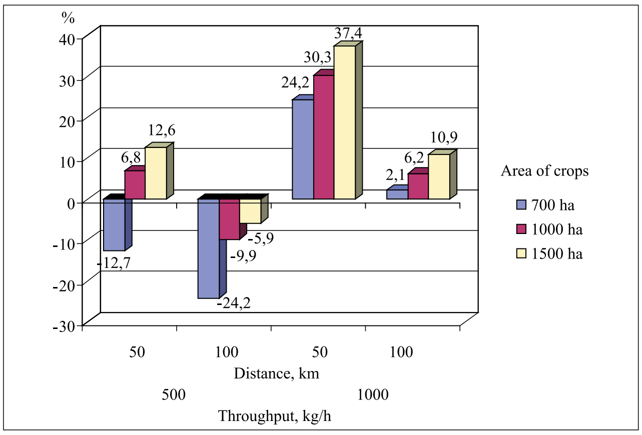


Fig. 2. The profitability of oilseed flax processing with Line 2

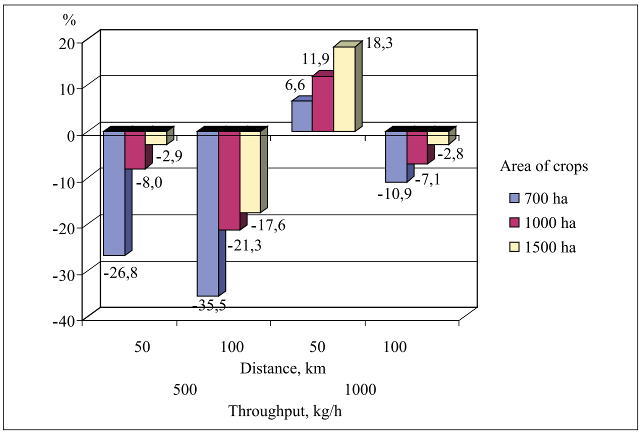


Fig. 4.The profitability of oilseed flax processing with Line 4

buildings, structures, vehicles and other fixed assets. Other initial data for the calculation are presented in *Table 2*.

The results of calculating the TEI of these lines are shown in *Figures 1-4* and *Table 3.*

The processing of oil flax with the throughput capacity of lines of 1000 kg/h and the distance of straw roll transportation to the processing site of 50 km is effec-tive for all areas under consideration. The production profitability in this case will range from 6.6 to 37.4% (*Fig. 1-4*), and the payback period of capital expenditures ranges from 48.5 to 3.1 years (*Table 3*). With an increase in the straw roll transpor-tation distance to 100 km, only oil flax processing with *Line 2* will be effective, but it is impossible to obtain fibre with a low content of chaff. This results in a limited sale of fibre or its sale at a lower price.

Oil flax processing at a capacity of 500 kg/h and with a distance of straw roll transportation to the processing site of 50 and 100 km is not effective for all

Table 3

Payback period of capital expenditures, years

Line	Crop acreage, ha											
	700				1000				1500			
	Distance, km											
	50		100		50		100		50		100	
	Capacity of equipment, kg/h											
	500	1000	500	1000	500	1000	500	1000	500	1000	500	1000
1	-	12.8	-	-	27.1	6.2	-	29.3	9.2	3.5	-	10.5
2	-	9.3	-	87.0	19.8	5.4	-	21.7	7.6	3.1	-	8.6
3	-	12.0	-	-	-	6.7	-	62.4	20.9	3.7	-	14.3
4	-	48.5	-	-	-	19.6	-	-	-	9.0	-	-

lines, regardless of the amount of processed raw materials, as it causes a loss or provides a high payback period (*Table 3*), which is associated with a significant rise in the cost of raw materials due to the greater distance of its transportation, and with a low throughput capacity because of an increase in costs per unit of finished products (*Fig. 1-4*).

The costs for organizing the processing of raw materials with *Line 2* (*Table 3*) will be recovered most quickly due to the optimal ratio of the fibre price, its yield and low capital expenditures (*Table 2*).

Line 3 deserves attention, as it, like *Line 4*, allows to obtain fibre with a low content of chaff (*Table 3*), hence, fibre will be sold better.

Line 4 is recommended to be used at a flax acreage of 1000 hectares and above and throughput capacity of lines of at least 1000 kg/h, and straw roll transporting to the processing site over a distance of not more than 50 km (*Fig. 4*).

Conclusions

Processing of oil flax grown on an area of 500 hectares, at a throughput ca-pacity of 500 kg/h, on small-sized equipment and equipment of normal size is inef-fective and often unprofitable.

The processing of oil flax grown on an area of at least 1000 hectares is most effective, with a throughput capacity of at least 1000 kg/h for raw materials and for straw roll transporting to the processing site over a distance of 50 km.

The research has provided technological and economic data that can be used to organize oil flax processing into marketable fibre.

REFERENCES

1. Lukomets V.M. Perspektivy i rezervy rasshireniya proizvodstva maslich-nykh kul'tur v Rossiyskoy Federatsii [Prospects and reserves for the expansion of oil crop production in Russia] // *Maslichnyye kul'tury. Nauchno-tekhnicheskiy byulleten' Vserossiyskogo nauchno-issledovatel'skogo instituta maslichnykh kul'tur*. 2015. Issue 4 (164). 81-102. (In Russian)

2. Shushkov R.A. Obosnovaniye tselesoobraznosti ispol'zovaniya SVCh-izlucheniya dlya sushki l'notresty v lente [Rationale for the use of microwave radia-tion to dry flax in swaths] // *Molochnokhozyaystvennyy vestnik*. 2016. N4(24). 99-111. (In Russian)

3. Golovenko T.N. Promyshlennoye ispol'zovaniye solomy l'na maslichnogo kak v mire, tak i v Ukraine [Industrial use of straw oilseeds flax - the world's and Ukrainian experience] // "Molodiy vcheniy". Sichen'. 2017. N1 (41). 37-39.

4. Volobuyev V.A., Revenko V.Yu. Sposob zadelki v pochvu pozhnivnykh i sternevykh ostatkov rasteniy l'na maslichnogo [Method of embedding into the soil of flax stubble remains] // *Maslichnyye kul'tury. Nauchno-tekhnicheskiy byulleten' Vserossiyskogo nauchno-issledovatel'skogo instituta maslichnykh kul'tur*. 2015. N1(161). 96-100. (In Russian)

5. Novikov E.V., Basova N.V., Ushchapovskiy I.V., Bezbabchenko A.V. Maslichnyy len kak global'nyy syr'yevoy resurs dlya proizvodstva volokna [Oil flax as a global raw material resource for fibre production] // *Molochnokhozyaystvennyy vestnik*. 2017. N3(27). 187-204. (In Russian)

6. Tikhosova A.A., Putintseva S.V., Golovenko T.N. Perspektivy ispol'zovaniya volokna l'na maslichnogo dlya proizvodstva tekstil'nykh materialov [Prospects of using oilseed flax fibre for producing textile materials] // *Vestnik Vitebskogo gosudarstvennogo tekhnologicheskogo universiteta*. 2013. N24. 74-82. (In Russian)

7. Dolgushkin N.K. Tekhnologicheskaya modernizatsiya – osnova effek-tivnosti APK, ustoychivogo razvitiya sel'skikh territoriy [Technological moderniza-tion as the basis of agricultural industry efficiency and the sustainable development of rural territories] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2016. N3. 3-6. (In Russian)

8. Beylis V.M. Otsenka material'no-tekhnicheskikh resursov tekhnologiy proizvodstva sel'skokhozyaystvennykh kul'tur [Assessment of material and tech-nical resources of crop production technologies] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2017. N3. 39-44. (In Russian)

9. Ushchapovskiy I.V., Novikov E.V., Basova N.V. Tekhniko-ekonomicheskiy analiz pererabotki maslichnogo l'na v korotkoye volokno [Tech-nical and economic analysis of the primary processing of oil flax into short fibre] // *Maslichnyye kul'tury. Nauchno-tekhnicheskiy byulleten' Vserossiyskogo nauchno-issledovatel'skogo instituta maslichnykh kul'tur*. 2017. Issue 4 (172). 113-118. (In Russian)

10. Koroleva Ye.N., Novikov E.V., Ushchapovskiy I.V., Shevaldin D.M., Bezbabchenko A.V. Issledovaniye razlichnogo sostava tekhnologicheskogo oborudovaniya dlya pervichnoy pererabotki maslichnogo l'na v likvidnoye volokno [Study of different elements of processing equipment for primary processing of oil flax in marketable fibre] // *Tekhnika i oborudovaniye dlya sela*. 2017. N8(242). 16-19. (In Russian)

The paper was submitted to the Editorial Office on 13.06.2018

The paper was accepted for publication on 23.08.2018

Conflict of interest. The authors declare no conflict of interest.

УДК 631.42

CC BY

DOI 10.22314/2073-7599-2018-12-4-41-47

Laboratory Study Results of Soil-Cutting Operating Elements

Igor V. Liskin[1],
research associate;
Yakov P. Lobachevsky[1],
Dr.Sc.(Eng.), corresponding member of the Russian Academy of Sciences, chief research associate;
Denis A. Mironov[1],
Ph.D.(Eng.), Research Associate,
e-mail: mironov-denis87@mail.ru;
Sergei A. Sidorov[1],
Dr.Sc.(Eng.), chief research associate;
Andrei I. Panov[2],
Ph.D.(Eng.), senior lecturer

[1]Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation;
[2]Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Moscow, Russian Federation

Abstract. Studying the wear of soil-cutting working tools in the field conditions has certain difficulties associated with the impermanence of soil properties. The paper presents the results of a laboratory study of the power characteristics in the process of wearing of a soil-cutting wedge in an artificial abrasive soil medium. (*Research purpose*) To determine the nature of changes in cutting forces in vertical and horizontal planes depending on the conditions and a degree of wear of a soil-cutting wedge. (*Materials and methods*) For the experiment, use was made of quartz as an abrasive material, paraffin with additives of ceresin and petrolatum as binding components; cement was additionally introduced to change the granulometric composition of a soil model, and a cross-planer was used as a drive mechanism. (*Results and discussion*) It has been shown that the horizontal component, or traction resistance, increases linearly with increasing the depth of cutting. An increase in the soil-cutting velocity also leads to an increase in the traction resistance of the wedge, and its magnitude increases in a power-law dependence on the velocity. It has been established that the cutting angle affects not only the variation of the wedge traction resistance, but also the shearing pattern, which changes as it increases and changes from shear shavings into shift shavings, which contributes to the traction force growth. It has been found that an increase in traction resistance is affected by an increase in the hardness of abrasive material and a decrease in the distribution density of solid particles in its volume. As the width of the back chamfer and the angle of its inclination to the furrow bottom increased, the traction characteristics both in the vertical and horizontal planes increased as well, the back chamfer width having the greatest influence on the vertical component. As the blade worn out depending on the friction path, the vertical component of frictional forces increased sharply, while the horizontal component increased insignificantly. (*Conclusions*) The results of the conducted studies have shown that the wedge depth mainly depends on the back chamfer width. The traction resistance of the wedge is greatly influenced by physical and mechanical properties of an abrasive medium, cutting conditions and a degree of the blade blunting.

Keywords: abrasive model of soil, soil wedge, back chamfer, intensity of blade wear.

For citation: Liskin I.V., Lobachevsky Ya.P., Mironov D.A., Sidorov S.A., Panov A.I. Laboratory study results of soil-cutting operating elements. *Selskokhozyaistvennyye mashiny i tekhnologii*. 2018. 12(4): 41-47. DOI 10.22314/2073-7599-2018-12-4-41-47. (In Russian)

Studying the wear of soil-cutting working tools in the field faces certain difficulties due to the variability of soil properties, its heterogeneity and changing weather conditions [1]. Because of the seasonality of fieldwork, studies often do not fit into one cycle (year), they have to be postponed for the next year, increasing the test time and accumulating errors in experimental results.

In the post-harvest period, the root and stubble residues remaining in the topsoil (plow layer) exert a great influence on the performance characteristics of soil-cutting elements [2]. Therefore, laboratory research methods are often the only possible ones.

The research purpose is to determine the nature of changes in cutting forces in the vertical and horizontal planes, depending on the conditions and the degree of wear of a soil-cutting wedge.

Materials and methods. The paper presents the results of a laboratory study of power characteristics in the wear of a soil-cutting wedge in an abrasive medium including solid particles most often found in soil (quartz particles of a size ranging from 0.05 to 0.5 mm) and paraffin with additional components to change the properties of the abrasive soil environment model. Another basic component of soil is clay particles, which make soil plastic and determine its rheological properties [3]. Under natural conditions, soil samples of the same granulometric composition can change their properties depending on humidity (weather conditions).

The substantiation of the use of technical paraffin with additives of ceresin and petrolatum as a binding abrasive particle instead of moistened clay was based with an analytical calculation of the similarity criteria by V.A. Venikov's method to ensure the compliance of the soil model based on the sand-paraffin mixture with the real soil conditions of different regions of the Russian Federation [4, 5].

Preliminary tests have shown that the creep variation curves of water-saturated chernozem samples with different preliminary compaction are similar to the samples when clay with water is replaced with technical paraffin with various additives of abrasive (quartz) and dust particles (cement, gypsum, etc.) in the soil environment. The use of paraffin as a binder allows obtaining a soil model that demonstrates stable properties for a long time. The choice of paraffin in the considered studies was based on the experimental data of G.N. Sineokov, who noted that in wedge cutting at an ambient temperature of 18-22°C, a mixture of paraffin with an abrasive is destroyed by shearing, like loamy soils [6]. The results of laboratory studies have shown the similarity of the wear pattern of blades in an artificial abrasive material consisting of quartz sand and paraffin with natural soil conditions. A back chamfer formed on the blade and inclined at a negative angle to the furrow bottom, and the forces of cutting resistance increased.

The paper presents the laboratory study results describing the action of cutting forces in vertical $P_в$ (buoyancy force) and horizontal $P_г$ (resistance to motion) planes (*Fig. 1*).

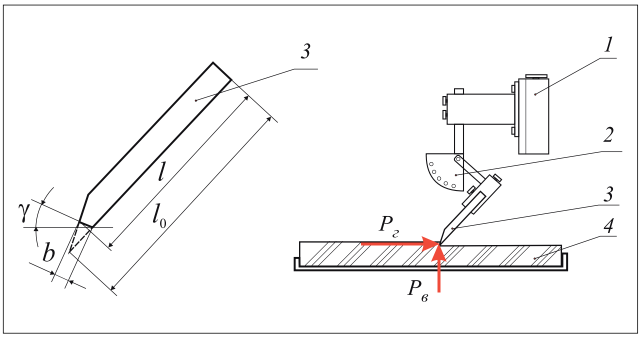


Fig. 1. Scheme of a fragment of a laboratory installation for determining the force characteristics with cutting forces in the vertical ($P_в$) and horizontal planes ($P_г$):
1 – a drive mechanism with a dynamometer; 2 – a device for sample setting; 3 – a prototype; 4 – an abrasive medium; b – the back chamfer width; γ – the inclination angle of the back chamfer to the furrow bottom; l – the length of the sample when it wears out; l_0 – the length of the new sample

Results and discussion. Experiments on the influence of the cutting conditions on the traction resistance of the soil-cutting wedge were carried out with samples of steel 45 having an angle of sharpening of θ = 30° and a thickness of the cutting edge of 0.2 mm. The relatively sharp blade and the absence of the back chamfer did not make a significant effect on the value of Pв and its values ranged around the zero mark. A cross-planer was used as a drive mechanism.

Fig. 2 shows the dependence of the traction resistance $P_г$ of the soil-cutting wedge on the depth *h* and the cutting speed *υ*.

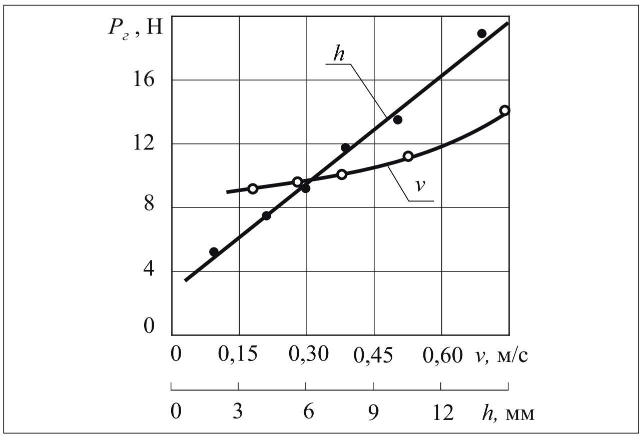


Fig. 2. Effect of depth and cutting speed on traction resistance

With increasing depth *h* of cutting, the value of $P_г$ continuously increases in a linear manner. This indicates an increasing force in the detachment of shavings, the dimensions of which increase in proportion to the depth.

Measurements of traction resistance in field conditions during testing on loamy soils (*Fig. 3*) have confirmed the linear dependence obtained under laboratory conditions within the limits of measuring the tillage depth from 16 to 28 cm during plowing.

Fig. 3. Measuring plow traction resistance in field conditions

An increase in the velocity *υ* also leads to an increase in the traction resistance of a soil-cutting wedge, with the value of $P_г$ increasing in a power-law dependence on *υ*, and the equation of the curve $P_г = f(υ)$ is described by an equation of the type $y = ab^x$, where *y* and *x* respectively denote $P_г$ and the velocity-dependent coefficient *υ*. This indicates that after reaching a certain velocity range, the sizes of the soil fragments of the formation begin to decrease rapidly (lumpiness). In this case, the forces of resistance of the soil medium to the wedge movement begin to increase rapidly, which inevitably leads to an increase in the pressure on the cutting edge of the blade and, correspondingly, its more intensive wear [7].

The influence of the cutting angle *α* on the traction resistance $P_г$ of the wedge blade is shown in *Fig. 4*.

The curve $P_г = f(a)$ can be divided into three characteristic regions. In section *I* a linear increase in $P_г$ is observed with increasing *α*. Section *II* is distinguished by a sharp increase in $P_г$ with a characteristic heel region. In section *III* the curve again becomes flat and further growth of $P_г$ is observed in a relationship close to linear.

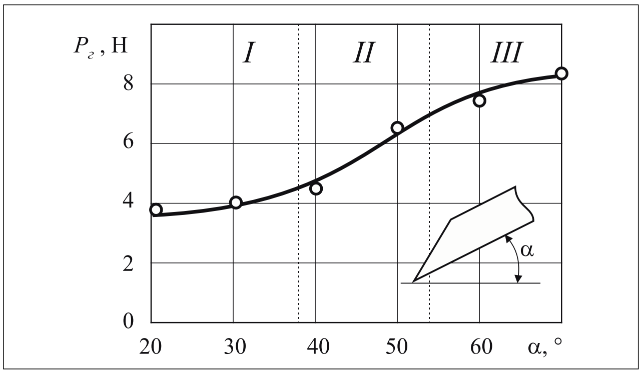


Fig. 4. Dependence of the traction resistance Pг on the angle α

Analyzing the dependence of $P_г = f(\alpha)$, we can conclude that as the angle *α* is increased to 40° in the section *I*, the values of $P_г$ are increased due to an increase in energy required to fracture the formation. With an increase in *α*, the size of shavings decreases, crumbling improves, accordingly, traction resistance increases, as well as in the case of cutting speed increasing. In section *II*, within the range of the cutting angle from 40 to 55°, there is an area of a densified core formation, where, as the blade moves forward, the friction of abrasive particles with the metal surface is accompanied by internal friction between the abrasive particles periodically appearing before the blade, which increases the cutting forces. In section *III*, when *α* is more than 55°, further growth of $P_г$ is observed. In this case, in addition to the densified core and increased energy of formation fracturing, a gradual change in the pattern of formation fracturing with the transition from shear shavings (*Fig. 5a*) to shift shavings has a significant effect on traction resistance (*Fig. 5b*).

The results of the conducted studies have shown that when the type of soil destruction changes from shear shavings to shift shavings, the energy of soil destruction increases due to the replacement of the fracture type as caused by the effect of normal tensile stresses on fracture under the action of shear stress tangent lines [8].

Fig. 6 shows the dependence of the cutting force $P_г$ on the hardness of the artificial soil *H* (curve *1*) and the distribution density in the amount of abrasive particles *ρ* (curve *2*).

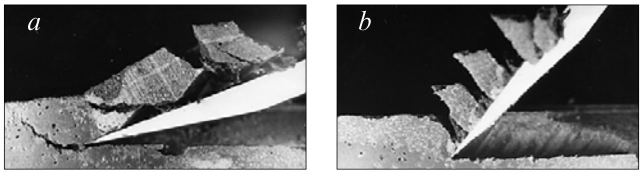


Fig. 5. Destruction of the formation with a transition from shear shavings (a) to shift shavings (b)

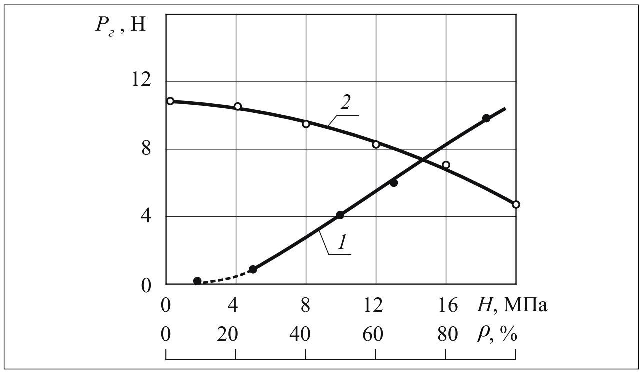


Fig. 6. The effect of hardness H and the distribution density of the abrasive particles ρ on the cutting force $P_г$

As can be seen from *Fig. 6*, the value of $P_г$ increases with increasing *H*, and the function $P_г = f(H)$ is close to linear and decreases with increasing *ρ*. The decrease in the value of $P_г$ in the second case is caused by a decrease in the values of the soil connectivity indicators *τ* and *σ* due to an increase in the amount of quartz solid particles larger in size than fine particles of pulverized cement added to the «artificial soil» in experiments.

Under operating conditions, similar indicators are obtained when processing heavy loamy soils with a high content of fine clay particles, where the traction resistance is much higher than on soils with a significant content of larger quartz particles, for example, sandy and sandy loamy soil types [9-12].

At the next stage of the study, the influence of the parameters of the back chamfer of the wedge blade on the cutting forces was determined.

For the experiments, two batches of worn samples were prepared with an initial sharpening angle θ_0 of 30°. Samples of the first batch had the same angle of sharpening after wear, equal to 60° (the angle of inclination of the back chamfer to the furrow bottom *γ* was 10°), but different values of the back chamfer width *b* = 0.5; 1.0; 1.5; 2.0; 2.5; 3.0 mm. This made it possible to determine the effect of the width *b* of the back chamfer on the cutting forces in two planes (vertical $P_в$ and horizontal $P_г$), regardless of the angle of its inclination to the furrow bottom *γ* (*Fig. 7*).

The results of the study on the influence of the back chamfer width on the traction resistance of the soil-cutting wedge have shown that with increasing parameter *b*, the values of both $P_в$ and $P_г$ increase as well, and the intensity of growing the force $P_в$ considerably

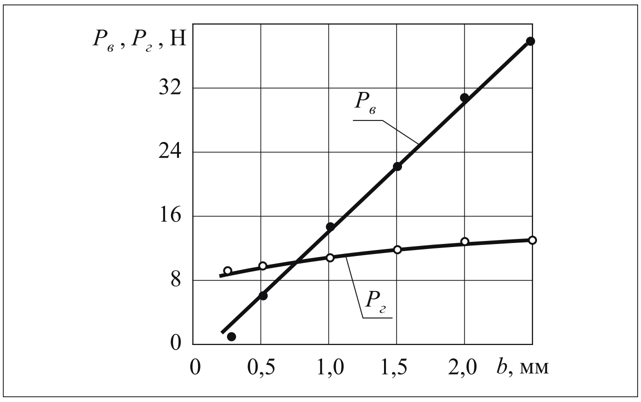


Fig. 7. Dependence of cutting forces $P_г$ and $P_в$ on the width b of the back chamfer

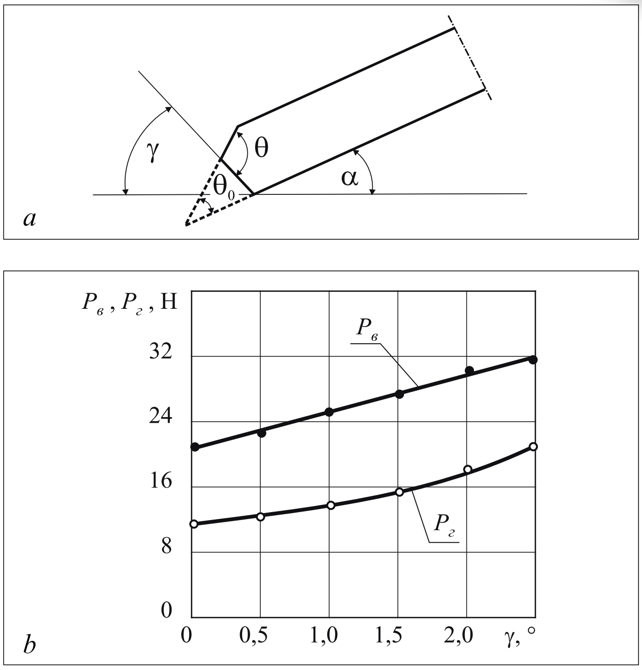


Fig. 8. Dependences of $P_в$ and $P_г$ on the inclination angle of the back chamfer γ

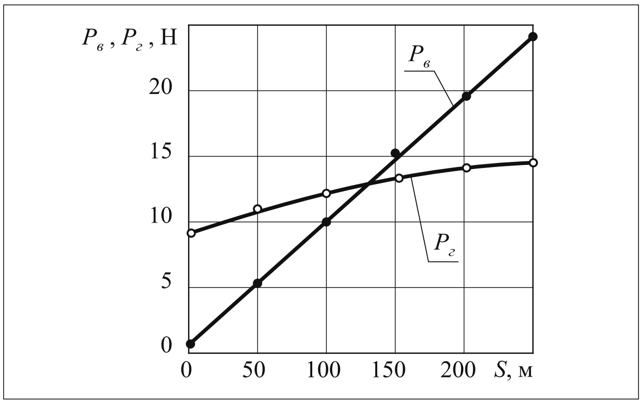


Fig. 9. Dynamics of changes in $P_в$ and $P_г$ in the course of the blade wearing

exceeds the increase in $P_г$. Hence it follows that the value of parameter *b* (at $\gamma = 10°$) has the greatest effect on the deeper penetration of the wedge blade, while the traction resistance with increasing parameter *b* varies to a much lesser extent.

The second batch of samples had equal back chamfer width *b* of 1.5 mm, but different wedge angles $\theta = 40$, 50, 60, 70 and 80°. The use of samples with the same value of parameter *b* for setting at one cutting angle $\alpha = 20°$ and a single constant angle of initial sharpening $\theta_0 = 30°$ made it possible to determine the pattern of changes in cutting forces as a function of the angle of the back chamfer inclination to the furrow bottom, the value of which was $\gamma = \theta - \theta_0 - \alpha$ (*Fig. 8a*).

Dependences of the cutting force components on the angle *γ* of the back chamfer inclination to the furrow bottom are shown in *Fig. 8b*.

With an increase in parameter *γ*, as well as *b*, an increase in the values of $P_в$ and $P_г$ is observed, however, there is no pronounced acceleration of growth of any of the parameters as compared with the other, that is, the angle *γ* plays the same role in changing the vertical and horizontal components of cutting forces, and its increase leads to a decrease in deeper penetration and an increase in traction resistance of the wedge.

In addition, an experiment was conducted to study the cutting forces in the dynamics of wedge blade wear. *Fig. 9* shows the dependence of the indicators $P_в$ and $P_г$ on the friction path *S*. The parameters *b* and *γ* were continuously varied.

As the blade wears out, depending on the path *S*, the vertical component of the cutting forces $P_в$ sharply increases, but the value of $P_г$ increases insignificantly. This indicates that the blade wear has the greatest impact on the penetration ability of the soil-cutting wedge, while its traction resistance varies insignificantly.

The results of the conducted studies have shown that the depth of the soil wedge mainly depends on the parameters of the back chamfer and, in particular, on its width. As a result of the conducted research, it can be noted that the composition selected as a substitute for natural soil conditions, including abrasive particles of quartz sand and paraffin, adequately reflects the processes occurring in the natural soil environment when it interacts with the working tools of tillage machines. Thus, if we compare the data obtained in field studies on the wear of the blades of soil-cultivating tools with the results of laboratory studies, we can conclude that there is a direct relationship between the width of the back chamfer and the angle of its inclination to the furrow bottom. Laboratory tests allow reproducing more precisely and accurately certain factors, in particular, cutting conditions (speed, tillage depth, geometric parameters of the blade typical for tillage tools) and to determine their influence on the power characteristics of the blade itself and the single blade in the considered case, and not in combination with other components, for example, plow-bottom share surface. In this case, individual factors are superimposed, which leads to distortion of the results and an increase in errors in the experimental data. Similar phenomena occur in the study of the effect of physical and mechanical properties typical for natural soil conditions, taken according to individual criteria, which cannot be done under real soil conditions, which can be divided into components (hardness, cohesion of abrasive particles, the presence of additional inclusions, etc.) only in laboratory studies.

The traction resistance of the soil-cutting wedge is strongly influenced by physical and mechanical properties of soil (abrasive medium), cutting conditions (speed, depth, angle of the blade inclination to the furrow bottom) and the degree of the blade blunting (the sharpening angle).

Conclusions

1. The most acceptable material replacing the natural soil environment is an abrasive mixture with stable properties, regardless of the study duration, for example, artificial soil mass based on solid abrasive particles and paraffin.

2. The physical-and-mechanical properties of the abrasive medium (hardness, cohesion of abrasive particles, the presence of additional dust-like inclusions), cutting conditions (speed, depth, cutting angle) and the sharpness of a wedge blade (a degree of blunting) have the greatest impact on the traction resistance of the soil wedge.

3. The penetration ability of the soil wedge depends on the blade wear characterized by the formation of a back chamfer in the process of wear, that is inclined at a negative angle to the direction of travel, where the fundamental geometrical chamfer parameter acting on the wedge penetration is its width.

REFERENCES

1. Kashatanov A.N., Sizov O.A. Problemy vosstanovleniy ugodiy, vybyvshikh iz sel'skokhozyaystvennogo ispol'zovaniya [Problems of restoring lands abandoned from agricultural use] // *Ekonomika sel'skogo khozyaystva Rossii*. 2008. N11. 174. (In Russian)

2. Izmaylov A.Yu., Lobachevskiy Ya.P., Sizov O.A., Volobuyev V.A. Tekhnologii, tekhnicheskiye sredstva, dlya vosstanovleniya neispol'zuyemykh i degradirovannykh sel'khozugodiy [Technologies and technical means applied for restoration of unused and degraded farmland] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2009. N4. 17-21. (In Russian)

3. Kozlov A.V., Novikov D.A., Mashakin A.M. Sovremennoye sostoyaniye otechestvennykh zalezhnykh zemel' i perspektivy ikh vosstanovleniya [Current state of domestic fallow lands and the prospects for their recovery] // *Mezhdunarodnyy studencheskiy vestnik*. M.: MGAO. 2015. N1. 121-123. (In Russian)

4. Venikov V.A. Teoriya podobiya i modelirovaniya [Theory of similarity and modeling]. M.: Vysshaya shkola. 1976. 480. (In Russian)

5. Izmaylov A.Yu., Liskin I.V., Lobachevskiy Ya.P., Sidorov S.A., Khoroshenkov V.K., Mironova A.V., Luzhnova Ye.S. Primeneniye teorii podobiya dlya modelirovaniya iznosa pochvorezhushchikh lezviy v iskusstvennoy abrazivnoy srede [Application of the theory of similarity for the modeling of wear of soil cutting blades in an artificial abrasive medium] // *Rossiyskaya sel'skokhozyaystvennaya nauka*. 2016. N6. 48-51. (In Russian)

6. Sineokov G.N. Proyektirovaniye pochvoobrabatyvayushchikh mashin [Designing of soil-cultivating machines]. Moskva. Mashinostroyeniye. 1965. 283. (In Russian)

7. Liskin I.V., Mironov D.A., Kurbanov R.K. Obosnovaniye parametrov iskusstvennoy pochvennoy sredy dlya laboratornogo issledovaniya iznashivaniya lezviya [Determination of artificial soil environment parameters for laboratory research of blade wear] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2017. N4. 37-42. (In Russian)

8. Chisholm T.S., Porterfield J.G., Batchelder D.G. A soil bin study of three-dimensional interference between flat plate tillage tools operating in an artificial soil. Trans. of ASAE. 1972. Vol. 15. N1. 43-48. (In English)

9. Mironov D.A., Liskin I.V., Sidorov S.A. Vliyaniye geometricheskikh parametrov dolota na tyagovyye kharakteristiki i resurs lemekhov otechestvennykh plugov [Influence of geometrical parameters of a chisel on traction characteristics and resource of domestic plowshares] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2015. N6. 25-29. (In Russian)

10. De Albuquerque J.C., Hettiaratchi D.R. Theoretical mechanics of subsurface cutting blades and buried anchors // J. Agr. Eng. Res. 1980. Vol. 25. 121-144. (In English)

11. Izmailov A.Yu., Sidorov S.A., Lobachevskiy Ya.P., Khoroshenkov V.K., Kuznetsov P.A., Yurkov M.A., Golosiyenko S.A. Nauchnyye printsipy povysheniya iznosostoykosti rabochikh organov pochvoobrabatyvayushchey tekhniki [Scientific principles of increasing wear resistance of working elements of soil-cultivating machinery] // *Vestnik Rossiyskoy akademii sel'skokhozyaystvennykh nauk*. 2012. N3. 5-7. (In Russian)

12. Izmailov A.Yu., Lobachevskiy Ya.P., Sidorov S.A., Khoroshenkov V.K., Luzhnova Ye.S., Mironov D.A., Zaytsev A.I., Rodionova I.G., Pavlov A.A., Amezhnov A.V. Ispol'zovaniye bimetallicheskikh staley dlya povysheniya resursa rabochikh organov sel'skokhozyaystvennykh mashin [The use of bimetallic steels for increasing the service life of the working elements of agricultural machines] // *Vestnik Rossiyskoy akademii sel'skokhozyaystvennykh nauk*. 2013. N2. 80-81. (In Russian)

The paper was submitted to the Editorial Office on 17.07.2018

The paper was accepted for publication on 11.09.2018

Conflict of interest.
The authors declare no conflict of interest.

УДК 631.316

CC BY

DOI 10.22314/2073-7599-2018-12-4-48-52

Zone of Soil Loosening with Cultivator Sweeps

Vladimir V. Vasilenko,
Dr.Sc.(Eng.), honored professor,
e-mail: vladva.vasilenko@yandex.ru;

Sergey V. Vasilenko,
Ph.D.(Eng), associate professor;
Vitaliy S. Borzilo,
M.Sc. student

Voronezh State Agrarian University named after Emperor Peter I, Voronezh, Russian Federation

Abstract. Cultivator sweeps are placed remotely relative to each other or as parts of combined working tools with spherical discs, chisels and other parts, so the propagation of a zone of soil deformation during their operation at different depths and at different speeds is studied by designers for the calculation of technological runs in order to avoid their clogging with soil. (*Research purpose*) To determine the dependence of the width of the soil loosening zone with a cultivator sweep on the depth of travel and the speed of travel. (*Materials and methods*) Studies have been conducted on a stubble soil background after harvesting of winter wheat. Humidity and hardness of soil at a depth of 0 to 30 centimeters varied accordingly from 9 to 13 percent and from 0.28 to 0.87 megapascals. The structure of the unit has been represented by the tractor MTZ Belarus 1221,2 and the cultivator KRN-5,6. Each section of the cultivator housed a universal sweep with a design working width of 220 millimetre. (*Results and discussion*) It has been found that a sweep forms a loosened strip and a strip of soil scattering, the width of which depends linearly on the tillage depth ranging from 10 to 22 centimeters and varies in the range from 31 to 42 and 38 to 58 centimeters, respectively. The unit travel speed ranging from 3 to 13 kilometre per hour does not affect the width of the loosening zone, and the zone of soil scattering increases according to the law of a weakly expressed quadratic parabola. The authors present empirical dependences of the width of the loosening and scattering zones on the tillage depth, the travel speed and the sweep width. (*Conclusions*) It has been found that the interval between the sweeps in one row should not be less than the specified width of the loosening zone, which has been confirmed as exemplified by a successful arrangement of working elements with a width of 410 millimetre on the combined units of the RVK series. Combined tools work with high technological reliability for sunflower stubble, without being clogged with soil and plant residues during the main field operations performed according to the minimal impact technology.

Keywords: zone tillage, moving apart the soil zone, depth of processing, movement speed, linear dependence, quadratic parabola, cultivators-leveller of the soil.

For citation: Vasilenko V.V., Vasilenko S.V., Borzilo V.S. Zone of soil loosening with cultivator sweeps. *Sel'skokhozyaistvennye machiny i tekhnologii*. 2018. 12(4): 48-52. DOI 10.22314/2073-7599-2018-12-4-48-52. (In Russian)

Combinations of soil cultivating tools mounted on one frame, and sometimes on one rack, require the determination of the minimum possible distance between the component parts, in which the soil can move forward along the technological passages without clogging. Cultivator sweeps are often used in combination with spherical discs and chisel elements. Of great interest to the designers of combined tools are the issues of the propagation of the soil deformation zone to various depths and for different travel speeds to provide for the rational arrangement of the sweeps on cultivator frames or sections for continuous or inter-row cultivation.

The arrangement compactness of working tools is necessary to reduce the size and metal capacity of the product [1]. It is especially important to take into account the trajectories of the soil layer movement when setting up additional working tools for serially produced tillage implements. For example, recent studies on increasing the angle of turnover of soil layers during reversible plowing have proved that to expand the furrow, additional working tools should push the overturned layer only after it has completed its turnover [2, 3]. The subsequent layer will smoothly settle into a wide furrow with a full revolution of 180°. As a rule, when two working tools simultaneously affect the soil layer or area, the deformation zones of the treated medium must not be allowed to overlap. It is necessary to distribute the formation of these zones in time or in space, otherwise the probability of the tool failure will increase because of the obstruction of technological passages for the soil. The only exception is made for active rotating or vibrating tools [3, 4]. With deep loosening of the soil by the cultivator, its deformation spreads forward and sideways. The range of soil movements increases with the travel speed of the unit [5-7]. The greater the travel speed and the depth of the cultivator sweep are, the greater the force of interaction with the soil and the normal stress in the sweep construction are, and this contributes to an increase in the range of soil movement [8].

Research purpose. Experimental study of the width of the soil loosening zone tilled with a cultivator sweep with a change in the tillage depth and the travel speed.

Materials and methods. Experiments have been carried out on one of the farms in the Voronezh Region on a stern background after harvesting of winter wheat. Humidity and hardness of the soil at a depth of 0 to 30 cm varied accordingly from 9 to 13% and from 0.28 to 0.87 MPa. The unit composition was the tractor MTZ Belarus 1221,2 and the cultivator KRN-5,6. Each section of the cultivator was equipped with one pointed universal sweep with a working width of 220 mm. In a field section of 50 × 50 m the unit performed operating runs with the preset tillage depth. The time was measured with a stopwatch, the actual tillage depth and the width of the loosened strips – with metal rulers. During the data processing, average values of the measurement results for all sections of the cultivator were calculated.

Results and discussion. It has been visually established that the sweep wedges out the soil layer into two streams as a result of the deforming effect of a working tool shin. The loosened parts of the formation are displaced in both directions from the sweep axis. Some amount of the soil rises to the front of the rack, then slides off it and is thrown aside. As a result of this action, a groove is formed behind the sweep stand, the dimensions of which increase with the speed and the tillage depth. At a unit travel speed of 10 km/h or more and a tillage depth of 6-8 cm, the furrow bottom is bare.

The results of measurements of the width of the tilled strip have shown that the loosening zone and the soil dispersion zone should be distinguished. Dispersion is always wider than loosening, and if we take it into account when arranging the working tools on the frame, we may get flaws in the process of the soil tillage. The relationship between the loosening zone width and the tillage depth has been determined at a speed of the unit of 9-10 km/h. This relationship has turned out to be a linear dependence (*Fig. 1*), it can be approximated by the expression:

$$b_{\text{рых}} = b_{\text{кон}} + 0.91a, \qquad (1)$$

where $b_{\text{рых}}$ is the width of the loosening zone, cm;

$b_{\text{кон}}$ – design width of the sweep, cm;

a is the tillage depth, cm.

The dependence of the dispersion zone width on the tillage depth is also linear:

$$b_{\text{разб}} = b_{\text{кон}} + 1.65a, \qquad (2)$$

where $b_{\text{разб}}$ is the width of the spreading zone, cm.

The influences of travel speed on the loosening zone width at a tillage depth of 12 cm has not been revealed (*Fig. 2*). The width of the loosened strip remained within 33-35 cm, there are no trends to change it. As for the width of the soil dispersion band, its dependence on the travel speed can be approximated by a parabola:

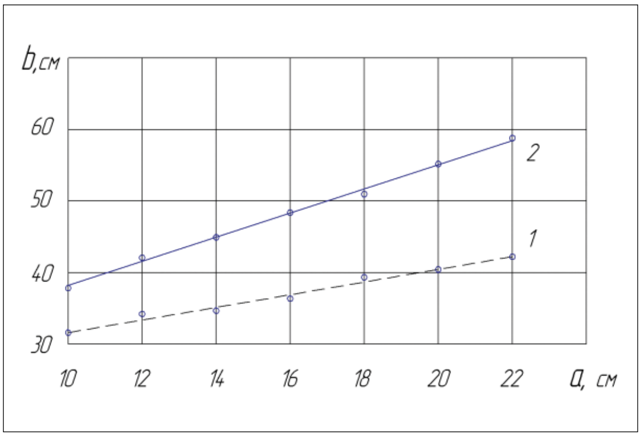


Fig. 1. Dependence of the loosening zone width (1) and the soil dispersion zone (2) on the cultivator sweep depth (experimental data)

$$b_{\text{разб}} = b_{\text{кон}} + 15.65 + 0.056V, \qquad (3)$$

where V is the unit travel speed, km/h.

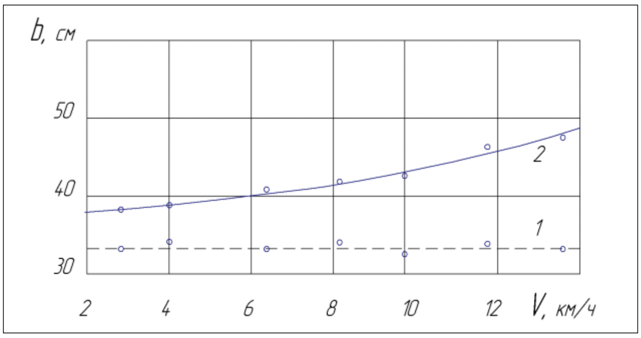


Fig. 2. Dependence of the loosening zone width (1) and the soil dispersion zone (2) on the unit travel speed (experimental data)

The resulting empirical relationships were applied in the design of cultivators-levelers RVK-6, RVK-4, RVK-3. Their production was implemented by joint efforts of Voronezh State Agrarian University and machine-building small enterprises «Aqua-Svar» and «VSZ-Holding», established on the basis of the Voronezh machine-tool plant (*Fig. 3*).

These are trailed combination tools with different working widths for attaching to tractors of traction classes from 1.4 to 5. They are designed for minimal

Fig. 3. RVK-6 cultivator-leveler

tillage instead of plowing. The working tools are two rows of spherical cutters with a diameter of 660 mm and an individual frame attachment system, two rows of pointed cultivator sweeps 410 mm wide, a double supporting roller equipped with flat discs, and a rod bar for final leveling of the soil surface. Individual fastening of disks instead of the battery one reduces the longitudinal size of the implement, especially when setting large approach angles. In places where the outer disks are turned with the concave part outward, at a high travel speed, the soil is thrown far aside, so that special screens are mounted on the frame to reflect the dispersing soil inside the operating width. The set of working tools on this combined implement ensures its reliable operation on any soil background. It does not require primary tillage (stubble cleaning) and can prepare the soil from the stubble background in one operating run to the full readiness state for sowing winter crops. The maximum tillage depth is up to 20-22 cm. The advantages of combined cultivators equipped with spherical discs and sweeps are manifested in the reduction of energy consumption and good leveling of the soil surface [9-10].

It is a common fact that disk tools form a wavy bottom of the furrow. Given the diameter of discs is 660 mm, with a two-row arrangement at intervals of 500 mm in each row, a depth of 20 cm and an approach angle of 25°, the height of residual ridges at the furrow bottom is 18 cm. For leveling the furrow bottom, the cultivator sweeps and disks are adjusted to the same tillage depth.

The width of a loosening zone tilled with the cultivator sweep is 59 cm in accordance with the expression (1). As for the width of the dispersion zone, according to expression (3) it is 65 cm, and taking account of expression (2) it can reach 80 cm. Therefore, when designing the sweeps arrangement, the distance between them in one row was assumed equal to 800 mm (*Fig. 4*). With a 410 mm operating width, the soil is completely cut with minimal overlapping of cutting zones, only 0.5 cm, but this is sufficient given the additional effect of the discs.

The longitudinal distance between the rows of sweeps depends on the calculated speed of motion. To avoid overlapping deformation zones, the soil raised up by the front row should have time to return to the field surface before the approaching of the rear row of sweeps. The vertical speed of soil tossing with a sweep can be calculated from the expression:

$$V_{\text{вер.}} = Vtg\alpha, \text{ m/s},$$

where V – the unit travel speed, m/s;

α is the sweep lifting angle, for universal sweeps $\alpha = 18°$.

The tossed soil is up in the air for:

$$t = \frac{2V_{\text{вер.}}}{g}$$

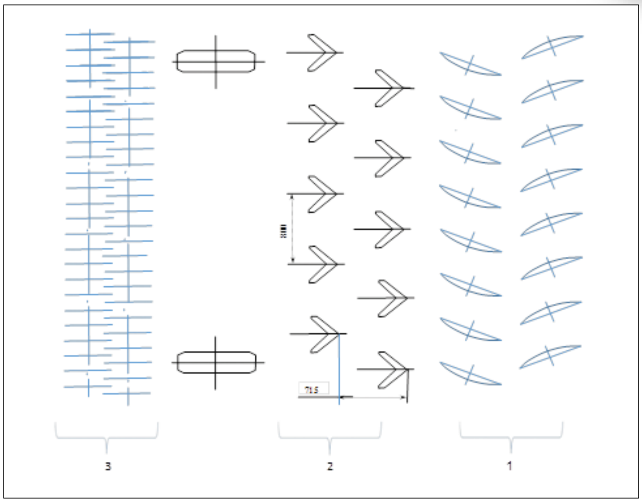


Fig. 4. Diagram of the arrangement of working tools on the cultivator-leveler RVK-4 (top view): 1 – two rows of spherical disks; 2 – two rows of sweeps; 3 – two-shaft needle roller

where g is the acceleration caused by gravity, m/s^2.

Of all the variants of standard cultivator sweeps, the widest widths have been chosen to be as wide as possible in order to avoid the stocking of racks. If on the field there are residues of long-stemmed crops, numerous racks work like a rake, accumulating surviving stalks.

At the estimated speed of the unit travel $V = 3.33$ m/s, the initial sped of tossed soil is $V = 1.07$ m/s, the tossing time $t = 0.22$ s, the minimum distance between the sweep rows is $L = Vt = 0.71$ m. This distance is also provided between rows of cultivator sweeps in a series of cultivators-levelers of the RVK type. Such a design allows to avoid clogging with soil and plant residues, even over untouched sunflower stubble, and prepare the soil for sowing grain in one operating run (*Fig. 5*).

Conclusions. The width of the soil loosening zone tilled with a universal cultivator sweep linearly depends on the tillage depth ranging from 10 to 22 cm and varies from 31 to 42 cm with a design operating width of 22 cm. The dispersing zone of the loosened soil also depends linearly on this parameter and varies from 38 to 58 cm at the same tillage depths. The unit travel

Fig. 5. RVK-4 cultivator-leveler operating on sunflower stubble

speed varying from 3 to 13 km/h has no effect on the loosening zone width, and the zone of soil dispersion increases according to the law of a weakly expressed quadratic parabola.

When the cultivator sweeps are placed on the implement frame, the interval between them in one row should be designed to be greater than or equal to the width of the soil dispersion zone (if possible), and necessarily larger than the loosening width determined from the given graphs. The soil dispersion forms a smaller thickness of soil layers, which does not clog technological passages between the sweeps.

A series of unified trailed combination RVK cultivators-levelers with different operating widths designed according to the results of the given calculations, operates with a full coefficient of technological reliability, without clogging with soil and plant residues during the main tillage operations of the minimal impact technology.

REFERENCES

1. Yefremova Ye.N. Agrofizicheskiye pokazateli pochvy v zavisimosti ot razlichnykh obrabotok pochvy [Agrophysical indices of soil depending on various soil cultivation modes] // Izvestiya Nizhnevolzhskogo agrouniversitetskogo kompleksa: Nauka i vyssheye professional'noye obrazovaniye. 2013. N2.67-72. (In Russian)
2. Bartenev I.M. Udarnoye razrusheniye i aktivnyy oborot pochvennogo plasta pri vspashke [Impact destruction and active circulation of a soil stratum in plowing] // Lesotekhnicheskiy zhurnal. 2016. N1. 98-110. (In Russian)
3. Vasilenko V.V., Vasilenko S.V., Zybin M.V. Uvelicheniye ugla pe-revorota plasta pri vspashke [Increasing the layer revolution angle in plowing] // *Vestnik Voronezhskogo GAU*. Voronezh, 2013. 1 (36). 98-100. (In Russian)
4. Klenin N.I. Sel'skokhozyaystvennyye mashiny [Farm machinery]. M.: KolosS. 2008. 816. (In Russian).
5. Vasilenko V.V., Afonichev D.N., Vasilenko S.V., Timofeyev I. Yu. Obosnovaniye napravleniya vibratsii pochvoobrabaty-vayushchego rabochego organa [Determination of the vibration direction of a tillage tool] // *Vestnik Voronezhskogo GAU*. Voronezh, 2017. 4 (55). 134-139. (In Russian)
6. Hanna H. Mark, Marley Stephen J., Erbach Donald C., Melvin Stewart W. Soil &Tillage Research, Methods for measuring soil velocities caused by a sweep 28 (1994). 315-328. (In English)
7. Rudenko N.Ye., Nosov I.A., Kayvanov S.D., Petukhov D.A. Resurso-sberegayushchiy propashnoy kul'tivator [Resource-saving row-crop cultivator] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2017. 4. 31-36. (In Russian)
8. Rudenko N.Ye., Kayvanov S.D., Zavyalik F.N. Innova-tsionnaya strel'chataya pochvoobrabatyvayushchaya lapa [Innovative sweeps] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2016. 6. 16-20. (In Russian)
9. Chiorescu E., Chiorescu D. The variation of the unitary stresses occurring in the working part in relation to the type of soil, using the finite element method. IOP Conf. Series: Materials Science and Engineering 227. 2017. 1. 20-23. (In English)
10. Fanigliulo R., Biocca M., Pochi D. Journal of Agricultural Engineering 2016; XLVII:519 Effects of six primary tillage implements on energy inputs and residue cover in Central Italy 177-180. (In English)

The paper was submitted to the Editorial Office on 18.05.2018

The paper was accepted for publication on 25.07.2018

Conflict of interest.
The authors declare no conflict of interest.

УДК 631.313

CC BY

DOI 10.22314/2073-7599-2018-12-4-53-56

Arrangement of Spherical Disks for Frontal Harrows

Aleksei F. Zhuk[1],
Ph.D.(Eng), key expert;

Kazbek A. Sokht[2],
Dr.Sc.(Eng.), professor,
e-mail: kazbek.sokht@yandex.ru

[1]Federal Scientific Agroengineering Center VIM, Moscow, Russian Federation;
[2]Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russian Federation

Abstract. Disk-type spherical working tools are widely used in soil-cultivating machines, where they serve as an element base for combined units and disk harrows, including the multi-row ones with disks on individual racks. The tools are used in the implementation of traditional technologies based on reversible plowing, with surface tillage after late-harvested predecessors, for example, corn, sunflower, and also in NO-TIL technologies. (Research purpose) To determine the arrangement of working tools on the disk harrow frame, which reduces the required number of disks and improves the quality of soil cultivation. (Materials and methods) The authors have analyzed the arrangement of disk harrow working tools and determined their rational arrangement and mutual positions in the rows, which increases the tillage width between adjacent soil strips, thus improving the completeness of soil shearing and loosening over the entire operating width with simultaneous decreasing of the required number of disks. (Results and discussion) The authors have determined the interrelated arrangement of disks in their rows, aimed at improving soil shearing, so that the number of strips tilled into a ridge by adjacent disks increases. It has been shown that the arrangement of working tools of the consecutive row determined by the orientation of the adjacent disks of the previous row, allows to economize one working tool for every 400 millimetre of its operating width when shearing the soil all the way across the entire width of the disk harrow. (*Conclusions*) It has been established that when soil is tilled with a disk and moved toward the already processed adjacent strip, the technological width of the disk coverage increases due to the deformation of soil tearing and shearing. The authors have proposed the arrangement order of spherical disks and their mutual orientation, which improves the quality of soil cultivation, the completeness of soil shearing along the entire operating width, and leads to a reduction in the number of disks.

Keywords: soil cultivation, disk harrow, disks arrangement, reduction of the number of disks, completeness of soil shearing.

For citation: Zhuk A.F., Sokht K.A. Arrangement of spherical disks for frontal harrows. *Selskokhozyaistvennyye mashiny i tekhnologii*. 2018. 12(4): 53-56. DOI 10.22314/2073-7599-2018-12-4-53-56. (In Russian).

Agrotechnical requirements for soil cultivation by disk harrows depend on its purpose: pre-sowing tillage after reversible plowing, or basic surface tillage, or other type. In this case, the most important requirement for a disk harrow is the completeness of soil shearing and shifting the soil layer along the entire operating width. This requirement should be met by multi-row harrows with front disks on individual racks. The parameters for arranging disks in such harrows are selected experimentally. Increasing the number of disks per unit of width increases their cost as compared to traditional battery-type harrows, and worsens the stability of their performance in heavily foul fields.

The research purpose is to improve the quality of soil cultivation and reduce the necessary number of disk working tools by correcting their arrangement on the harrow frame.

Materials and methods. When a flat disk with an approach angle α is operating, the soil is subject to the deformation of compression and shearing. When a conical or spherical disk deviated from the vertical plane by the angle β is used, there is a kind of tear and shear deformation. This makes it easier to lift the soil layers up along a spherical or tapered disk. A single disk, as a rule, loosens the monolithic soil only by the width of a strip cut in it by a section in the form of a segment of an ellipse with a chord at the soil surface level (*Fig. 1*) [1-3].

However, the lateral tear and shear stresses made by the disk can destroy an additional strip of soil produced by the front disk between the tilled and already treated soil [4].

The length of shearing elements formed as a result of tearing and shearing depends on the width of the soil strip between the strip cut by the disk in the monolith and the soil with a structure broken by the front disk processing the adjacent strip. This length should be less than the average chip length, since the disk moves in the longitudinal direction, and lateral destruction of the additional soil strip occurs only as a result of the temporary action of normal stresses on the partition

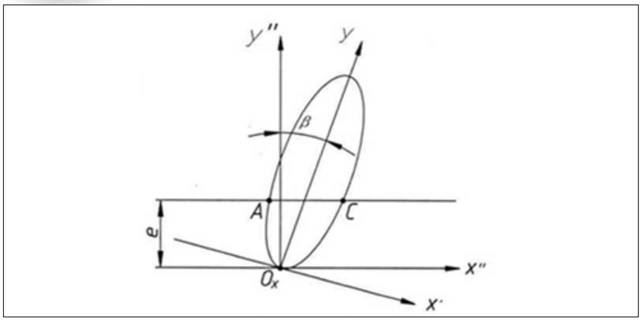


Fig. 1. The profile of the soil cut out of a monolith with a spherical (concave) disk with an approach angle α and inclination angle β(e is the depth of treatment)

wall until the first shearing element is formed in the lateral direction (*Fig. 2*) [5].

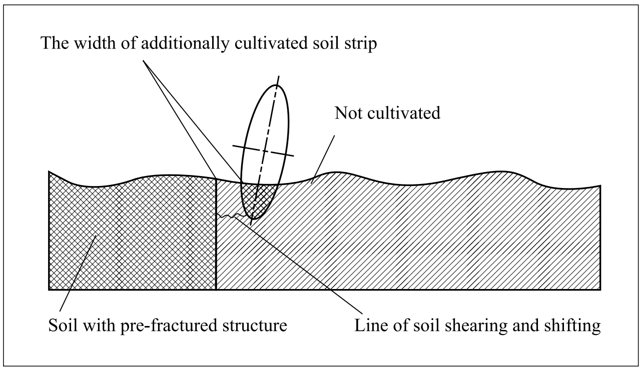


Fig. 2. An increase in the width of the strip tilled by the disk due to tearing and shearing between the strips of tilled and already cultivated soil

Thus, two disks located one after another in different rows till adjacent strips of soil, while the second disk makes soil ridges or pushes the soil aside in the same direction as the first one. Then, with the same parameters of both disks, the second one can till the soil of a larger width than the first one by the length of one shearing element. The length of one fragment depends on the soil type and structure, its moisture, hardness, the presence of root residues, operating modes and parameters of the disk tool (tillage depth, unit travel speed, an approaching angles and disk inclination), the values of which vary on the same field and have a random character [6, 7].

To clarify the correction factor of the planned disk operating width, depending on their location relative to the adjacent front disks, the authors have conducted experimental studies and recommended rational arrangement of working tools.

Results and discussion. Disk harrows with individual fastening of working tools to the frame, despite the small inter-disk distance, leave untilled strips on the dense soil. This is the result of incorrect arrangement of working tools on the frame. The width of the strip b tilled separately by the mounted disk is [8, 9]:

$$b=\sqrt{4e_n\sin^2\alpha(2R\cos\beta-e_n)\cos^2\beta}, \quad (1)$$

where $e_п$ is the agrotechnically permissible height of the longitudinal ridge formed between adjacent runs of two disks; R is the disk radius; α is the approaching angle of the disk; β is the slope angle of the disk. The width of the tilled soil strip.

Figure 3a shows a fragment of the technological scheme of most frontal multi-row disk harrows with individual fastening of the working tools. The variants of the mutual arrangement of pairs of working tools that till adjacent soil strips (pairs 1-2, 2-4, 3-4 and 1-3). Their characteristic feature is that only in one pair (3-4) the disk located at the rear part tears and shifts the soil towards the furrow open in front of the disposed disk of the same pair. Such a pair is called an effective pair. In the technological layout of the working tools proposed by the authors (*Fig. 3b*), there are three effective pairs (1-4, 2-3, 1-2) and one non-effective – (3-4).

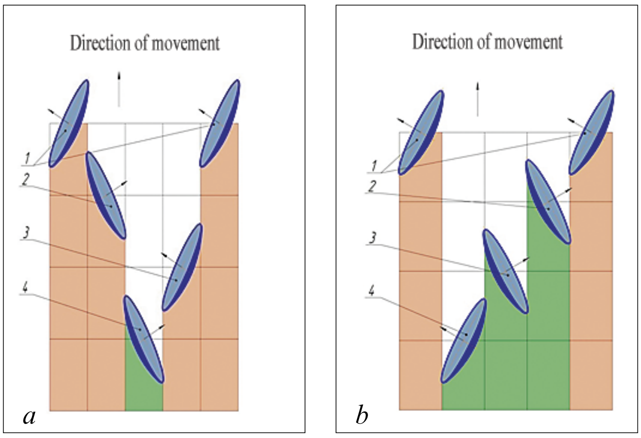


Fig. 3. Fragments of the technological schemes of disk harrows: with the approaching angle, the disks opposite to the approaching angle in the previous row (a), and with the soil tillage as a result of its tear or shear deformation (b)

The results of the calculations and experimental studies have shown that when mounting disks with a diameter of 560 mm at a distance of 400 mm in one row according to the scheme (1-4-3-2), the technological width of the effective pairs of disks was an average of 50%. The effective operating width is given by:

$$b=k\sqrt{4e_n\sin^2\alpha(2R\cos\beta-e_n)\cos^2\beta}, \quad (2)$$

where k is the coefficient of an increase in the width of the tilled strip.

It is larger than that of conventional inefficient pairs and depends on soil conditions and disk parameters [10-12]. If the technological width b of the strip tilled in the monolith is 80 mm, then taking into account tearing off or shifting in the transverse direction, the pair of disks will process a strip with a width of 100-130 mm, that is wider by 20-50 mm. For a full 4-row disk harrow of a four-meter-long operating width, 32 disks instead of 40 are sufficient for the entire width of the soil area. With their traditional arrangement, complete soil shearing is not achievable, and with the recommended arrangement, a smaller number of disks are provided [13].

Conclusions

1. When arranging working tools on disk harrows, it is necessary to take into account the dependence of the technological width of the tilled strip on each working element on the relative position of a pair of disks that tills adjacent strips of soil.

2. When the soil is tilled with a disk, moving it towards the already cultivated adjacent strip, the disk operating width increases by a factor of 1.3-1.7 due to the manifestation of the tear and shear soil deformation.

3. For a wide-spread 4-row disk harrows with disks of 560 mm in diameter with an approaching angle of 18° and an inclination angle of 10-11°, the number of disks can be reduced by 20%.

REFERENCES

1. Panov I. M., Vetokhin V.I. Fizicheskiye osnovy mekhaniki pochv [Physical fundamentals of soil mechanics] Kiiv: Feniks. 2008. 266. (In Russian)
2. Sokht K.A. Prognozirovaniye tekhnologicheskikh parametrov diskovykh pochvoobrabatyvayushchikh orudiy na etape ikh proyektirovaniya [Forecasting the technological parameters of disk tillage tools at the stage of their designing] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2011. 5. 28-30. (In Russian)
3. Zhuk A.F. Obosnovaniye parametrov dvukhdiskovykh sektsiy boron [Determination of the parameters of two-disk sections of harrows]. *Tekhnika v sel'skom khozyaystve*. 2011. 4. 4-7. (In Russian)
4. Upadhyaya S.K., Andrade-Sanchez P., Sakai K., Chancellor W.J., Godwin R.J. Chapter 3: Tillage. In Advances in Soil Dynamics. American Society of Agricultural and Biological Engineers. 2009. 273-359. (In English)
5. Lobachevskiy Ya.P., El'sheykh A.Kh. Obosnovaniye rasstanovki diskovykh rabochikh organov v kombinirovannykh pochvoobrabatyvayushchikh agregatakh [Determining the arrangement of disk working elements in combined soil-cultivating units] // *Sel'skokhozyaystvennyye mashiny i tekhnologii*. 2009. N4. 22-25. (In Russian)
6. Sineokov G.N., Panov I.M. Teoriya i raschet pochvoobrabatyvayushchikh mashin [Theory and calculation of the parameters of soil-cultivating machines]. M.: Mashinostroyeniye. 1977. 328. (In Russian)
7. Gukov Ya.S. Obrobitok gruntu. Tekhnologiya i tekhnika [Soil removing. Technologies and machinery]. Kiiv: Tov. "DIA". 2007. 276.
8. Sokht K.A. Mashinnyye tekhnologii vozdelyvaniya zernovykh kul'tur [Mechanized technologies of cultivating grain crops]. Krasnodar: Prosveshcheniye Yug. 2001. 270. (In Russian)
9. Kanarev F.M. Rotatsionnyye pochvoobrabatyvayushchiye mashiny i orudiya [Soil tillage rotary implements and tools]. M.: Mashinostroyeniye. 1983. 144. (In Russian)
10. Zhuk A.F. Pochvovlagosberegayushchie agropriyemy, tekhnologii i kombinirovannye mashiny [Soil-and-moisture-saving farm practices, technologies and combinations]. M.: Rosinformagrotekh. 2012. 144. (In Russian)
11. Kulen A., Kuipers Kh. Sovremennaya zemledel'cheskaya mekhanika [Modern agricultural mechanics]. M.: Agropromizdat, 1986. 349. (In Russian)
12. Nartov P.S. Diskovyye pochvoobrabatyvayushchiye orudiya [Soil tillage disk tools]. Voronezh: Voronezhskiy universitet. 1972. 182. (In Russian)
13. Vol'skiy V.F. Viznachennya zon ratsional'nikh znachen' parametriv sferichno-diskovogo robochogo organu [Determining the zones of rational values of parameters of a spherical-disk robotic tool]. Ekobiotekhnologii ta biopaliva v APK. Energia. 2012. Kiiv-Lyublin-Simferopol'-L'viv. 2012. 104-105. (In Russian)

The paper was submitted to the Editorial Office on 21.05.2018

The paper was accepted for publication on 27.08.2018

Conflict of interest.
The authors declare no conflict of interest.