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INFLUENCE OF PARALLEL DRIVING SYSTEMS AND DIFFERENTIATED FERTILIZER APPLICATION ON THE EFFICIENCY OF USING MACHINE AND TRACTOR UNITS IN THE SOUTHERN CHERNOZEM OF NORTH KAZAKHSTAN

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Abstract

The article presents the results of evaluating the effectiveness of the use of modern electronic driving systems for machine-tractor units in the precision farming system and comparative tests of a new cultivator-fertilizer for shallow non-moldboard cultivation and subsoil differentiated application of mineral fertilizers in the fallow field of southern chernozems of the northern region of Kazakhstan. In the Republic of Kazakhstan, near and far abroad, technical means for subsoil application to a depth of more than 14 cm with a differentiated application system for non-moldboard processing are not produced. Therefore, such work has not been carried out, which does not allow evaluating the effectiveness of the use of modern electronic systems for driving aggregates and differentiated application of fertilizers for flat-cutting cultivation on the southern chernozems of the northern region of Kazakhstan. The purpose of the tests is to evaluate the effectiveness of the use of modern electronic driving systems for machine-tractor units in the precision farming system.

Keywords: precision farming, electronic systems, parallel driving, mineral fertilizers, differentiated application, electronic map, test results

INTRODUCTION

The grain-sowing regions of Northern Kazakhstan are distinguished by a rather severe sharply continental climate with hot summers and frosty winters. The distribution of precipitation during the warm period of the year is not uniform. In the north, the amount of precipitation falls 260–280 mm, in the south 80–100 mm.

Data of long-term observations indicate that every second year in this region is dry with high daytime temperatures - more than +30 °C and low relative humidity - no more than 40%. The moisture deficit is 500–800 mm. Therefore, the main limiting factor that determines the riskiness of agriculture is the insufficiency and instability of the provision of moisture and heavy soil texture.

The territory of Northern Kazakhstan is basically the bottom of the sea, so all the main types of soils are found there. In the direction from north to south, the following types of soils can be distinguished: ordinary chernozems, southern chernozems, dark and light chestnut, solonets and solonchaks, floodplain soils (in river valleys). About 60% of agricultural land is located on chernozem soils, about 40% on chestnut soils.

According to the mechanical composition, the most common are heavy loamy (50.7%) and medium loamy (21.2%) soils. Such soils contain from 45 to 80% of physical clay in their composition, therefore they are prone to self-compacting under the influence of natural factors and human activities.

The main part of agricultural soils (more than 80%) contain humus in the arable layer no more than 3–5%.

The flat terrain and a significant number (more than 70%) of windy days per year, when the wind speed exceeds 5 m/s, contribute to the manifestation of wind erosion of the soil.

A distinctive feature of the soil-protective (traditional) technology of cultivating agricultural crops is non-moldboard tillage with the preservation of stubble and other crop residues on the surface of the field. Of great importance in this technology is the development of field crop rotations with a short rotation and a field of pure fallow, as well as the use of fertilizers. At present, soil protection technology is being improved and developed in the direction of rational crop rotation, reduction in the number of mechanical treatments and the use of differentiated fertilization.

The introduction of global satellite positioning technologies, such as GLONASS and GPS, into everyday life since the end of the 20th century, gave impetus to the development, first in Western Europe and the United States, and then in the EAEU countries, of coordinate (precision) agriculture.

One of the main directions in coordinate (precision) farming is the technology of differentiated fertilizer application (DFA), which provides changes in the doses of applied fertilizers in the corresponding zones of the field, depending on the potential yield in each of the zones and soil fertility. The use of DFA makes it possible to achieve the highest possible yield, reduce the environmental burden on the environment, and use fertilizers more efficiently. According to studies, the savings of mineral fertilizers with DFA can be more than 50% in comparison with the traditional method of application (Farm profits and…, 2016; Emerson *et al*., 2016; Precision agriculture'15, 2015; Precision agriculture…, 2014; Bruce *et al*., 2015; Katalin *et al*., 2008). Therefore, mineral fertilizer spreaders manufactured by foreign companies, as an option, are equipped with DFA systems.

Despite some lag in the post-Soviet space in the level of development of electronics, which is the basis for the introduction of precision farming technologies in general and DFA technology in particular, scientists in the CIS countries are actively working in this direction.

Agrochemical surveys conducted in the regions of Northern Kazakhstan show that the soils of 78% of the area are deficient in phosphate fertilizers, which is one of the main elements of plant nutrition and at the same time has a great influence on the drought resistance of plants. The greatest yield increase in crop rotations can be obtained with a single application of a full dose of mineral phosphorus fertilizers in a fallow field per rotation. In this case, the best option is considered to be intrasoil application without turnover of the soil layer and uniform distribution of fertilizers in the arable layer (Abramov *et al*., 2018; Eremin *et al.*, 2017; Lichman *et al.*, 2017; Yakushev *et al.*, 2016; Yakushev *et al.*, 2007; Nukeshev *et al*., 2010; Nukeshev *et al.*, 2007; Abuova *et al.*, 2019).

It should be noted that mineral fertilizers must be applied in a fallow field in the soil layer, which retains a stable moisture content of at least 17–20% throughout the summer period. Such conditions are provided on ordinary chernozems at a depth of 12–14 cm, on southern chernozems and chestnut soils, moisture is maintained at a depth of 16–18 cm.

In the Republic of Kazakhstan, near and far abroad, technical means for subsoil application to a depth of more than 14 cm with a differential application system for non-moldboard processing are not produced. Therefore, the evaluation of the effectiveness of differentiated fertilization for flat-cutting cultivation was carried out in the chernozem zone using sowing complexes, with fertilization to a depth of 10–12 cm (Polishchuk *et al.*, 2021; Polishchuk *et al.*, 2020). On the southern chernozems and chestnut soils, such studies were not carried out due to the lack of a tool to carry out this technological process.

Therefore, when using modern technologies for the cultivation of grain and fodder crops, a problem arose in creating the necessary technical means and in assessing the differentiated application of the main dose of mineral fertilizers in a fallow field for flat-cutting cultivation on southern chernozems.

Research Purpose

To evaluate the effectiveness of the use of modern electronic driving systems for machine-tractor units in the system of precision farming and the developed cultivator-fertilizer for shallow non-moldboard cultivation with a system of differentiated fertilization.

MATERIALS AND METHODS

To collect information on subsoil fertilization systems, available literature sources and technical characteristics were studied.

The processing of the received scientific and technical information on the systems of subsoil fertilization was carried out by standard methods of comparison, analysis and synthesis.

The structural and technological scheme of the cultivator and additional equipment for dosing, transporting and distributing fertilizers along the working width, in the direction of travel and according to the criterion of reliability of the technological process are substantiated (Derepaskin *et al*., 2016; Derepaskin *et al*., 2022; Derepaskin *et al*., 2021; Tokarev *et al*., 2020; Derepaskin *et al*., 2021; Derepaskin *et al*., 2020; Derepaskin *et al*., 2014; Derepaskin *et al*., 2015). It has been established that the best is the combined method of subsoil application, in which the dosage is carried out by a coil sowing mechanism, and transportation and distribution behind the working body is carried out by air flow. However, this method is not without drawbacks, which include the low reliability of the technological process as a result of the suspension of dusty particles and clogging of the pipeline with fertilizers at the outlet of the metering mechanism. To eliminate these shortcomings and improve the reliability of operation, reduce the uneven distribution of fertilizers along the width and course of movement, and reduce the energy intensity of the technological process, an improved combined system for differentiated subsoil fertilization has been developed (Derepaskin *et al*., 2020; Derepaskin *et al*., 2014; Derepaskin *et al*., 2015).

High dosing accuracy with differentiated application is ensured by a reel sowing mechanism with a changing working width, and fertilizers are fed into an additionally installed mixing chamber into a low-pressure zone, where fertilizers are picked up by the air flow and transported to the working bodies with their subsequent distribution in the soil.

The use of an additional mixing chamber and the supply of fertilizers to the low pressure zone eliminates the possibility of clogging of the pipeline in the area of free fall of fertilizers from the sowing mechanism to the mixing chamber, which increases the reliability of the technological process

For differentiated application of fertilizers according to the generalized desirability function, the Agronavigator-Dosator system was chosen, consisting of: the Agronavigator plus navigation complex, GLONAS/GPS antenna and actuators (Derepaskin *et al*., 2020; Derepaskin *et al*., 2014).

According to reasonable parameters, a cultivator with a system of differentiated fertilization was made and comparative field tests were also carried out. Conditions for testing under production conditions: field background – black fallow and stubble of cereals (wheat, barley). The actual values of the test conditions are determined in accordance with the requirements of GOST 20915 (GOST 20915-2011, 2013). Agrotechnical assessment was carried out in accordance with the requirements of GOST 33736 (GOST 33736-2016, 2017). Energy assessment was carried out in accordance with the requirements of GOST R 52777 (GOST R 52777-2007, 2007), technical and operational indicators were determined in accordance with GOST R 52778 (GOST R 52778-2007, 2008). The economic assessment was carried out according to ST RK GOST R53056 (ST RK GOST R 53056-2010, 2010).

The data obtained from experimental studies were processed by the method of mathematical statistics using the Excel computer program.

The main statistical characteristics of the results of comparative tests were the arithmetic mean values of the estimated indicators.

RESULTS

The technological process of intrasoil application of mineral fertilizers consists of five consecutive operations. These are the dosage of fertilizers, transportation of fertilizers to the working body, non-moldboard loosening and cutting weeds with the formation of a furrow, the distribution of granular fertilizers across the width of the working body, the placement of fertilizers with a layer of soil and leveling the field surface.

Conventionally, the tool that performs this technological process can be divided into soil-cultivating working bodies and a system of subsoil fertilization. The system consists of dosing, transporting and distributing parts (Tokarev *et al*., 2020; Derepaskin *et al*., 2021; Derepaskin *et al*., 2020; Derepaskin *et al*., 2014; Derepaskin *et al*., 2015).

Checking the performance of the system of dosing, transportation and differentiated changes in the rate of fertilizer application was carried out in laboratory conditions. To do this, a task map with broken cells was loaded into the DFA navigation complex, each cell contains a conditional application dose from 20 to 120 kg/ha, with a step of 10 kg/ha. In the simulation mode, the movement of the unit across the field was simulated and when crossing a cell with a set dose of application, a command was given to change the length of the working part of the coil and sampling was carried out to measure the actual dose of fertilizer application. According to the results of laboratory tests of the system of differentiated application of mineral fertilizers, it was established that the deviation of the actual dose of fertilizer application from the specified one was 2.4–5.0% and the uneven distribution of fertilizers over the width of the working body was 14.8–18.4% (Tokarev *et al*., 2020; Derepaskin *et al*., 2021; Derepaskin, *et al*., 2020; Derepaskin, *et al*., 2014; Derepaskin, *et al*., 2015).

A detailed description of the procedure for testing the system performance in the laboratory is presented in the articles (Tokarev *et al*., 2020; Derepaskin *et al*., 2020) A detailed description of the procedure for testing the system performance in the laboratory is presented in the articles (Tokarev *et al*., 2020; Derepaskin *et al*., 2020).

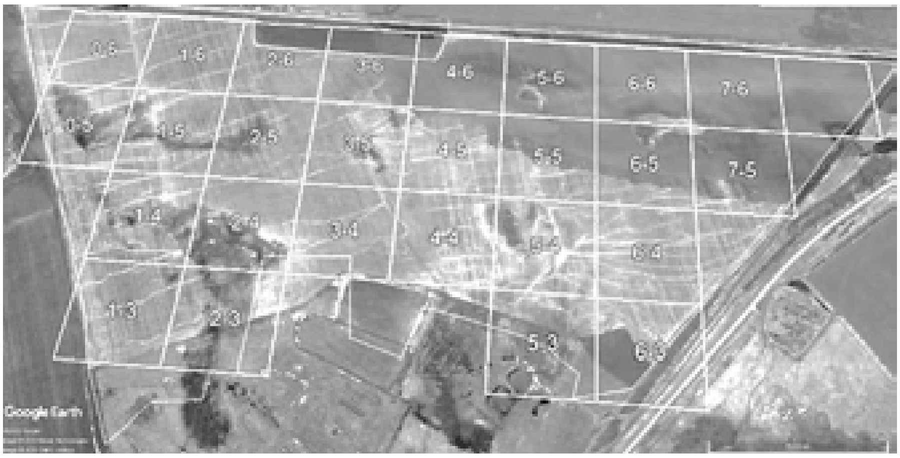
The results of laboratory studies have shown that a system with reasonable parameters for dosing, transporting and distributing mineral fertilizers provides the required quality of work and can be used for differentiated subsoil application, which was confirmed by the results of tests under production conditions that were carried out on the fields of the Zarechnoye OPF on the second flat-cut steam treatment with simultaneous differentiated application of fertilizers, ammophos. The farm uses a four-field grain fallow crop rotation. The first treatment of the fallow field was carried out with herbicides. The main species of weeds is represented by sow thistle, wormwood and millet. Soil infestation with weeds was 80 pcs/m^2. According to the mechanical composition of the cultivated layer, the field plot was a typical representative of the soils of the northern region of Kazakhstan (soil type – southern chernozem, mechanical composition - heavy loam). The average soil hardness in the 0–20 cm layer was 4.7 MPa, humidity – 7.7%, density – 1.45 g/cm^3.

The soil survey showed that according to the degree of availability of P_2O_5, 19 elementary plots belong to class II (low availability) – 20–50 mg/kg of soil, 6 elementary plots belong to class III (medium supply) – 50–100 mg/kg of soil, 2 elementary plots belong to class IV (high availability) – 100–150 mg/kg of soil, according to the degree of availability of $N\text{-}NO_3$, all the studied elementary plots belong to class I (very low availability) and class II (low availability), according to the content of organic matter (humus) – to areas with very low (less than 2.0%) and low (2.0–4.0%) humus content.

The differentiated dose of mineral fertilizer application (ammophos), depending on the availability of P_2O_5 elementary plots, was 60 kg.a.i./ha (120 kg of physical weight) for class II plots, and 45 kg.a.i. for class III plots./ha (90 kg of physical weight), for plots of class IV – 0 kg.a.w./ha.

In case of continuous application without using the DFA system, the same unit was used as a base case for comparison, operating under identical conditions with the system of differentiated application of mineral fertilizers turned off, the application dose was constant and amounted to 60 kg.a.w./ha (120 kg of physical weight). Based on the soil survey, an electronic task map was developed for the cultivated fallow field (Fig. 1).

The tractor “Kirovets” K-739 of traction class 6 was used as an energy source. The view of the unit in the work is shown in Fig. 2.



1: *General view of the electronic task map of the cultivated fallow field (Google Earth program)*

2: *A unit consisting of a tractor “Kirovets” K-739 and a cultivator equipped with a system of intrasoil differentiated application of mineral fertilizers. The view at steam work.*

I: *Influence of the system of differentiated application of mineral fertilizers on the agrotechnical and energy performance of the unit as part of K-739 + cultivator-fertilizer*

Indicator	Indicator value				
	According to regulatory documentation and technical specifications (T3)	Implement without Variable Fertilizer Application (DFA)	Variable Fertilizer Implement (DFA)		
Agrotechnical indicators					
Constructive capture width, m	7.2	7.2	7.2		
Working width, m	-	6.7	7.05		
Overlap size, m	-	0.5	0.15		
Dose of application,given, kg/ha	20–120	120.0	0.0	90.0	120.0
Actual application dose, kg/ha	-	124.2	0.0	74.8	99.8
Deviation of the actual dose from the given one, %	± 5.0	3.5	0.0	1.69	1.68
Uneven distribution of fertilizers over the working width of the tool, %	≤ 10.0	5.4	-	5.6	5.4
Depth of processing, cm	16.0 ± 1.5	16.5	16.6		
Soil crumbling (content of lumps up to 50 mm incl.), %	≥ 60.0	65.1	64.5		
Comb height, cm	≤ 8.0	7.2	7.4		
Cutting weeds, %	100	100	100		
Change in the content of erosion-dangerous soil particles less than 1 mm in size in a soil layer of 0–5 cm, %	shouldn't increase	-3.5	-3.1		
Energy indicators					
Driving speed, km/h	7–10	9.0	9.0		
Hourly fuel consumption, kg/h	-	61.2	61.2		
Power consumed by the tool to overcome traction resistance, kW	-	132.8	133.0		
Traction resistance, kN	-	53.1	53.8		
Fan speed, min^{-1}	≤ 2850	2 400	2 400		
Power spent on the fan drive, kW	≤ 4	1.8	1.8		
Power consumed by the implement, kW	-	134.6	134.8		
Specific energy consumption, MJ/ha	-	78.0	76.8		
Productivity per hour of main time, ha	-	6.03	6.34		

As a result of the agrotechnical assessment, it was found that for all the above indicators, the unit equipped with the TLD system "Agronavigator dispenser" and the unit without the system ensure the quality of the technological process in accordance with the requirements of regulatory documentation (RD) (Tab. I).

The system of differentiated application of mineral fertilizers influenced the actual dose of application. Compliance of the actual dose of fertilizer application with the given one, taking into account the permissible deviation when using the system of differentiated application of mineral fertilizers, allows us to note that all components of the system responsible for automatically changing the dose of application when the unit moves across the field, as well as the sowing units of the implement, are calibrated and adjusted with a sufficient degree of accuracy.

The navigation complex included in the system allows you to control the machine in parallel driving mode, which reduces the amount of overlap and, as a result, increases the working width of the machine by 5.2% compared to the machine operating without the system.

According to the results of the energy assessment, which was carried out simultaneously with the agrotechnical one, it was found that the system of

II: *Influence of the system of differentiated application of mineral fertilizers on the operational and technological performance of the unit as part of K-739 + cultivator-fertilizer*

Indicator	Indicator value	
	Unit without DFA system	Unit with DFA system
Working speed, km/h	9.0	9.0
Working width, m	6.7	7.05
Productivity, ha/h:		
– per hour of regular time	6.03	6.34
– per shift hour	4.64	4.88
– per hour of operating time	4.64	4.88
Time usage coefficients:		
– replaceable	0.77	0.77
– operational	0.77	0.77
The coefficient of reliability of the technological process	0.99	0.99
Specific fuel consumption kg/ha	12.81	12.48
Number of service personnel, people	1	1
Application dose, specified, kg/ha	120.0	0.0 90.0 120.0
Actual application dose, kg/ha	125.0	101.6

III: *The effect of the system of differentiated application of mineral fertilizers on the economic efficiency of the unit as part of the tractor K-739 +cultivator-fertilizer*

The name of the indicator	The value of the indicator according to the samples of the compared equipment		Index of the indicator change, %
	without a system	with a system	
Total cash costs, euro/ha	590	529	-10
Labor costs, people-h/ha	0.209	0.206	-2
Specific fuel consumption, kg/ha	12.81	12.59	-2
Annual economic effect, thousand euros		59.1	
Capital investments, thousand euros	116.2	118.5	2
Payback period of additional capital investments, years	-	0.41	-
The upper limit of the price of new equipment, euro	-	75 112	-
The price of equipment according to the manufacturer, euro	-	30 000	-

differentiated fertilization does not have a significant effect on such indicators as traction resistance, traction power, while due to a decrease in the overlap and an increase in productivity, the specific energy costs are reduced by 1.5% – from 78.0 MJ/ha to 76.8 MJ/ha.

The results of the operational and technological assessment showed that the use of a system of differentiated fertilization allows you to get the following effect: increase the working width of the unit by 5.2%, increase the unit's productivity per hour of shift time by 4.9%, reduce specific fuel consumption by 4.7%, reduce the actual dose of mineral fertilizers by 20.3% (Tab. II).

The achieved savings of mineral fertilizers when using TLD on electronic maps in Kazakhstan are lower than those obtained by a number of authors on European and American soils (Farm profits and…, 2016; Emerson *et al.*, 2016; Precision agriculture'15, 2015; Precision agriculture…, 2014 ; Bruce *et al.*, 2015; Katalin *et al.*, 2008). This is due to the relatively low required doses of fertilizers for crops.

The coefficients of the use of shift and operational time in the two compared variants were 0.77, since no technical failures were observed during the tests.

Based on the test data obtained, a comparative assessment of the economic efficiency of the units with a system of differentiated fertilization and without a system was carried out. The calculations used the results of research, the initial data of the normative reference literature. The results of the comparative economic assessment are presented in Tab. III.

The results of the economic assessment showed that the use of a system of differentiated application of mineral fertilizers allows you to get an annual economic effect of 59.1 thousand euros, reduce total costs by 10%, while the payback period for additional capital investments was 0.41 years.

CONCLUSION

For the first time developed in Kazakhstan, a cultivator-fertilizer with a system of differentiated subsoil application of mineral fertilizers for flat-cut processing ensures the implementation of the technological process in accordance with agrotechnical requirements. Agrotechnical, energy and operational-technical indicators were obtained using elements of differentiated subsoil application of mineral fertilizers using electronic field maps. It has been established that the use of elements of differentiated subsoil application of mineral fertilizers does not affect the quality indicators of the technological process, but contributes to an increase in productivity and a decrease in the specific consumption of fuel and fertilizers.

The use of a GPS navigation system, a parallel driving system (GPS navigation with a course indicator), a developed cultivator equipped with an Agronavigator-Dispenser TLD system for differentiated fertilization for non-waste fine processing provided an increase in the productivity of the unit for one hour of shift time by 4%, a reduction in labor costs by 5%, specific fuel consumption by 4.7% and fertilizer consumption by 20.3%.

Annual savings in total cash costs from the operation of a cultivator – fertilizer with a system of differentiated application of mineral fertilizers amounted to 59.1 thousand euros.

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