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Development Of A Method For Differentiated Fertilizer Application In Conditions Of Precision Agriculture According To Soil Fertility Monitoring.

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ABSTRACT

The aim of the research is the development of new methods and technical facilities for improving the process of soil fertility monitoring with the purpose of its equalization by differentiated application of fertilizers and obtaining the highest possible yield of agricultural crops. In the course of the research, a new method for studying and constructing soil fertility maps in terms of the thickness of the humus layer, being determined with the help of a special penetrometer,was developed. We obtained a strong inverse correlation between the soil firmness and the thickness of the humus horizon and the high comparability of soil firmness changing maps with maps of the thickness of the humus horizon, for preliminary calculation and differentiated application of fertilizers. To implement the method of differentiated application of fertilizers, special equipment and software installed on the seeding machine were developed. In the course of research, the dependence of the thickness of the humus layer (G) on the firmness (Y) was obtained, which reflects the inverse linear dependence of the thickness of the humus layer on the firmness of the soil (for the experimental plot) G = 1.437-0562Y. In each specific case (by type and characteristics of soils), this dependence will be changed. In the experimental plot, the doses of fertilizers were calculated for obtaining the planned grain yield. The differentiated application of the calculated doses ensured the equalization of soil fertility on the field and the production of almost identical soybean yields at different sites, and also increased the yield to 20%. The proposed method and technical facilities for soil fertility monitoring regarding the thickness of the humus layer for differentiated fertilizer application allow effectively equalizing the fertility of the soil and obtaining an extra yield with the general reduction in costs relative to traditional methods of fertilizer application.

Keywords: fertilizer, agriculture, precision agriculture, soil.

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INTRODUCTION

Further increase in the efficiency of farming is based on precision agriculture systems [1-4], ensuring the maximum possible yields of crops with rational use of fertilizers and plant protection agents to reduce the cost of crop production. When using precision agriculture systems, one of the most important and laborious processes is the mapping of fields with the allocation of sufficiently homogeneous areas for the presence of macroelements: nitrogen, phosphorus and potassium. At present, several methods are used to map the homogeneity of fields by fertility.

The biomass control system *Crop-sensor*is based on the work of a contact sensor made in the form of a pendulum [5]. It is fixed in front of the tractor, at a constant height, when in contact with plants, the pendulum deflects, the onboard computer calculates the biomass of the plants. Based on these data, fungicides and growth stimulants can be differentlyapplicated.

To implement on-line mode, information on the agricultural requirements of a particular crop is preliminarily collected, then the dosage is calculated taking into account information coming from the sensors directly during the execution of the technological operation. These include, for example, the sensor so-called *N sensor* [6]. The sensor is a design that has five optical sensors operating in the red and infrared ranges. When moving through the field, the sensor scans the plants and the onboard computer detects the presence of chlorophyll and the biomass of the plants from the light reflected from the leaves and calculates the fertilizer dose necessary for the plot. The dosage of fertilizers is changed by slide valves. The *N sensor* covers about 70 m^2 of plant standin one second.

Precision agriculture technologies provide for the collection and processing of information for each field parcel, for this purpose yield sensors are produced mainly of two types - optical and magnetic resonance[7]. Optical sensors scan the mass collected, which is passing through a beam of light, and send data to the onboard computer, which calculates the mass of the grain. Magnetic resonance work on the principle of excitation of electromagnetic pulses when a grain hits the plate and sends data to the onboard computer. At the same time, the GPS system collects data on the location of the combine and writes it to the computer's memory. After the end of harvesting, the data from the onboard computer is transferred to a stationary agromanager's PC, where a yield map is plotted with locks on the terrain [8]. On these maps it is possible to identify problem areas with low yields, conduct agrochemical or agro-physical analysis of these areas to find ways to equalize fertility, and consequently, the yield of future crops.

Agrochemical analysis of soils is carried out by selection of soil samples at various sites of the field [9]. When samplingthe chernozems, the field is divided into elementary plots with an area of no more than 3 hectares. Areas of plots should be reduced if the history of a particular field is not known or previously large doses of fertilizers were used on it, or the field is formed as a result of the unification of several sites. The number of samples taken at elementary plots should be at least at amount of 20-40 taken from a depth of 0-30 cm.

All of the listed methods in comparison with the developed ones, in our opinion, have one significant disadvantage as high labor input.

MATERIALS AND METHODS

Based on the experimental data of the Samara State Agricultural Academy regarding determining the thickness of the humus layer in terms of specific resistance and firmness of the soil, in order to increase the efficiency of the use of mineral fertilizers, the method of differentiated application of fertilizers, depending on the thickness of the humus layer, is proposed [14-15].

This method includes:

1. Determination of the soil firmness on the field;
2. Construction of a map of lines of an equal level of firmness of the investigated area;
3. Determination of the thickness of the humus layer by carrying out the pits in the places of minimum, medium and maximum soil firmness;

4. Determination of the presence of N, P, K in the places of pits;
5. Sowing with simultaneous application of calculated doses of mineral fertilizers.

At the first stage of its implementation, the algorithm comprises a calibration experiment, the essence of which is that on the lines of equal firmness (Y), the thickness of the humus layer (G) is determined at several points by the method of pits. The practical implementation of the calibration experiment consists of the following sequence of work.

Initially, according to the firmnessgram, the coordinates of the points in which it is necessary to open the pits and take the proper samples from them are determined. On the lines of equal firmness, the number of pits shall not be less than 5.

Excavation, measurements and sampling are carried out in any accessible way. The simplest and most accessible method is drilling to a depth of 1 m. The results of the measurements are entered in the calibration table (table 1). Elements of the calibration table are: y_i - the values of the horizontal firmness of the soil, taken from the diagram (fig. 1) in the i-th dimension; g_i is the depth of occurrence of the humus layer in the i-thpit, measured by any of the available manual methods (ruler, instrument or other device).

Table 1: Calibration table

Experiment	Y (mPa)	G (m)
1	1,2	0,72
2	1,7	0,60
3	2	0,50
I	y_i	g_i
N	y_n	g_n

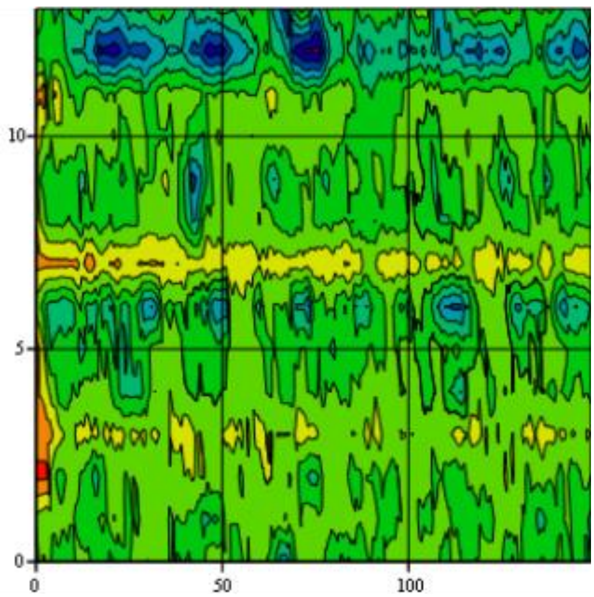

Figure 1: Map of lines of equal firmness level

RESULTS AND DISCUSSION

The investigations were carried out on a plot of 1 hectare, soil type was medium loamy chernozem, during the work the channels were dug out, the depth of occurrence of the humus layer was determined visually with help of a ruler.

Algorithm for processing the calibration table data. In the general case, the dependence G = f (Y), the reflection of which is the data of table 1, can be approximated by a linear equation:

$$G = в_0 + в_1 \cdot Y \,, \qquad (1.1)$$

where$в_0$, $в_1$ – unknowncoefficients, which are determined by the least square method according to the following formulas:

$$в_0 = \frac{\sum_{i=1}^{n} g_i \cdot \sum_{i=1}^{n} y_1^{\,2} - \sum_{i=1}^{n} y_i \cdot \sum_{i=1}^{n} y_i \cdot g_i}{n \cdot \sum_{i=1}^{n} y_i^{\,2} - \left(\sum_{i=1}^{n} y_i \right)^2} \,, \qquad (1.2)$$

$$в_1 = \frac{\sum_{i=1}^{n} y_i \cdot g_i - \sum_{i=1}^{n} y_i \cdot \sum_{i=1}^{n} g_i}{n \cdot \sum_{i=1}^{n} y_i^{\,2} - \left(\sum_{i=1}^{n} y_i \right)^2} \,,$$

For the experimental field$в_0$= 1,437; $в_1$ = -0,562.

Taking these values into account, the dependence of the thickness of the humus layer on the firmness of the soil is described by a linear model of the form:

G = 1,437 – 0,562Y (1.3)

This equation reflects the inverse linear dependence of the thickness of the humus layer on the firmness of the soil (fig. 2).

With the help of this equation it is not difficult to move from firmnessgram to humus cartogram. It has been determined that there is a strong inverse correlation from 0.75 to 0.8between the thickness of the humus layer and the firmness of the soil. This is explained by the fact that as the thickness of the humus layer increases, the soil becomes looser throughout its depth, and denser with a decrease in thickness.

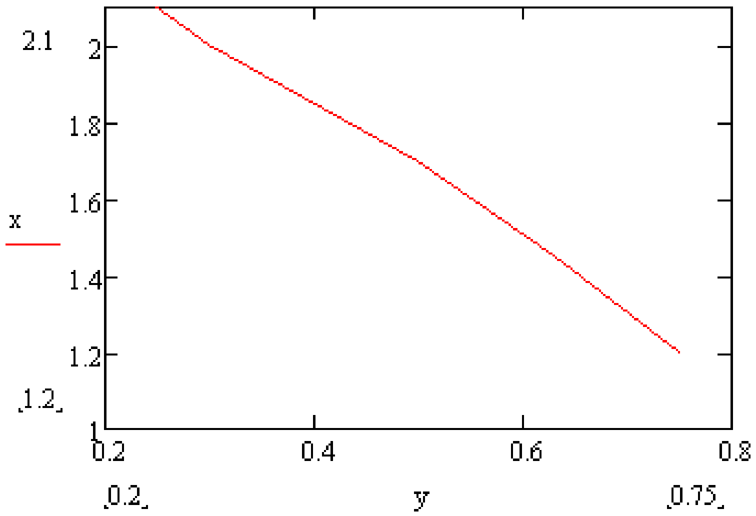

Figure 2:Dependency diagram Y = f (x) = 1,437-0,562•x

After completing the described transition procedure for all firmnessgram lines (fig. 1), we obtain a humus cartogram (fig. 3).

Analysis of this cartogram indicates that in a real situation, any section of a field of 1 ha or more has a complex character of the thickness of the occurrence of the humus layer of the soil.

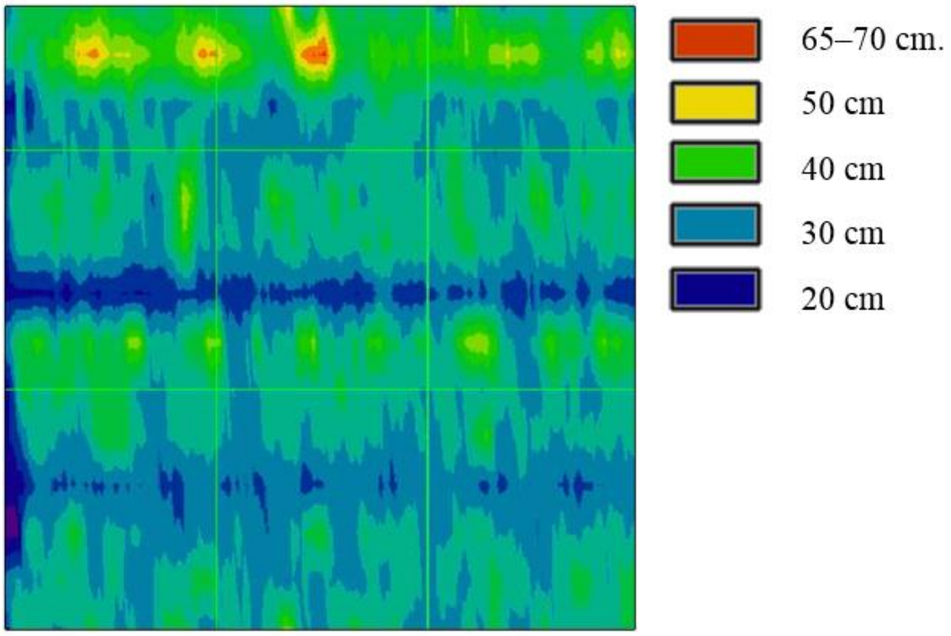

Figure 3: Map of the heterogeneity of the thickness of the humus layer

In connection with this work, it is planned to develop and install special equipment for the sowing unit, taking into account the state of the soil in terms of humus content, to ensure a differentiated application of fertilizers.

The developed device consists of two blocks connected together by means of controllers, that are a measuring unit and a dosing unit.

The measuring unit is a set of mechanical and electronic devices installed on the seeding unit (seeder).

For the basic machine in work, a pneumatic seeder of precision sowing UPC-8 (Vesta) was adopted. This seeder is designed for sowing a wide range of legumes, sunflower seeds and fodder crops. Technical characteristics: working width is 5.6 m; number of sown rows is 8; speed of movement is from 2.5 to 9 km/h; productivity is from 2 to 5.04 ha/h.

The mechanical part of the measuring unit (fig. 4) consists of a deformer representing a plate in the form of a flat knife 10 mm thick and 335 mm long, sharpened from both sides at an angle of 28°, having three holes for fixing bolts. Due to constant contact of the deformer part with the soil (abrasive medium), the web was made of 65G steel with subsequent heat treatment. The length of the blade makes it possible to change the depth of the deformer moving into the soil, depending on the depth of secondary tillage.

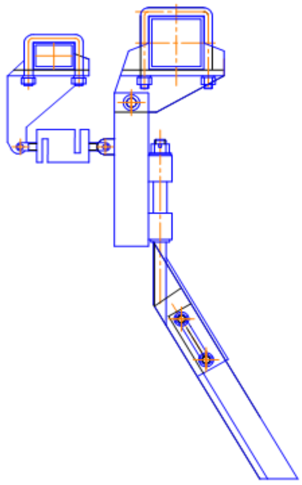

Figure 4: The scheme of a measuring unit

In general, the proposed scheme works as follows: the measuring unit is installed with the necessary interval on the frame of the seeder, the interval is selected for the specific seed rows of a certain crop. The deformer is set to the required depth of work in such a way as to pass below the depth of the secondary treatment by 5-7 cm. During the movement, the deformer tests the soil pressure on the cutting edge, the soil pressure is transmitted through the transfer mechanisms and recorded by the strain tensor.

The slots formed by the deformer will promote the accumulation and conservation of moisture during the vegetative period of plants. As can be seen from the figure 4, the deformer is installed under a passive angle to the movement of the unit, this is done so that during the process of measuring the soil firmness, a compacted soil core will not form before the deformer, which will distort the results of measuring.

In the design being developed, the dosing unit is a rectangular bunker tapering in the lower part, which has two outlets for fertilizers. The transmitting shaft passing at the bottom of the hopper is divided into two equal parts with a coiled screw spiral directed to the side walls of the hopper, in increments of 25 mm.Such a step width allows for more accurate dosing of the fertilizer. Above the shaft there are peaks preventing the fertilizer flow from entering the outlet holes. The upper part of the bunker serves for loading fertilizers and is closed by a lid.

On the lower side wall of the bunker there is a servo-gear mounted on the bracket, intended for transferring the torque from the electric motor to the shaft of the traction device. It consists of a geared motor and a chain sprocket. The torque from the motor shaft of the reducer is transmitted to the shaft of the traction device by chain transmission. Based on the calculations carried out, the SF 7152 gearbox, which is the best for this design, was chosen.

Before the start of the work, the dosing units (4 pieces) are mounted on the seeder frame (fig. 5) with the help of brackets. Mineral fertilizers are filled in and the machine starts moving. With a program delay of 1 second, servoshafts are turned to rotate the shafts of the fertilizer dispensers, fertilizers coming out of the bunkers enter the track lines connected to the fertilizer coulters, passing through them fertilizers are introduced into the soil. The applied dose of fertilizers is constantly changed by the frequency of rotation of the servoshaft, depending on the thickness of the humus layer.

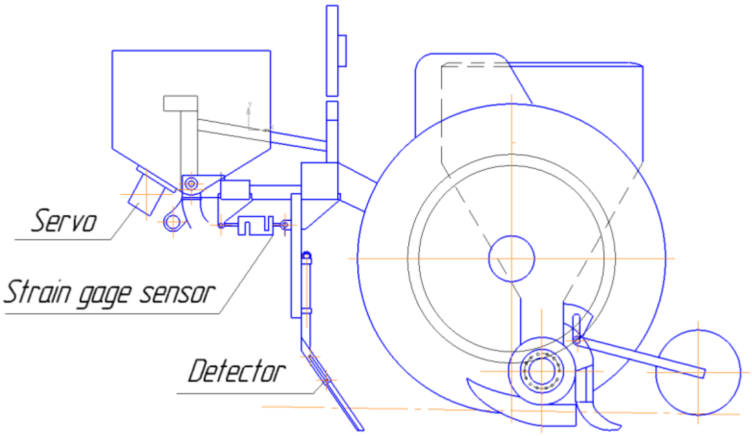

Figure 5: The scheme of installation of devices on a sowing machine

As a controlled servoshaft a geared motor was used. In preliminary studies, it was established experimentally that when the bunker is fully filled with fertilizers, the torque on the shaft of the fertilizer dispenser at steady state operation is about 70 kg*cm. Taking into account the increased load of 30% at the moment of the start of rotation, the geared motor must have a power reserve, as a result of which the SF7152 motor-reducer was chosen for these parameters. The cylinder motor SF7152 consists of a reversible collector electric motor of direct current with a maximum torque of 100 kg*cm. The gear ratio of the electric motor and gearbox is 1:50, the speed is 55 rpm, the electric motor's power is 150 W. Each motor was installed on the bottom of a fertilizer box (fig. 6), fixed by a bracket and connected by a chain drive to the shaft of the fertilizer dispenser.

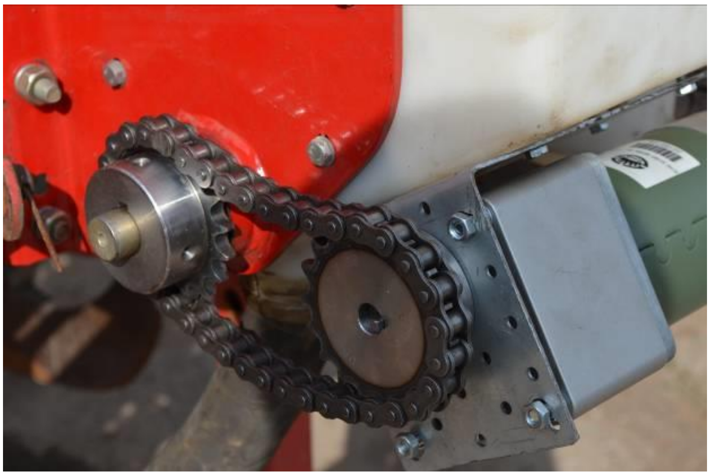

Figure6: A dosing unit in working position

To smooth control of the rotational speed of each geared motor, the BMD collector motor control units (controllers) were used.

Due to the small voltage variation at the load of the sensor of 0.02 mV per 100 kg, the design of the ADC modules HX711 for the connection of strain gages in the amount of 8 pcs was included.

In the process of working with strain gages, a digital signal was taken, which made it possible to repeatedly increase the accuracy of determining the firmness of the soil, and also to use strain gauges with different force ratings at different depths of the soil horizon.

The generalized block scheme of the system for measuring and controlling the metering devices has the form which is shown infigure 7.

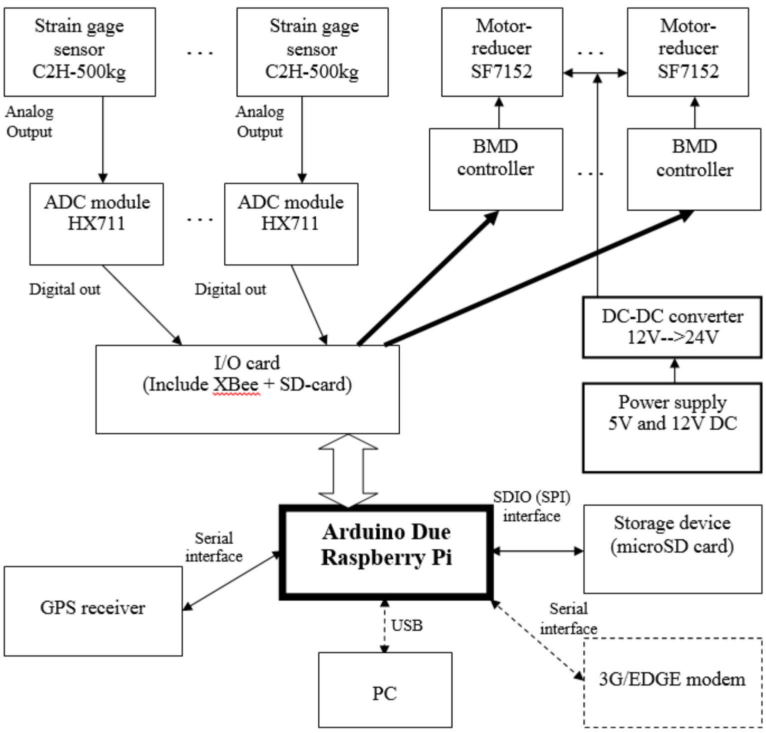

Figure 7: The generalized block scheme of the system for differentiated fertilizer application

Once a second the program is called initiated by the interrupt timer. During the execution of the program, the microcontroller sequentially polls eight sensors-strain gages 5 times each to more accurately determine the sensor readings and eliminate the "pop-up" values. To read the indicators of soil firmness sensors, analog inputs No.1 ... No. 8 of the AT91SAM3X8E microcontroller are used, on which voltages from 0 to 5V are possible (which corresponds to the effect on the sensor with a force of 0 to 500 kg). According to the calibration table, the actual firmness index of the soil is calculated depending on the read value of the voltage from the strain gage sensor. Calculation by the calibration tables of the magnitude of the change in the rotational speed of the shaft of each geared motor is carried out. The output of control pulses for the motor-reducers is made through 8 (from the 1st to the 8th) digital outputs of the microcontroller.

Through the first serial port (UART) of the microcontroller, using the standard protocol of working with GPS receivers (NMEA0183), the exact time and coordinates of the object are read. They are written to the flash card, for further use in processing the results.

Recorded on the flash-media in the table received data of the system operation and the controller goes into the waiting mode of the next interrupt.

The power supply system consists of two main elements of the power supply system of strain gauges and a microcontroller, as well as the power supply unit of the servo shift. The sensors are powered by the installation of an additional battery with a voltage of 12 volts with a capacity of 75 a/h. The strain gauge sensors (they can use power up to 36 volts) are connected directly to the battery.The AT91SAM3X8E microcontroller is connectedvia the DC-DC voltage converter 12-5V.

The developed equipment and method were used in soybean plantings for differentiated sowing application of mineral fertilizers. Before the beginning of the work, the soil was analyzed at 20 points per 50 hectares and its firmness and humidity were measured at the sampling points. After that, calibration coefficients were obtained to determine the thickness of the humus layer and the fertilizer doses for seeding were calculated in sections with different thicknesses of the humus layer.

According to the results of these tests, it was found that the accuracy of dosing of fertilizer mixture was increased by 22%, the yield of soybean with differentiated fertilizer application compared to the traditional method of application increased by an average of 20%, the efficiency of fertilizer use increased. All these data were obtained in unfavorable weather conditions in the vegetation period of 2017. Under better meteorological conditions, the efficiency of fertilizer use is assumed to be higher.

Thus, the introduction of differentiated fertilizers application with the proposed method and technical devices for the production of soybean as well as other crops allows creating the most favorable conditions for the growth and development of plants and more rational use of mineral fertilizers.

1. Для повышения эффективности дифференцированного внесения удобрений в системе точного земледелия наряду с известными способами предварительного картирования полей по плодородию целесообразно использовать предложенный способ картирования полей по твёрдости почвы и мощности гумусового горизонта
2. Проведенными исследованиями установлена сильная обратная корреляция между твёрдостью почвы и мощностью гумусового горизонта – соответственно плодородием.
3. Дифференцированное внесение удобрений с использованием предложенных технических решений для мониторинга плодородия по твердости почвы и мощности гумусового горизонта позволяет значительно увеличивать урожайность возделываемых культур при рациональных затратах на удобрения при их дифференцированном внесении.

CONCLUSION

1. In order to improve the efficiency of differentiated fertilizer application in the system of precision agriculture, along with the known methods of preliminary mapping of fields by fertility, it is advisable to use the proposed method of fields mapping by the soil firmness and the thickness of the humus horizon.
2. The conducted studies established a strong inverse correlation between the firmness of the soil and the thickness of the humus layer and, respectively, the soil fertility.

3. Differentiated fertilization application with the use of the proposed technical solutions for monitoring of soil fertility by the firmness of the soil and the thickness of the humus horizon makes it possible to significantly increase the yield of cultivated crops with rational costs for fertilizers through their differentiated application.

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