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Methods of Applying Fertilizers in Precision Agriculture

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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.

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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:

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

where $У_{ПЛ}$ –the planned yield;

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

The planned yield for separate plots is calculated using the formula

$$У_{ПНуч} = K_{ПР} \cdot У_{БНуч}, \quad (2)$$

where $У_{БНуч}$ – 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 – 12500 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:

$$П_{П} = Ц_{ур} У_{П} S_{П} - D_{вн} Ц_{уд} S_{П} \frac{100}{A_{\%}} - \\ - Ц_{гор} P_{гор} S_{П} - З_{инф} S_{П} - Ц_{пр} - Ц_{контр}, \quad (3)$$

for separate plots:

$$П_{уч} = \sum_{i=1}^{N} (Ц_{ур} У_{iуч} S_{iуч} - D_{івнуч} Ц_{уд} S_{iуч} \frac{100}{A_{\%}} - \\ - Ц_{гор} P_{гор} S_{iуч} - З_{инф} S_{iуч}) - Ц_{пр} - Ц_{контр}, \quad (4)$$

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

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

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

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

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

$Ц_{гор}$ – the price of fuel, rub/l;

$P_{гор}$ – fuel consumption, l/ha;

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

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

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

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

$S_{п}$ – the field area, ha;

$S_{iуч}$ – the plot area, ha.

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

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

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

yield:

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

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

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

$N_{Bн}$ – 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.*

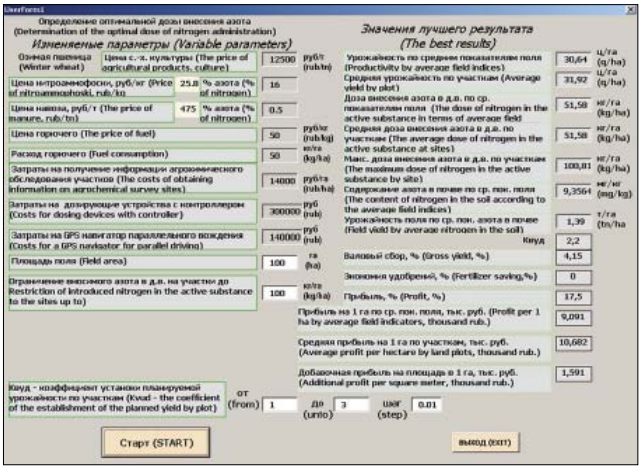

Fig. 1. Type of software interfrace

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

Таблица 1 / Table 1

Расчеты валового сбора урожая, прибыли, средней и максимальной доз внесения удобрений
Calculations of gross harvest, profit, average and maximum application of fertilizers

Способ внесения удобрений Method of applying fertilizers	Валовой сбор урожая, ц/га Gross harvest, centner/ha	Прибыль, тыс. руб. Profit, ths. rub.	Средняя доза внесения удобрений, кг/га Average application of fertilizers, kg/ha	Максимальная доза внесения удобрений, кг/га Maximum doses of fertilizer application, kg/ha
По средним показателям поля Application of fertilizers on average values of the field	24,8	7,34	11,55	11,55
Дифференцированное внесение под планируемую урожайность Differentiated application of fertilizers to the planned yields	24,08	6,92	14,14	40,38
Пропорционально-дифференцированное внесение Proportional-differentiated application of fertilizers	24,31	7,63	11,55	16,26
Дифференцированное внесение на 3 статистических интервала почвенного азота The differentiated application of fertilizers to three statistical intervals of soil nitrogen	24,31	7,63	11,55	16,26

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*.

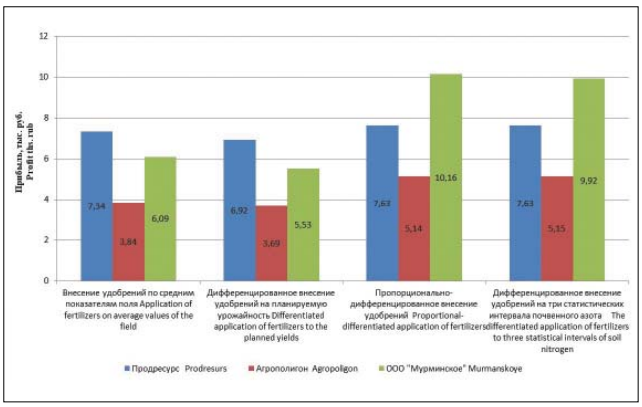

Fig. 2. Comparison of profits on three types of soils in four ways

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 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.

Таблица 2 **Table 2**

РАСЧЕТЫ ВАЛОВОГО СБОРА УРОЖАЯ, ПРИБЫЛИ, СРЕДНЕЙ И МАКСИМАЛЬНОЙ ДОЗ ВНЕСЕНИЯ УДОБРЕНИЙ
CALCULATIONS OF GROSS HARVEST, PROFIT, AVERAGE AND MAXIMUM APPLICATION OF FERTILIZERS

Способ внесения удобрений Method of applying fertilizers	Валовой сбор урожая, ц/га Gross harvest, centner/ha	Прибыль, тыс. руб. Profit, ths. rub.	Средняя доза внесения удобрений, кг/га Average application of fertilizers, kg/ha	Максимальная доза внесения удобрений, кг/га Maximum doses of fertilizer application, kg/ha
По средним показателям поля Application of fertilizers on average values of the field	23,98	3,84	23,98	23,98
Дифференцированное внесение под планируемую урожайность Differentiated application of fertilizers to the planned yields	23,98	3,69	33,42	99,90
Пропорционально-дифференцированное внесение Proportional-differentiated application of fertilizers	24,06	5,14	32,72	63,95
Дифференцированное внесение на 3 статистических интервала почвенного азота The differentiated application of fertilizers to three statistical intervals of soil nitrogen	25,04	5,15	32,50	56,78

Таблица 3 **Table 3**

РАСЧЕТЫ ВАЛОВОГО СБОРА УРОЖАЯ, ПРИБЫЛИ, СРЕДНЕЙ И МАКСИМАЛЬНОЙ ДОЗ ВНЕСЕНИЯ УДОБРЕНИЙ
CALCULATIONS OF GROSS HARVEST, PROFIT, AVERAGE AND MAXIMUM APPLICATION OF FERTILIZERS

Способ внесения удобрений Method of applying fertilizers	Валовой сбор урожая, ц/га Gross harvest, centner/ha	Прибыль, тыс. руб. Profit, ths. rub.	Средняя доза внесения удобрений, кг/га Average application of fertilizers, kg/ha	Максимальная доза внесения удобрений, кг/га Maximum doses of fertilizer application, kg/ha
По средним показателям поля Application of fertilizers on average values of the field	24,06	6,09	44,67	44,67
Дифференцированное внесение под планируемую урожайность Differentiated application of fertilizers to the planned yields	24,06	5,53	48,41	96,17
Пропорционально-дифференцированное внесение Proportional-differentiated application of fertilizers	27,60	10,16	44,67	129,24
Дифференцированное внесение на 3 статистических интервала почвенного азота The differentiated application of fertilizers to three statistical intervals of soil nitrogen	27,35	9,52	44,76	90,40

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 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.

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.

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