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Technology of differentiated application of nitrogen fertilizers according to the map of steady intra-field heterogeneity of soil fertility

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Abstract. The article presents the results of studies of precision farming technology in the experimental field of the validation landfill. It allows assessing the fertility zones and differentially affecting the identified field soil heterogeneity in order to increase the yield of winter wheat. A description of the “Agronavigator-Asur-Dozator” navigation system is given. The system allows a given dose of fertilisation depending on the working speed of the machine and its location in the field. It also provides parallel driving of agricultural machinery with different accuracy of determining the coordinates and automatic control of making granular mineral fertilizers. An original scheme of experiments on the differentiated winter wheat subcortex by the square-nesting method with an interval of 50 kg on a regular network with a step of 80 × 90 m and determination of yield with GPS reference using the specialized software of the Agronomist is given. The effectiveness of mineral fertilizers in different areas of the map of the steady intra-field heterogeneity of soil fertility of the land cover is substantiated and the economic efficiency of differential fertilizer application is calculated.

1. Introduction

The Decree of the Government of the Russian Federation of August 25, 2017 No. 996 provides for the creation and introduction of modern technologies for the cultivation of agricultural crops [1], including precision farming technologies, which will be aimed at obtaining a sustainable level of yield of agricultural crops in areas of non-uniform fertility due to the differential impact on factors limiting productivity. Differential fertilization is a method of applying fertilizers and chemicals, allowing to take into account local characteristics within each field, the main purpose of which is the effective use of fertilizers and plant protection products to increase the economic effect and reduce the environmental burden.

Equal fertilization with a heterogeneous composition of nutrients in the soil leads to their local overdose or deficiency. Consequently, fertilizers must be applied in accordance with the needs of plants, which ensures optimal efficiency of their use [2, 12].



Also, the effectiveness of differential fertilization, as it is well known, largely depends on the intra-field heterogeneity of soil fertility and land cover. Most studies on the effectiveness of differential fertilizer application, both in our country and abroad, have shown that it is not always economically justified, since the level and severity of the intra-field diversity of soil fertility are not taken into account [3, 13].

Over the past decade, precision farming has been developing intensively in our country. Most agricultural producers of the Russian Federation in the application of mineral fertilizers use different systems of parallel driving, of both foreign and Russian production. At the moment, domestic producers, together with universities and research institutes, are developing the elements of precision farming. For example, since 2009, the Northern Trans-Ural State Agricultural University (Tyumen) and the Centre of Precision Farming LLC (Novosibirsk) have been working together on the development of the “Agronavigator” navigation system with the ability to connect additional equipment, including the differentiated application of mineral fertilizers on task maps, which provides automation in the performance of field work [4, 5, 14]. Thus, the modern market gives a large selection of elements of precision farming, both in functional and financial capabilities. Thus, a fertilizer spreader manufactured by a certain company can be equipped with another company's precise positioning system, aggregating all this with practically any energy tool corresponding to the required power characteristics. All this allows the agricultural producer to independently assemble the agricultural unit of the configuration necessary to introduce elements of precision farming.

The situation is somewhat more complicated with assignment maps for the implementation of coordinate farming technologies. In fact, assignment maps do not depend on the brand and manufacturer of agricultural equipment. At the same time, a number of manufacturers of agricultural machinery for precision farming are trying to introduce artificial restrictions on the loading of maps prepared by third-party organizations. However, it is obvious that not a single machine comes with ready-made assignment maps for each specific field of agricultural producers. As a result, these farm maps are obtained from other sources, the number of which in the Russian Federation is limited [6].

In order to implement this direction on the basis of the validation testing ground of the Novokubansk branch of Rosinformagrotep (KubNIITM), since 2015, research has been carried out on elements of precision farming technologies, which reduce the laboriousness of technological operations, quickly create electronic maps of fields with exact actual boundaries and areas, carry out real-time monitoring of the state of crops, to assess fertility zones and differentially affect the identified internal heterogeneity fields [7].

2. Materials and methods

The purpose of the study is to assess the effectiveness of the differentiated application of nitrogen fertilizers using the maps of stable intra-field heterogeneity of soil fertility (IFHSF).

To achieve this purpose, the following tasks were set:

- To build a map of sustainable intra-field heterogeneity of soil fertility and land cover using the method of retrospective monitoring of soil and land cover based on remote sensing data;
- To make digital maps for the differential application of mineral fertilizers on top-dressings of winter wheat using the square-nesting method on the basis of the map of steady intra-field heterogeneity of soil fertility and land cover;
- To equip the mineral fertilizer spreader with a parallel driving system with automatic control of the flow rate of granular fertilizers to withstand the dose with changes in speed and location on the field, load the task cards and produce two additional feedings of winter wheat;
- To determine the yield by the manual method in the three fertility zones with a GPS reference using the specialized software of the Agronomist's Diary;
- To establish the effectiveness of the differentiated application of mineral fertilizers in different areas of the map of the steady intra-field heterogeneity of soil fertility and land cover and to assess the economic effect.

3. Results and discussion

In 2018, within the framework of research and development works at the KubNIITM validation testing ground, an experiment was carried out on the differential application of mineral fertilizers on winter wheat dressing in areas of inter-field heterogeneity of the soil-land cover by the Belarus 1025.2+ Bogballe M2 vehicle equipped with the Agronavigator-Assur navigation system (LLC “Precision Farming Systems”, Novosibirsk city (figures 1 and 2).

This system allows a given dose of fertilization depending on the working speed of the machine changes and its location in the field. It also provides parallel driving of agricultural equipment with different coordinates and automatic control of the process of applying granular mineral fertilizers [8].



Figure 1. Bogballe M2 Spreader equipped with “Agronavigator-Asur-Dozator” system together with Belarus 1025.2 tractor.



Figure 2. General view of the map for the differential fertilisation on the monitor of Agronavigator (in the Russian language).

3 programs are pre-installed were installed in the navigation system: spraying, differentiated application of granular fertilizers and seeding control. In our experiments, a program of differential fertilization was used, which provided control of the spreader valves using an electric linear actuator.

Maps for winter wheat top dressing in areas with low, medium and high relative levels of soil fertility were developed jointly with a specialist of the Northern Trans-Ural State Agricultural University according to the map of steady intra-field heterogeneity of soil fertility of the land cover for this field 11/1, made by Agronote LLC using the method of retrospective monitoring [9]. Maps of stable intra-field heterogeneity, obtained by the retrospective monitoring technology of soil-land cover using dozens of multi-temporal remote sensing data Landsat are the most informative maps of intra-field heterogeneity for the purposes of coordinate farming [10-11].

The first fertilizing of crops with ammonium nitrate was conducted in March 14, 2018, the second additional feeding was conducted in April 05, 2018. Both additional fertilizing processes were carried out in a differentiated quadrant-nesting method with an interval of 50 kg on a regular network with a step of 80×90 m. Weight amounted to 50, 150, 250, 350 kg.

To obtain yield results, in June 23, 2018 the manual measurement was performed with GPS reference using the “Agronomist's Diary” software. For the economic analysis, the points of measurement of the yield were superimposed on the map of the steady intra-field heterogeneity of soil fertility and land cover which are summarized in table 1.

With low doses of fertilizers of 50 kg/ha, the yield of winter wheat is almost the same for all three fertility zones of the IFHSF map and is about 50 c/h, with a spread from zone to zone from 49.6 to 52.8 c/h. With increasing doses of fertilizers, a smooth increase in yield is observed. Yield growth occurs almost linearly for the first and third zones and exponentially for the middle zone No 2.

The increase in yield per unit of fertilizer applied (responsiveness to fertilizer) according to the results of the experiments was different for each of the zones. In zone No 3, which is the zone of reduced fertility, according to the IFHSF map, the yield increase is the smallest and it reaches 62.4 centners per hectare at the maximum dose of fertilizers (table 1). In zone No 1 of high fertility, with

high doses of fertilizers, the yield is 88.4 centners per hectare. The zone of fertility normal for this field (zone No 2) gives up to 80.0 c/h. Accordingly, the yield increase at the same doses of fertilizers for the zones is: 26%, 50% and 68%, respectively.

Table 1. Yield measurements by IFHSF zones.

Zone type	Field No	Fertility zone	Fertility average, kg/h	Yield, c/h
High fertility	16	1	50	52,8
	13	1	150	69,6
	14	1	250	78,4
	15	1	350	88,4
Medium fertility	64	2	50	52,8
	49	2	150	53,6
	101	2	250	68,2
	27	2	350	80
	99	3	50	49,6
Weak fertility	100	3	150	54,4
	38	3	250	58
	102	3	350	62,4

To calculate the economic efficiency of the application of differential fertilizer on the data obtained in the experiment from 11/1 field, we modelled different strategies for the differential fertilizer application and calculated their economic efficiency. Option 1 is the use of the same amount of ammonium nitrate over the entire field with the main economic dose of 250 kg/h in two supplements. In variants 2 and 3, the differential application of different doses for the IFHSF zones according to the strategy of increasing the marginal income was modelled, when the fertilizer dose was increased in the best parts of the field and reduced in the weak ones. At the same time, the total amount of fertilizers in all variants remained unchanged. In option 2, in the weak zone, the total dose of two supplements is reduced to 150 kg/h, in the middle - economic dose - 250 kg/h, in the strong zone we move 100 kg/h of nitre from the weak zone and increase the dose to 350 kg/h of nitrate by two feedings. In option 3, in the weak zone, we reduce the dose to 50 kg and transfer 100 kg/h to medium and strong zones, increasing them to 350 kg of nitrate. Option 4 is calculated according to the strategy of levelling yields, when more fertilizer is applied to the weak zone, and reduced in the strong zone. The main requirement when modelling various options for differential fertilization is to leave the amount of fertilizer at the level consumed by the farm in the amount of 18 tons per field. For calculation, we use the cost of wheat in the amount of 1000 rubles/kg and the cost of ammonium nitrate 15 rubles/kg. In all options, other costs remain unchanged. This allows calculating the economic effect and comparing options for the cost of additional products.

4. Conclusion

Based on the experience and simulation of various applications of differential fertilization, we can draw the following conclusions:

- The use of the “Agronavigator-Asur-Dozator” navigation system allowed to improve the quality of the technological process of making granular mineral fertilizers, due to the precise keeping of the specified dose of application, regardless of the operating speed of the unit (i.e., when the unit’s moving speed increases, the dampers automatically open maintaining a given dose of introduction, and with a decrease they close, respectively) and exclude the operation of two signalmen in this operation;

- The use of the retrospective monitoring method allowed us to create a map of the stable intra-field heterogeneity of soil fertility and land cover, which in turn made it possible to assess the state of the fertility zones in the experimental field;
- The mobile application “Agronomist Diary” allowed to automate the work of an agronomist (working with electronic maps of fields; satellite monitoring of crops; keeping reference books on technological operations, seeds, fertilizers; monitoring of intra-field heterogeneity of the field);
- Technologies of differentiated application based on the in-field heterogeneity of soil fertility and land cover are the main factors of economic growth and development of an agricultural enterprise.

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