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OPTIMIZATION OF OPTIONS FOR DIFFERENTIAL APPLICATION OF NITROGEN FERTILIZERS IN THE PRECISION FARMING SYSTEM

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ABSTRACT. This paper aims to present the use of various treatments for the differential application of nitrogen in the precision farming system. To assess the state of the vegetation cover, both ground-based observations and associated remote sensing methods were used. Assessment of the state of plants (Menkovsky of AFI, 2009–2011) was carried out according to the phases of their growth and development using an N-tester in the field, as well as analysis of plant samples in a specialized laboratory. Remote sensing was carried out at the time of the analysis of plant samples using unmanned aerial vehicles equipped with cameras that allow shooting in different areas of the spectrum. The test sites with predetermined doses of nitrogen fertilizers for decrypt the obtained images were used. It is shown that for differential application of nitrogen fertilizers in spring wheat crops it is advisable to use the optical characteristics of the state of plants performed using calibration test sites. We have found that the maximum yield in the differentiated nitrogen applications treatment (TK-4) was 4510 kg per hectare (kg ha^{-1}). At the same time, the minimum in the TK-1 treatment was 3780 kg ha^{-1}. On average, over the years of research differentiated fertilizer application increased the collection of protein per hectare by 15–17%. In the TK-4 treatment for three years, a grain was obtained that corresponded to the first quality class (exceed 14%) in terms of protein content. Our novel research has shown that for characterizing the state of plants an assessment is given which was performed using calibration test sites.

Introduction

The technology for the precise application of fertilizers and other agrochemicals based on the results of assessing the state of soil and land cover is a very urgent task. Wherein, the economic and environmental problems of agricultural production are also important. We should be noted that the information concerning precision farming is rather large (Abler, 2004; Anselin *et al.*, 2004; Godwin *et al.*, 2003; McBratney *et al.*, 2005). Also by authors (Beluhova-Uzumova *et al.*, 2019) have been conducted an extensive review of the literature and gave an analysis of the economic efficiency of technique and technology regarding precision farming.

Nevertheless, there are still unresolved issues related to the underdevelopment of the general theory of control of such objects and systems, not to mention about high precision instruments, methods, machines and equipment, which are necessary for the implementtation of above-mentioned technology. At the same time is important the low efficiency of existing software and information support and of course relevant databases and knowledge, and adaptation of technologies to agro-climatic and other conditions of production (Report to EC Directorate, 2007; Report of GSC EU. 2019). Significantly limits the capabilities of precision farming technologies and techniques underutilization of associated remote sensing means with detailed ground-based observations. This is because there is no scientific backlog in this area, where a common methodology is not developed and reliable methods for obtaining and applying information about the state of crops. Besides, the test sites for decrypting the obtained images are not developed.

One of the most important technological operations in the precision farming system is the differential application of nitrogen fertilizers, which is made taking into account small-scale heterogeneity within the field (Blackmore *et al.*, 1994). The main task of our investigations is the optimal management of sowing to achieve an established crop and specific quality for this variety (Yakushev, 2016).

Material and Methods

The studies were carried out in the field conditions of the Menkovsky ($59^0$42' up to $59^0$46' N and $30^0$18' up to $30^0$20' E) of Agrophysical Research Institute (AFI) located in the Pskov soil district (Gagarina *et al.*, 1995), where the most common are sod-weakly and medium-podzolic soils. Among these soils, light and medium loamy and loamy sand on the moraine prevail.

As for remote sensing, it was done from an unmanned aerial vehicle (UAV) using two SLR cameras, which make it possible to obtain images in the visible and near-infrared ranges using the upgraded Canon EOS Rebel T1i digital camera. To obtain images in the visible range, an Olympus E-510 camera was used. Each of the digital cameras used for aerial photography of agricultural fields was connected to a UAV remote control.

In the experiments, the following experimental treatments were used:

1. Control, without fertilizing (2.33 ha)
2. High-intensity (HIO) – fertilizer application according to the maximum need of plants for the planned yield of 5 t ha^{-1} (area 2.27 ha);
3. A treatment with differentiated fertilizer application (differentiated application was made based on a preliminary agrochemical examination of the field with map assignments, the area of the plot was 2.5 ha (Yakushev *et al.*, 2010);
4. A treatment with the introduction of nitrogen feeding in the "on-line" mode using an optical device N-sensor. In this case, the sensor was calibrated using a portable N-tester instrument directly in the crop. For brevity, this methodological treatment will be called TK-1 (the average area for 2009–2011 was 3.19 hectares);
5. Treatment with the introduction of nitrogen feeding, when the N-sensor was calibrated according to the optical characteristics of the test sites (hereinafter referred to as the TK-2 treatment, the area is 3.24 ha);
6. The treatment for introducing nitrogen fertilizing according to task cards created in advance based on the classification of the aerial photographs of crops. At the same time, the classification was carried out in two ways: automatically (hereinafter – TK-3, the average area for 2009–2011 is 3.36 hectares)
7. The treatment for applying nitrogen fertilizing using test sites as standards (hereinafter – the TK-4 treatment, the area is 3.31 hectares).

The yield for treatments TK 1 – TK 4 of the grain of the spring wheat (variety of 'Ester') was assessed. Test sites for calibration were laid before sowing plants with a given dose of nitrogen fertilizers, as follows: 0, 30, 50, 70, 90, 110 kg of the active substance (a.s.) per 1 ha (Fig. 1). The area of each test site is 100x100 m.

In this case, the experimental treatments were a variety of information in agricultural technologies. The experiments were designed in such a way as to compare not only different treatments but also a variety of technologies. So, the control treatment (without fertilizing) was an extensive technology, which is used in farms with poor financial and instrumental support. The high-intensity treatment, on the contrary, was a rich, high-intensity technology that a well-financed household could afford.

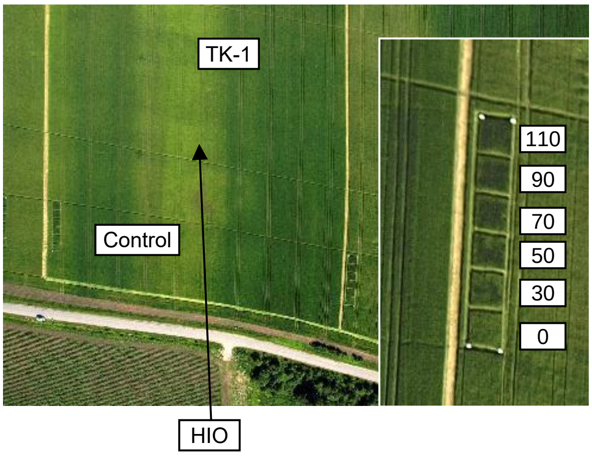

Figure 1. Test calibration sites and field with different fertilizer treatments. On the right – the test pads (100x100 m) with added doses of nitrogen: 0, 30, 50, 70, 90, 110 kg of active substance per 1 ha. On the left is a field (20.2 ha) with different doses of nitrogen fertilizers, but treatments TK-2, TK-3 and TK-4 have turned out to be outside the given image fragment

Nitrogen and potassium fertilizers were applied differentially depending on their content in the soil. In this case, fertilizers were applied in proportions N70P70K70 (in the form of nitrogen + phosphorus with N16P16K16) + N40 (in the form of ammonium nitrate) + K40 (in the form of potassium chloride).

Field experiments were carried out during the growing seasons of 2009–2011.

Statistical processing of the research results was carried out using a calculation algorithm based on data from a two-factor analysis of variance of the STAT software package (1991) of VIUA or All-Russian Research Institute of Fertilizers and Agricultural Soil Science.

Results

During the study, the climate was characterized by moderately warm summers and long winters with thaws. Spring and autumn were lingering. The average annual air temperature was +3.4 °C. The absolute maximum was +33 °C; the absolute minimum was –43 °C. The frost-free period is an average of 126 days, the largest 164 days and the smallest 101 days. The course of soil temperature repeated the course of air temperature. The maximum depth of soil freezing was observed in March (2017) and averaged 52, the largest – 112 cm, the smallest – 10 cm. The annual rainfall was 708 mm. During the warm period, 467 mm fell out, and in the cold – 241 mm. The average annual absolute humidity (***f***) or in other words the density of water vapour saturation was 7.6 g m^{3-1}, relative – 81%. In the summer ***f*** ranged from 8.0 to 14.4 g m^{3-1}, relative about 66–80%. The long-term average evaporation from land is 430 mm. The radiation balance is generally positive, but the distribution of heat throughout the year is uneven. Most of the solar heat (up to 75%) was spent on evaporation, the rest – on melting snow and ice. This is due to the position of the territory in the zone of excessive moisture.

Agro-climatic conditions for the phases of growth and development of wheat are presented in Table 1. It shows how the hydrothermal coefficient HTC changes with each year. According to our results was relatively varied annually in the phases of growth and development of spring wheat. The total amount of HTC in the 2009 year differed significantly from the results of the remaining years in comparison with other trials of field experiments.

As a result, (Table 2), it was established that in 2009 when spring wheat was cultivated using zonal technology, the productivity increased significantly in comparison with the TK-3 treatment. In 2009 and 2010, there was a tendency to increase the yield in comparison with the TK-1 treatment. Differentiated nitrogen application compared to the continuous application regardless of the year of the experiment and the methodological approach to its application significantly increased productivity by 2.0–9.4 kg ha^{-1} or by 6–26 %.

Table 1. Agroclimatic conditions of the phases for growth of the spring wheat

Year	Values of hydrothermal coefficient (HTC)					Total
	Sowing – Tillering	Tillering – Flowering	Sowing – Flowering	Flowering – Harvesting	Sowing – Harvesting	
2009	0.8	5.5	3.8	4.1	3.9	18.1
2010	1.1	4.4	3.6	0.9	2.6	12.6
2011	2.8	1.5	1.9	3.9	2.8	12.9

Among the differentiated nitrogen applications, the maximum yield in the TK-4 treatment was 4510 kg per hectare (kg ha^{-1}) regardless of the year of the experiment, and the minimum in the TK-1 treatment was 3780 kg per hectare. There were no significant differences in the grain yield between the TK-2 and TK-3 treatments. The exception is the TK-3 treatment in which in 2009 the minimum yield among the TK treatments was noted.

The yield of the grain of the spring wheat (variety of 'Esther') for treatments TK-1–TK-4 in comparison with "Control" and for treatment "HIO" was obtained in Table 2. Where is visible that the use of application fertilizers provides a significant increase in yield. During the three years, the minimum yield in the control treatment was an average of 2500 kg per hectare that is not so very much.

When the spring wheat has been cultivated in 2009 by zonal technology (HIO treatment) then the productivity of this in comparison with treatment TK-3 was significantly increased.

Table 2. The yield of grain (kg ha^{-1}) of the spring wheat (variety of 'Esther') depending on the use of different technologies in various weather conditions

Treatment	2009	2010	2011	Average (A)
Control	2840	2250	2410	2500
HIO	4690	2970	3050	3570
TK-1	4550	2950	3830	3770
TK-2	5330	2770	3750	3950
TK-3	4310	3210	4120	3880
TK-4	4780	4090	4660	4510
Average(B)	4420	3040	3640	3700
LSD 05 (AB) = 456		LSD 05 B = 698		LSD05 A = 1715

During the corresponding investigation of the influence of the technologies concerning the differentiated top-dressing application of nitrogen fertilizing it comes necessary to determine the share of the influence of random (weather conditions – influencer "Year" (A) and a fixed influencer – (technology of nitrogen application) – (B).

Statistical processing of the data showed that the influencer fertilizing (46%) made the largest contribution to the formation of spring wheat grain of 'Ester' variety. The second influencer in terms of the impact on the crop was weather conditions (40%) and the least influence on the formation of grain yield was exerted by the interaction of influencer Year (13%).

One of the important indexes of technology effectiveness is the collection of protein per unit area. Analysis of the data (Table 3) shows that irrespective of the methodological approach to their application of fertilizers is significant increases related to the collection of protein in comparison with the control treatment. An average collection protein was increased by 19–56% per hectare related over the years of research for differentiated fertilizer application compared with the high-intensity treatment. It should be especially noted that treatment TK-4 gave the largest collection of protein – 685 kg ha^{-1} (Table 4).

Table 3. The content of protein (%) in spring wheat grain depending on the use of different technologies in various weather conditions

Treatment	2009	2010	2011	Average (A)
Control	11.17	9.37	13.30	11.28
HIO	11.97	12.19	12.90	12.35
TK-1	12.37	13.23	16.10	13.90
TK-2	11.86	14.38	16.20	14.15
TK-3	11.00	14.03	15.60	13.54
TK-4	14.80	16.45	17.20	16.15
Average (B)	12.20	13.28	15.22	13.56
LSD05 (AB) = 0.80		LSD05 B = 0.46		LSD05 A = 0.33

Based on the above results we can conclude that the greatest variability (17%) of protein depending on year was in treatment TK-3 and *vice versa*, the smallest – in treatment HIO (4%), second in baseness is the treatment TK-4 (8%). The variation in the remaining treatments is also relatively high (14–15%), while it is noteworthy that the control treatment had a coefficient of variation 17%.

Data obtained from Tables 2 and 3 takes into account the content of protein in the grain yield, the visualization of the experimental results are presented in Fig. 2.

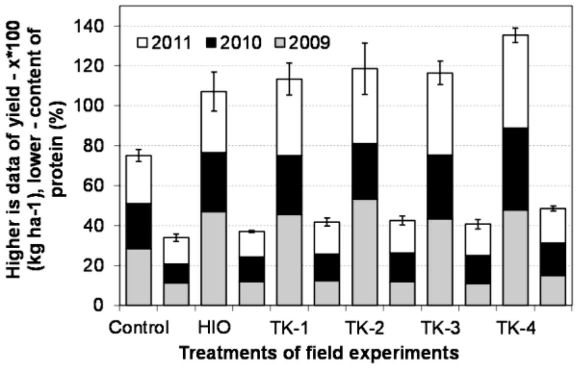

Figure 2. Content of protein in the grain yield of spring wheat (± standard deviation)

It is noteworthy that the experimental variations in their final indexes are arranged as a row in increasing order, while the results of protein (low bars in Fig. 2) correlate quite well in the same figure with the results of yields (high bars) of the crop. As noted above the total yield here of the TK-4 treatment was the largest. It also is worthy of the fact that the standard deviation of the data during the harvest of treatment TK-2 was the largest. After it, the HIO treatment is in second place, although according to the protein data of the standard deviation was the smallest with it. It seems that current analysis makes possible to get a very clear idea for comparing different varieties by year among themselves.

Discussion

All this gives the expected results if we have the appropriate sensors, corresponding software for mapping and the possibility of accurate compliance agricultural technology. It should be noted that in our case these conditions were fully met. This is warranting by the fact (Yakushev *et al.*, 2010) that treatment with differentiated fertilizer application (differentiated application) was made based on a preliminary agrochemical examination of the field with map assignments. It is also impossible to ignore the fact that precision farming represents a real opportunity for future research (Blackmore, 2003; Elipbeki, 2018).

In this case, we should pay attention to various strategies for applying nitrogen fertilizer. Commonly known strategies for applying nitrogen fertilizer a two are used:

- technology (off-line);
- technology (on-line);
- technology (off-line) has a two-stage:
  a) the use of complex nitrogen balance models or the use of dynamic nitrogen and soil models for calculating the doses of nitrogen (0, 30, 50, 70, 90, 110 kg of the active substance (a.s.) per 1 ha), compiling task maps and differential application of nitrogen (Yakushev, 2016; Ferguson *et al.*, 2011; Lekomtsev *et al.*, 2011).
  b) compilation of yield maps based on yield maps and other auxiliary means and differential application of nitrogen using injection technology or in the form of stabilized fertilizer (Larscheid *et al.*, 1997; Yakushev, 2016; Wagner *et al.*, 2007).
- Technology (on-line) usually has a two-stage:
  a) use of sensor systems, for example, Uaga N-sensor, CROP meter, *etc*., with which they evaluate the status of crops in real-time, determine the require doses of nitrogen in real-time and apply them (Feiffer *et al.*, 2007, Yakushev *et al.*, 2010);
  b) use of sensors in a real-time system with the addition of data on digital thematic maps of factors, for example, on soil properties, taking into account the goals of protecting the environment and nature, yield goals (Adamchuk, 2011; Novitski, 2017).

At the same time, we have found that the test sites have been used already (Bure *et al.*, 2017) in which noted that "a small region of the field where the qualitative indices of plants are already known", while "the main principle is that the existence of a linear relationship between the colour of plants and the dose of nitrogen must be analysed based on various qualitative factors". These studies have also found a wider application (Basso *et al.*, 2009; Shpaara *et al.*, 2009; Bure, Mitrofanova, 2016) where is to assess the level of ecological "data measured *in situ*, as well as an aerial photographic image of the object". Also, it should be noted that precision farming is a dynamically developing system of agricultural production (Shannon *et al.*, 2017). The theory and practice of its application in Russia are presented in the work of the author (Yakushev, 2016). State and prospects for the development of precision farming are reflected also in the works (Bongiovanni *et al.*, 2004; Truflyak *et al.*, 2018). The digitalization of agriculture is presented in recent works by authors (Kiryushin *et al.*, 2018).

Concerning the size of the field, some authors (Anselin *et al.*, 2004; Meyer-Aurich *et al.*, 2010) have had such opinion that economic gross advantage of site-specific management of nitrogen fertilizer depends on the type of sensor used and size of the field.

Weather analysis (Table 1) of the results related hydrothermal coefficient (HTC) is also useful where if summarize the results obtained over the years. It is clear that HTS directly affects the data of yield. We have found that between HTS and yield (Y) of spring wheat has the linear relationship (Y = 2,061HTC + 7,047) with a coefficient of representatives R^2 = 0.85.

According to the information in the literature (Lekomtsev *et al.*, 2011; Diacono *et al.*, 2013; Abler, 2004; Shannon *et al.*, 2017), concerning the spring wheat, our opinion is that the choice of this cereal culture was infallible. Firstly, for the above-mentioned region of Russia, the advantage of spring wheat cultivation is that planted in the early spring, grows quickly and is normally harvested in late summer or early autumn. Secondly, the simultaneous improvement of grain yield and corresponding grain protein percentage

(Löffler *et al.*, 1982). As already seen, this is well confirmed according to the above Fig. 2. Taking as a basis of a report of the National Institute of Food and Agriculture (USA) it is possible to approve with confidence that when protein content exceeds 14% then it means that increased the value of crop automatically (Ranson, 2018). According to above Table 3 mostly the protein content of the grain was exceed 14% in treatments TK-4 and TK-3, also TK-2 (excluding for them both in the year of 2009). It is still noteworthy that with TK-1 treatment in 2011 only the protein content in the grain corresponded to the expected result. It is important to note that the high-intensity treatment (HIO) of fertilizer application (Table 3) did not give us in a testing year of the field experiments the proper level of protein content in the grain. Since this question, remains insoluble then implies the logical deduction for the continuation of field experiments.

Conclusions

The results of our investigations have shown that characteristics of the state of plants. Assessment by using the calibration test plots was carried out.

Differentiated application of nitrogen fertilizers regardless of the year of the experiment and the methodological approach, significantly increased yield compared to a continuous application by 6–26%. Among the differentiated application treatments, the maximum yield was in the TK-4 treatment (4510 kg ha^{-1}). In this case, the method of applying nitrogen fertilizing using test sites as standards were used. No significant differences in the grain yield between the other treatments of precision farming were found.

Regardless of the methodological approach, with the differentiated application of nitrogen fertilizers, grain with protein content is higher than when using zonal technology by 10–24%.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

DM, AK, EN, PL – study conception and design
DM, AK, PL – acquisition of data
DM, AK, EN, PL – analysis and interpretation of data
AK, EN – drafting of the manuscript
DM, AK, EN, PL – critical revision and approved the final manuscript

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