Maintaining soil fertility by optimizing the use of nitrogen fertilizers in precision farming system

Peter Lekomtsev[1,*], and A*ndrey* Komarov[2]

[1]RSHU Sciences, 195027 St. Petersburg, Russia
[2]ARI Sciences, 195220 St. Petersburg, Russia

Abstract. The article presents data of research on conservation and improvement of soil fertility using precision farming technologies. The study was carried out under conditions of humid climate (North-West of Russia, Leningrad region). Technologies for differentiated application of nitrogen fertilizers were tested in the fields of the Agrophysical Research Institute. In comparison with high-intensity agricultural technologies, differentiated fertilizer application was used, which was carried out with the help of a solid mineral fertilizer spreader with an on-board computer and GPS Amazon ZA-M 1500. Precision farming technologies had slightly more complex modifications. They were characterized by the introduction of increasingly informative methods of differentiated use of nitrogen fertilizers, which reduced fertilizer doses. New instruments, equipment and technologies were used, including the use of an N-sensor optical instrument, aerial photographic maps and calibration test sites with predefined nitrogen doses.

1 Introduction

Wheat cultivation in many parts of the world is still dominated by extensive agriculture. It exists through the exploitation of natural soil fertility, depleting its reserves. The use of such technology ensures low crop yields. Insufficient use of fertilizers, other chemical inputs and modern agricultural technologies also leads to reduced yields and lower quality of production. For example, the average yield of cereals in Russia is about 2 t/ha-1, and in Kazakhstan only 1 t/ha-1 [1]. Water and wind erosion and other negative effects on soil fertility are a consequence of low crop production.

With the development of industrialization, extensive agriculture has been replaced by high-intensity technologies (HIT), where fertilizers and other means of chemicalization are fully used, technology, promising varieties and other resources [2]. Thus, in developed countries, due to the use of modern technologies, wheat yields reach 6-8 t/ha-1. However, the use of high-intensity technologies, while increasing the yield of cultivated crops, addresses economic issues but has serious environmental problems [3]. These problems are related to environmental pollution through the unsustainable use of fertilizers and other means of chemicalization. Precision farming technologies are designed to ensure the rational

* Corresponding author: pv6575@mail.ru

economic use of fertilizers, reduce environmental pressures and ensure the maintenance of soil fertility [4].

In these technologies, nitrogen is a key nutrient for high wheat yields. Nitrogen plays a crucial role in the formation of humus substances [4-5]. Soil nitrogen accumulation is a characteristic indicator of soil formation, and total nitrogen reserves determine soil fertility [5]. Calculations based on the agrochemical properties of soils and the level of planned yield allow predicting the efficiency of the use of nitrogen fertilizers and evaluating their economic efficiency.

The main problem with nitrogen management is that plants consume not only nitrogen from fertilizers, but also nitrogen from humus in soil. At the same time, the unsustainable use of soil nitrogen is reducing humus stocks and soil fertility [5-6].

The actual consumption of soil nitrogen by plants may be higher than the nitrogen of fertilizers, incl. and due to the so-called «extra» nitrogen, the appearance of which is caused by the application of fertilizers [7]. Therefore, it is advisable to characterize the state of nitrogen nutrition of plants by an indicator that gives an aggregate estimate of consumption of both nitrogen fertilizer and «extra» soil nitrogen. This indicator is referred to as the nitrogen absorption coefficient. NC characterizes the efficiency of plant consumption of mineral nitrogen reserves formed from fertilizer and «extra» nitrogen. In order to preserve the fertility of the soil, it is necessary to replenish the removal of food by the crop, which is carried out by fertilizers.

2 Research methodology

All the research in 2009-2011 was carried out in field rotations. The soil at the test sites is a dernovo-sub-ash super-solite with a weak acid reaction of 4.9-5.4 pH and a high phosphorus content of 575-724 mg/kg and potassium 280-336 mg/kg with a good humus reserve of 3.6-4.8%. The total nitrogen content of the soil varied from 0.19% to 0.40%, describing high soil fertility [8].

Agroclimatic conditions varied throughout the research seasons. In 2009 the Selivanov hydrothermal coefficient (HC) [9] was 3.9 during the sowing season, in 2010 - 2.6, and in 2011 - 2.8. At the same time, in 2009 plants suffered from lack of moisture during the planting season, in 2010 during sowing and flowering (during grain ripening) and in 2011 during flowering. Thus, during all the years of experimentation, the emerging weather conditions of the spring-summer growing period did not contribute to high spring wheat yields.

Each year, the test fields were divided into areas corresponding to the options studied. The width of the plots is a multiple of the width of the fertilizer and harvesting equipment and was 18 m. The length of the variant varied from year to year within the field length of 400-800 m. The experience options were separated by a protective band of 2 m [8].

The following levels of intensification (options) were considered:

1. «Control» - extensive technology (ET) - fertilizers were not introduced.
2. «High intensity technology» (HIT) - N110 P70 K110 (fertilizers were used in parts - N70 P70 K70 (as azophone) + N40 (ammonium nitrate) + K40 (as potassium chloride). Pesticide treatment: herbicide «Lintour»; 2-fold treatment with the fungicide «Sokol»; insecticide «Karate-Zenon».
3. «Precision farming technology» (PFT), using fertilizers and other inputs, is similar to high-intensity farming. However, nitrogen (ammonium nitrate) and potassium (potassium chloride) fertilizers were applied in a differentiated manner, taking into account the heterogeneous content of nitrogen and potassium in the soil, using precise application methods (reference).

The use of mineral fertilizers was as follows: Option 2 (high intensity technology) fertilizers were evenly distributed throughout the field.

Option 3 (precision farming technology) differentiates fertilizers according to soil nutrient content (baseline data). The fertilizer was introduced using a solid fertilizer spreader with on-board computer and GPS, Amazon ZA-M 1500 [8].

The remaining options were based on improved precision farming technologies that were applied through increasingly informative and differentiated nitrogen applications. These methods are based on an evaluation of the optical properties of the wheat biomass. Two of them were made online using the optical device N-sensor (link). In the first case, the sensor was calibrated using a portable N-tester (PFT-1).

In the second variant, the N-sensor was calibrated according to the optical characteristics of the test sites (version PFT-2). Experience (background) shows that the use of test sites with known amounts of nitrogen fertilizer in soil greatly simplifies the calibration process and improves the accuracy of Hydro-The N-sensor also eliminates the timeconsumption phase and expensive biochemical determination of chlorophyll and nitrogen concentrations in the laboratory [8].

A distinctive feature of the other two methods developed was the inclusion of nitrogen input data in the target maps, which were previously based on the classification of aerial photographs of crops (reference). The classification was carried out in two ways: automatically (hereinafter - version PFT-3) and using test grounds as reference (version PFT-4). The research was conducted using two varieties of wheat: «Ester» and «Krasnoufimskaya-100».

The area of the test sites of 25 m2, the doses of nitrogen introduced into their soil were: 0, 30, 60, 90, 120, 150, 180, 210 kg dw/ ha-1 (fig.1).

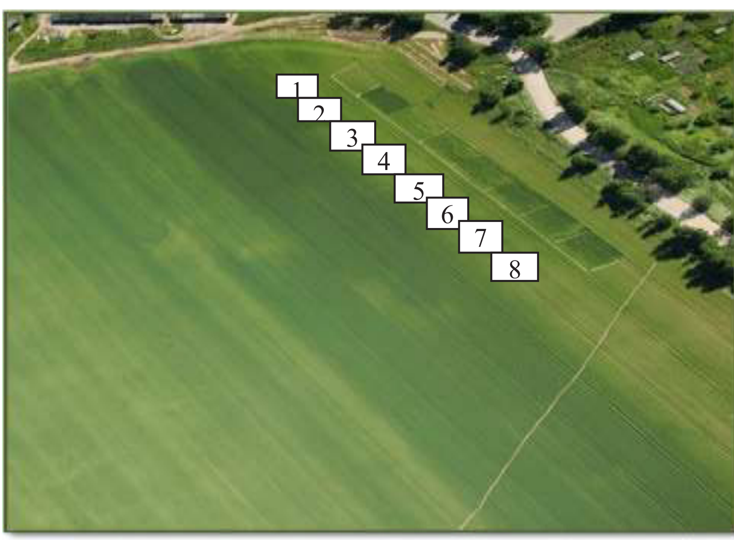

Fig. 1. Wheat field. Krasnoufimskaya with test sites. The test sites with 0, 210, 30, 60, 90, 120, 150, 180 kg/ha of mineral nitrogen applied to the soil are indicated by numbers (1-8).

The insertion of test sites and the calibration of the optical characteristics of plants on them provide a more correct interpretation of space and aerial photographs and their use directly in the management of the production process of crops.

3 Research results

On the basis of the studies conducted during 3 years it was found that with the intensification of technology spring wheat grain yield increases significantly (Fig.2). The highest grain yield of both studied varieties was noted in the variant of high-intensive technology with the introduction of fertilizers during the growing season on the task cards created on the basis of interpretation of aerial photographs. The variety Krasnoufimskaya-100 in all variants of the studied technologies in the years of research was formed significantly higher grain yield (by 6.4-27.1%).

Compared to the conventional high-intensive technology differential fertilization increased the grain yield of spring wheat varieties Esther by 5,6...26,3%, Krasnoufimskaya-100 - by 8,2...38,7%. A stronger response to the methods of differentiated fertilization was manifested in comparison with the most common variant of precision farming technology in the Esther variety by 3.1...25.7% and the Krasnoufimskaya-100 variety by 13.4-30.5%.

The most important aspect of rational farming is the preservation of soil fertility, which reflects the quality and amount of nitrogen accumulated in the humus (link). The magnitude of additional soil nitrogen use by plants depends on a number of factors, including soil type and degree of soil fertility (fertility), and it averages 0.24 units per 1 unit of fertilizer nitrogen applied [7].

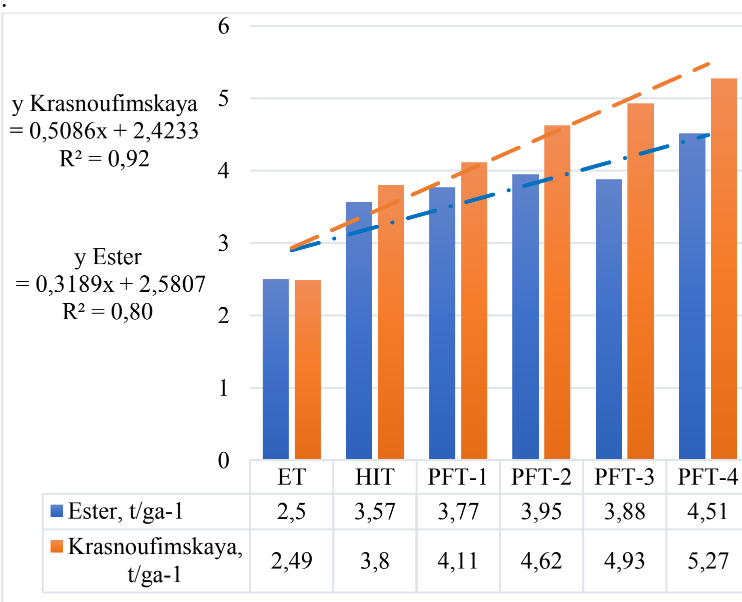

Fig. 2. Intensification of precision farming technologies on different wheat varieties.

Differential fertilizer application on average for the years of research increased the coefficient of nitrogen uptake relative to the conventional high-intensity technology with uniform fertilizer application in spring wheat variety Ester from 44.1% to 2.7 times, in spring wheat variety Krasnoufimskaya-100 from 12.5% to 2 times.

Table 1. Nitrogen uptake coefficient (NC), Ester variety,%.

Variant/year	2009	2010	2011	Average data
High-intensity technology (HIT)	50	12,6	17	26,5
Precision farming technology, PFT-1	54,9	17	56,1	42,7
PFT-2	73,7	55,2	46,4	58,4
PFT-3	44,2	20,9	49,5	38,2
PFT-4	65,2	74,1	76,9	72,1
Average data	57,6	35,96	49,18	47,58

On average over the years of research, in both varieties studied, the highest rate of nitrogen uptake was noted in the variant of differential fertilization according to the task maps created on the basis of decoding of aerial photographs by the optical characteristics of the test sites (72.1% and 75.7% of the variety Ester and Krasnoufimskaya-100 respectively), the minimum - in the variant of wheat cultivation by conventional high-intensive technology with uniform fertilization (26.5 and 37.7% respectively).

The better the plants use the nitrogen from the fertilizer and the more actively the absorbed amount is assimilated, the higher is its agrochemical efficiency or the payback of the fertilizer nitrogen by the increase in yield of the main product (YMP) [6]

Table 2. Nitrogen uptake coefficient (NC), Krasnoufimskaya-100 variety, %

Variant/year	2009	2010	Average data
High-intensity technology (HIT)	45,9	29,4	37,7
Precision farming technology, PFT-1	52,1	32,7	42,4
PFT-2	73,0	59,7	66,4
PFT-3	75,8	55,8	65,8
PFT-4	86,3	65,1	75,7
Average data	66,6	48,5	57,6

The payback of 1 kg of fertilizer nutrients to the yield increase depends on the doses, timing of their application and the type of crop. Differential fertilization increases the payback of 1 kg of nitrogen fertilizer with an increase in grain yield in both varieties studied (from 27,7% to 2,1 times in the variety Ester and from 43,5% to 2,5 times in the variety Krasnoufimsky-100).

The presented data are consistent with earlier studies [1-9]. It has been shown that the effective use of fertilizer nitrogen plays an important role in preserving soil fertility, obtaining environmentally safe products and protecting the environment. At the same time, the better the plants use nitrogen fertilizer and soil and more actively absorb it, the higher agronomic efficiency of fertilizer application and lower environmental stress on agrolandscapes

4 Conclusions

Differential fertilizer application increased NC on average over the years of research from 44.1% to 2.7 times in comparison with the zonal technology. On average over the years of research the maximum coefficient of nitrogen uptake was observed in the PFT-4 variant.

Optimization of the use of nitrogen fertilizers in the precision farming system contributed to the preservation of soil nitrogen reserves and the maintenance of soil fertility.

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