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Adaptive technologies for intensification of winter wheat grain production in biologized crop rotation

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Abstract. The studies were conducted at the experimental base of the Tatar Scientific Research Institute of Agriculture in 1996–2014 to adapt fertilizer systems and basic tillage to achieve yields of 3–5 t/ha. The article cited data on winter wheat – the second crop of the third rotation of the eight-field grain-grass-crop rotation for 2013–2014. We studied the effect of organomineral, organic, mineral fertilizer systems on the winter wheat yield using a differentiated approach to their use in combination with different primary tillage systems (dump plowing to the depth of the arable layer, multi-depth loosening and loosening to a depth of 15–16). The organomineral fertilizer system differed with the saturation with organic fertilizers of 7 t/ha of arable land per year + N36P32K60 according to the balance sheet for receiving 4 t/ha of grain with spring fertilizing using ammonium nitrate, where the yield was 4. 03 t/ha, and the saving on mineral fertilizers, depending on crop rotation and soil saturation with organic matter, was 25–35 %. The yield of winter wheat by the water-saving technology amounted to 4.03 t/ha with a planned level of 4.0 t/ha. At the same time, at the purchase price of 7 rubles/kg, the level of profitability rose to 195.85 %, the cost of 1 center of grain amounted to 236.6 rubles.

1 Introduction

Saving production costs has always been one of the most pressing problems in all countries [1–3]. At many farms, farming requires a lot of money. There is a need to develop and improve everything in terms of resource conservation, agricultural production technologies; the saving should concern not only fuels and lubricants, chemical fertilizers and fertilizers, but also the soil, since soil is the main source of production [4, 5].

In Russia, many experiments have been conducted to improve the techniques of crop cultivation technologies [6–8]. The integrated application of the main factors of agriculture (crop rotation, fertilizer systems, tillage, plant protection, plastic varieties) was not taken into account. The basic components of adaptive technologies, such as the parameters of effective biologized fertilizer systems [9, 10], plant protection products, tillage using modern domestic technology, as well as low-cost techniques for reproducing soil fertility and increasing arable land productivity, are insufficiently developed. The effects of the prolonged use in the rotation of various fertilizer systems on soil properties are poorly understood.

Comprehensive research on the development of adaptive moisture-saving technologies for grain production, providing increased arable land productivity and reproduction of soil fertility is relevant.

The main goal is development and implementation of resource-saving technologies for the cultivation of major crops, including winter wheat, with the maximum use of biological factors for intensifying agriculture, ensuring reproduction of soil fertility, obtaining stably planned crops with high quality products, and saving of mineral fertilizers by 30–35 %, fuel and lubricants by 20–25 %, grain cost reduction by 30–35 %.

In order to achieve this goal, the following tasks were set:

- to evaluate the complex influence of the main factors of increasing the efficiency of agriculture (crop rotation, adaptive biologized fertilizer systems, plant protection, gentle soil treatment, plastic varieties) on the reproduction of soil fertility, productivity and product quality of crops cultivated in the rotation, in particular winter wheat;
- to evaluate the economic efficiency of adaptive technologies for the intensification of grain production on the example of winter wheat.

2 Conditions, materials and research methods

Before stationary experiments, a profile of soil sections was described. Soil samples were taken over genetic horizons. In these samples, the humus content was determined according to Tyurin in the Ponomareva and Plotnikova’s modofication; the amount of absorbed bases was determined according to Kappen-Gelkovich’s method; Kappen hydrolytic acidity: gross nitrogen content was determined according to Kjeldahl’s method,

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phosphorus – according to Ginzburg's method, potassium – according to the estimate; pH in salt extract, the content of hydrolyzable nitrogen – according to Kornfield's method; potentiometric nitrate nitrogen (GOST 26951-86), ammonia nitrogen – according to the TsINAO GOST 26489-85 method, mobile forms of phosphorus and potassium – according to Kirsanov's method; total carbon content and fractional composition of humus – according to the Tyurin's method modified by Ponomareva and Plotnikova; soil density – according to N.A. Kachinsky's method in layers of 0–10, 10–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–90 and 90–100 cm.

The soil is gray forest, with a granulometric composition of heavy loam. The analyzes carried out before the experiment showed that the content of heavy metals in the soil fluctuates below the maximum permissible concentrations (MPC). The pH in the arable and subsurface layers before the studies was 4.9 and 5.0, respectively, hydrolytic acidity – 7.28 and 5.48 mEq/100 g of soil, humus content of 3.0–3.5 %, alkaline hydrolyzed nitrogen 100–122.5 mg/kg, P_2O_5 – 290–295 mg/kg, K_2O – 80–100 mg/kg, the amount of absorbed bases – 20–21 mEq/100 g of soil.

The technological features of grain was determined in the laboratory of grain technology in mixed samples. The protein content was determined according to GOST 10846–91, the quantity and quality of gluten – according to GOST 13586.1–68.

The determination of the biological activity of the soil by carbon dioxide emission was carried out according to the method by E. N. Mishustin, I. S. Vostrov, and A. N. Petrova (1987).

Stationary experiments were conducted (1996) in a grain-grass-crop rotation in two tabs with crop rotation: 1) steam (sideral); 2) winter wheat; 3) spring wheat with sowing alfalfa; 4–6) alfalfa; 7) spring wheat; 8) oats. The research continued during 2.5 rotations until 2015.

The following main soil cultivation methods were studied: dump plowing; loosening without turnover of the layer by 15–16 cm; multi-depth processing. The fertilizer systems were as follows: organic, organomineral, mineral. The mineral fertilizer system includes the application of mineral fertilizers according to the settlement-balance method for receiving 3, 4, 5 tons of grain per 1 ha. Siderates, manure and straw of the previous crop at the rate of 7 t/ha of arable land per year were used as organic fertilizers. The arrangement of options is randomized.

Experience outline

Option 1 – Control – no fertilizers

Option 2 – Background I – Mineral system – N0P0K48 applied to receive 3 t/ha of grain

Option 3 – Background I + ammonium nitrate for top dressing in spring

Option 4 – Background II – Mineral system – N55P45K85 applied for 4 t/ha of grain

Option 5 – Background II + ammonium nitrate for top dressing in spring

Option 6 – Background III – Mineral system - N116P102K115 applied to produce 5 t/ha of grain

Option 7 – Background III + ammonium nitrate for top dressing in spring

Option 8 – Background IV – Organic system with soil saturation with organic fertilizers 7 t/ha of arable land per year

Option 9 – Background IV + ammonium nitrate for top dressing in spring

Option 10 – Background V – Organic-mineral system with soil saturation with organic fertilizers of 7 t/ha of arable land per year + N0P0K25 applied for 3 t/ha of grain

Option 11 – Background V + ammonium nitrate applied in spring

Option 12 – Background VI – Organic-mineral system with soil saturation with organic fertilizers of 7 t/ha of arable land per year + N36P32K60 applied for 4 t/ha of grain

Option 13 – Background VI option + ammonium nitrate for top dressing in spring

Option 14 – Background VII – Organomineral system with soil saturation with organic fertilizers of 7 t/ha of arable land per year + N98P89K95 applied for 5 t/ha of grain

Option 15 – Background VII + ammonium nitrate for top dressing in spring

3 Results and discussion

In 2013, the air and soil drought, during the period when winter wheat eared, led to an excessive consumption of productive moisture and a sharp decrease in its reserves. So, the content of productive moisture in the soil layer ranged from 41.63–56.08 mm, depending on the tillage, which is estimated by the indicators of assessing moisture reserves as insufficient. The advantage of moldless loosening was observed.

During autumn tillering (October 15), the soil moisture in the meter layer was optimal 157–304 mm, in the phase of spring tillering (May 15) – good (159.3–163.7 mm), in the phase of shooting (June 10) – insufficient (41.6–56.1 mm), in the phase of full ripeness (July 29) – sufficient (79.4–81.3 mm). Heavy rainfall provided plants with productive moisture on all backgrounds of soil cultivation. Frequent rainfall smoothed out the difference in moisture accumulation between soil cultivation methods.

With an uneven distribution of moisture by months, in 2014, the dry summer (June, July) revealed a sharp differentiation in the content of productive moisture depending on the soil treatment systems and fertilizers. In the phase of autumn tillering (October 18), the soil moisture in the meter layer was optimal 168–309 mm, in the phase of spring tillering (May 13) – good (135–155 mm), and in the phase of shooting (June 10) – insufficient (35–41 mm), in the phase of full ripeness (July 29) – sufficient (20.07–35.99 mm).

Loosening to a depth of 15–16 cm (309 mm, versus 168 mm with dump plowing) was the most advantageous. The same pattern and moisture conservation was observed during the growing season (41.45 mm, versus 35 mm when plowing).

Our research has established that the type and norms of fertilizer application, soil cultivation and agro-climatic conditions affect the content of nutrients in the soil. The determination of the content of hydrolyzable nitrogen in the soil in the 0–20 cm layer showed that, due to the low soil temperature and passivity of microorganisms in the tillering phase of winter wheat, the mineral system had some advantage over the organomineral fertilizer system. It should be noted that the Nr content was higher compared to other cultivation backgrounds, which indicates an increase in humus mineralization during classical tillage, compared with soil-saving tillage.

A decrease in alkaline hydrolyzable nitrogen was observed due to increased growth of the aboveground biomass of winter wheat. The lowest rates were observed in variants with a mineral fertilizer system, since due to the lack of organic fertilizers, there was no possibility of replenishing nutrient reserves due to their decomposition. On the contrary, with the organomineral fertilizer system, an increase in the activity of soil microflora caused an increase in the reserves of hydrolyzable nitrogen.

The content of mobile phosphorus was very high, fluctuating within 250–310 mg/kg of soil. By the earing phase, a slight decrease was observed. For variants with an organomineral fertilizer system, the content of P_2O_5 was slightly higher compared to the mineral system. As the biological activity of the soil intensifies (June, July), the content of assimilable phosphorus increases and decreases markedly during the intensive consumption by plants.

The application of fertilizers had a positive effect on the potash regime of the soil. In the tillering phase, the content of metabolic potassium ranged from 65–145 mg/kg depending on the background of nutrition, which is characterized as an average indicator. Against the backdrop of subsurface soil cultivation methods, winter wheat plants were better provided with this element compared to dump plowing.

Table 1. Density of the arable layer after harvesting with various primary tillage systems

Depth of sampling, cm	Different depth of tillage without reservoir rotation	Loosening without turn of a layer on 15–16 cm	Plow plowing to the depth of the arable layer
control			
0–10	1.41	1.37	1.28
10–20	1.40	1.41	1.30
20–30	1.47	1.45	1.37
0–30	1.43	1.41	1.32
organic mineral fertilizer system			
0–10	1.24	1.24	1.19
10–20	1.34	1.33	1.25
20–30	1.34	1.38	1.33
0–30	1.31	1.32	1.26

Soil and fertilizer cultivation systems are the most important factors for changing such agrophysical parameters as density. It is known that the upper limit of the optimum density of the arable layer is 1.3 g/cm^3 [11]. In our experiments, the most optimal composition of the arable layer was created with the organomineral system of fertilizers (Table 1).

Applying organic fertilizers at the rate of 7 t/ha of arable land per year compared to the control option, a multi-depth processing system (alternating deep loosening with loosening by 15–16 cm without formation rotation, depending on the biology of the crop) contributed to a decrease in the density of the arable layer (0–30 cm) by 0.12 g/cm^3, annual loosening to a depth of 15–16 cm by 0.09 g/cm^3, plowing by 0.06 g/cm^3. Hence it is obvious that the applied organic fertilizers in the form of straw, manure and green manure play a large role in the improvement of the physical properties of the soil.

All soil microorganisms are the source of carbon dioxide formation, releasing it during breathing. Determination of carbon dioxide released by soil is the main biochemical method for determining the biological activity of soil. The more intensive is the release of carbon dioxide from the soil, the more active are biological processes in it, the better are the conditions for cultivating crops and the higher is their potential productivity [12].

Our studies show that the emission of carbon dioxide against the background of the organomineral fertilizer system, in both methods of primary tillage, is more intense (234.3-246.6 mg/m^2 per hour) than in the control without fertilizers (211.1-199.4 mg/m^2 per hour).

At the same time, loosening without soil overturning at a depth of 15-16 cm has an advantage. In other words, with systematic loosening without soil overturning, the biological activity of the soil improves compared to systematic mouldboard plowing. Top-dressing against the background of basic fertilizers increases the biological activity of the soil by 5-7%.

Table 2. Productivity of winter wheat with various methods of tillage and fertilizer systems, t/ha

Fertilizer systems	Loose cultivation without turnover	Plowing	Loosening without turn of a layer on 15–16 cm
1 option	3.08	2.80	3.05
2 option	3.31	3.13	3.23
3 option	3.38	3.26	3.29
4 option	3.78	3.42	3.63
5 option	4.03	3.60	3.76
6 option	3.94	4.19	4.18
7 option	4.40	4.38	4.46
8 option	3.23	3.14	3.28
9 option	4.22	3.34	3.39
10 option	3.43	3.53	3.55
11 option	3.64	3.70	3.65
12 option	3.64	3.62	3.75
13 option	3.96	3.69	4.03
14 option	4.21	4.32	4.45
15 option	4.48	4.40	4.57

Despite the arid climatic conditions of the vegetation period of 2013–2014, yield indicators reached the planned level and exceeded it (Table 2). The largest yield was obtained when using OMSU in the amount of 5 t/ha of grain against the background of landless tillage – 4.45 t/ha (91.4 % of the plan). For dump plowing, the yield was 4.32 t/ha. When using the mineral fertilizer system to obtain 5 t/ha of grain, the yield was 4.18 and 4.19 t/ha, respectively.

Application of ammonium nitrate positively affected the productivity of winter wheat. So, using OMSU for 4 t/ha of grain, 3.96 t/ha was harvested. Using the mineral system (LSG), 4.03 t/ha of grain was obtained. It should be noted that to obtain a similar yield with LSG, the total amount of NPK fertilizers applied amounted to 128 kg/ha, while for LSGs – 185 kg/ha. With the use of the organomineral system, fertilizer savings amounted to 30.9 %.

Non-subsurface cultivation methods were not inferior to the classic heap plowing, and in most cases they were better. First of all, this is due to the moisture-saving effect of subsurface cultivations, due to which optimal conditions are achieved for the growth and development of cultivated crop plants.

Table 3. Qualitative indicators of winter wheat grain with various fertilizer systems and soil cultivation methods

Fertilizer systems	Plowing		Loosening without soil overturning	
	Protein in dry basis, %	Raw gluten, %	Protein in dry basis, %	Raw gluten, %
1st option	11.7	20.40	15.7	29.04
5th option	17.4	34.32	17.9	34.60
9th option	11.7	20.10	14.1	27.02
13th option	17.65	35.84	18.33	36.84

Fertilizing increased the protein and gluten content in the grain (table 3). So, against the background of mouldboard plowing in the variant with the introduction of mineral fertilizers with the calculated norm N55P45K85 for producing 4 t/ha of grain and fertilizing with ammonium nitrate in the spring, compared to the control without fertilizers, the protein content increased by 5.7%, gluten by almost 14% with the indicator of the GDM device (gluten deformation meter) – 98 (II group of quality).

Against the background of loosening without soil overturning, these indicators slightly exceeded the results of mouldboard plowing. The protein content increased by 2.2%, gluten – by almost 5.56%, with a GDM device indicator of 102 (II quality group). Such indicators of protein and gluten are characteristic for grain of class I according to the requirements of GOST.

Against the background of the organomineral system, when organic fertilizers are applied at 7 t/ha of arable land per year + N36P32K60 introduced to produce 4 t/ha of grain + spring soil dressing with ammonium nitrate on both backgrounds of the main tillage (plowing and loosening) in comparison with the control without fertilizers, the protein content increased by 5.95 and 2.63%, gluten by 15.44 and 7.8%, respectively. The indicator of the GDM device was 95 and 97 (quality group II).

Against the background of an organic system with an organic saturation of 7 t/ha of arable land in combination with ammonium nitrate top-dressing, grain quality is low: protein content varies from 11.7 to 14.1%, gluten – from 20.10 to 27.02%, depending on the experimental option.

Calculations of the economic efficiency of winter wheat cultivation technologies showed that the most profitable was the extensive grain production technology (without fertilizers and plant protection products) – 132.1 %, with a prime cost of 1 center of products equal to 301.6 rubles. This fact proves the advantage of a biologically balanced, fruit-bearing crop rotation. The introduction and observance of a grain-grass-crop rotation with two fields of clover or three fields of alfalfa without fertilizing allowed us to obtain 2.69 t/ha of grain.

Resource-saving technologies (the use of a differentiated multi-depth non-subsurface soil cultivation system, an organic-mineral fertilizer system taking into account the nutrient content, integrated plant protection methods taking into account EPV) can significantly reduce direct costs and increase production profitability. According to this technology, with a yield of 4.23 t/ha of grain, the profitability was 124.2 %, while using intensive technologies, this indicator was 63.9 %. The cost of production amounted to 312.2 and 427.2 rubles per cent, for saving and intensive technologies, respectively.

4 Conclusion

The studies conducted in 2013–2014 showed that when growing winter wheat in the eight-field grain and grass-rotary crop rotation, an organomineral fertilizer system with an organic fertilizer saturation of 7 t/ha of arable land per year + N36P32K60 was more profitable. According to the balance sheet for 4 t/ha of grain with spring fertilizing using ammonium nitrate, where the yield as a result of loosening by 15-16 cm amounted to 4.03 t/ha. In the mineral system with the addition of N55P45K85 per 4 t/ha of grain, a crop was collected with dump plowing – 3.42 t/ha, with loosening by 15–16 cm – 3.63 t/ha, against the background of different depth loosening – 3.78 t/ha. In the organic fertilizer system with the introduction of organic fertilizers of 7 t/ha of arable land per year, the productivity is relatively low, which amounts to 3.14 t/ha against the background of plowing, when loosening without turnover of the bed and loosening loosening – 3.28 and 3.23 t/ha respectively.

With the use of the organic-mineral fertilizer system, the protein content in the grain increases by 5.95 and 2.63%, and gluten by 15.44 and 7.8%, depending on the main tillage; 25-35% savings on mineral fertilizers are achieved depending on crop rotation and soil saturation with organic matter.

The yield of winter wheat by the water-saving technology amounted to 4.03 t/ha with a planned yield of

4.0 t/ha. At the same time, at the purchase price of 7 rubles/kg, the level of profitability increased to 195.85 %, the cost of 1 center of grain amounted to 236.6 rubles.

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