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Efficacy of Offline Differential Fertilization by Ammonia Nitrate for Summer Wheat Growing

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Abstract — **Differential offline mineral fertilization of elementary field sectors is one of primary economical and ecological aspects of precision farming. Application of this technologies allows significantly reducing expenses for ammonia nitrate, i.e. fertilization depends on anticipated crop capacity and demand for summer wheat and ensures optimal content of soil nitrogen. It was proven that differential fertilization by ammonia nitrate simultaneously with sowing for anticipated crop capacity of 3.0 t/ha with spatially variable content of nitrate nitrogen of 25% in the soil layer of 0–40 cm, its low and moderate availability (8.1-17.9 mg/kg of soil) reduces the amount of fertilizer by 21.1–50.5% and reduces production expenses by 3.4-4.1% vs. traditional fertilization method with averaged amount along the field.**

Keywords — differential offline fertilization, ammonia nitrate, summer wheat, leached chernozem, profitability. Introduction.

I. INTRODUCTION

The Government of the Russian Federation has stated a challenging task for the agricultural sector: food security.

Accumulated experience became a reliable means for controlling and forecasting soil fertility and driver of advanced approaches to management of production processes ensuring increased efficacy and preservation of ecological sustainability of agroecosystems. The results were used to develop fertilizing systems for specific soil and climate conditions of Western Siberia and other regions of Russia, which is hard for agrarians in real practice due to existing diversity of fields [1, 9, 14, 16]. The climatic conditions of Western Siberia promoted the breeding of new resistant varieties of crops and denizen animals [1,2,3,4].

The nonuniformity of nutrients is distinctive for different soils. In sod-podzolic soils the coefficient of mineral nitrogen content variation amounted to 32–69%; in leached chernozem it amounted to 24–52%; in typical chernozem it is 22–59%. The content of labile phosphorus in sod-podzolic soils lies within 22–99%, labile potassium content is 12–64%; in chernozems the figures are 20–25% and 8–12%, respectively. Intra-field nonuniformity of mineral nitrogen content in soil had appreciable impact on crop capacity and quality of winter wheat. For typical chernozem, the coefficient of correlation between the nitrate nitrogen and protein content in grains is 0.83 [11, 12, 13].

Implementation of computers in farming industry enabled application of information technologies (IT) and mathematical simulation to account for a plethora of factors [5, 6]. Detailed investigation of soil formation in Siberia and development of simulation software have predestined further progress of precision farming in our region.

Producers of agricultural commodities actively use precision farming technologies [10, 17]. Precision farming allows reducing amount of additional materials for markers, maximizing machine width, minimizing overlaps and gaps from pass to pass, increasing productivity of agricultural machines and reducing load on machine operators. All the above reduce expenses and environmental impact and increase crop capacity as well [8].

One of the issues solved by precision farming is online and offline differential fertilization. As a rule, this technology is based on the nonuniformity of vegetation mass of crops (online) or soil variability on elementary sectors (offline) [19, 21].

Agrochemical study of fields is made using georeferencing by satellite navigation systems. Initially, the field is divided into elementary sectors and sampling is done by automatic samplers. The obtained data is used to compose cartograms of the content of main nutrition elements with due consideration of fertilizer doses and task mapping with consequent export to the field computer; the amount of fertilizer is adjusted automatically depending on the location and velocity of the machine in the field [18, 20].

Application of ammonia nitrate in a precision farming system should be economically viable and environmentally friendly; the choice of fertilization is conditioned by organizational and economical conditions of the enterprise focusing on maximum economic return and profitability of farming.

II. MATERIALS AND METHODS

The period of study was characterized by various weather conditions that are typical for Western Siberia. The least propitious year was 2015: average precipitation over the summer wheat vegetation period (93 days) was 296.4 mm; more propitious was year 2017 when the air temperature during vegetation (107 days) was lower than average multiyear values, total precipitation amounted to 281.5 mm, the hydrothermal index was 1.6-2.0, which indicated excessive humidification, while the sum of effective temperatures satisfied the summer wheat demand for heat.

The soil of experimental production field was leached chernozem. Humus content in ploughed layer (0–30 cm) varied from 7.65 up to 9.05%. Total nitrogen content in the ploughed layer was 0.43-0.44%; in the deeper layer of 30–50 cm, the content of that was 0.18-0.21%, which indicates sharp differentiation of the profile in terms of this indicator. The ploughed layer demonstrated high sum of exchange bases of 31.4–34.0 with hydrolytic acidity of 3.5-3.8 mg eq/100 grams of soil. The bulk density of the ploughed layer of leached chernozem was 1.07-1.25 g/cm^3.. The volume of pores corresponding to the total water capacity in a one-meter-thick layer varied from 42 to 57%. The range of active water (lowest moisture–discontinuous capillary moisture) in layer 0–30 cm was only 35–40 mm.

Scientific and production test was carried out on two fields with one type of soil. This was conditioned by the fact that the study was performed for crop rotation deployed in time and space on the fields of scientific-experimental farm of the Northern Trans-Ural State Agricultural University. The experiment was conducted in a typical for northern forest steppe crop rotation link: corn – wheat – wheat.

The area of field #63 was 46.6 ha (experiment area was 37.5 ha), for #63 it was 57.8 (experiment area was 45.0 ha), while the area of elementary sectors varied from 2.5 to 3.0 ha.

TABLE I. ASSIGNED NUMBERS OF ELEMENTARY SECTORS TO VARIANTS

Field #63	Field #67
Variant 1 7, 10, 11;	Variant 1 2, 7, 12;
Variant 2 5, 12, 14;	Variant 2 3, 8, 13;
Variant 3 4, 6, 13;	Variant 3 5, 10, 15;
Variant 4 15, 9, 8;	Variant 4 4, 9, 14;
Variant 5 1, 2, 3.	Variant 5 1, 6, 11.

The estimation of differential mineral fertilization using navigation system was performed for 5 variants divided into elementary sectors (Fig. 1).

Variant 1 – Control (no mineral fertilizers);

Variant 2 – Mineral fertilization for anticipated crop capacity of summer wheat of 3.0 t/ha taking into account the average nitrogen content on the field "farm dose" (traditional fertilization method);

Variant 3 – Differential mineral fertilization for anticipated crop capacity of summer wheat of 3.0 t/ha taking into account the nutrition elements content on elementary sectors;

Variant 4 – Differential mineral fertilization for anticipated crop capacity of summer wheat of 4.0 t/ha taking into account the nutrition elements content on elementary sectors;

Variant 5 – Differential mineral fertilization for anticipated crop capacity of summer wheat of 4.0 t/ha taking into account the nutrition elements content on elementary sectors with additional fertilizing at tillering phase of summer wheat.

Fig. 1. Experimental production fields divided into elementary sectors

Agrochemical properties of soils were determined using standard methods of agrochemical service of Russia: reaction of the soil medium was determined by salt extract (GOST 26483-85), content of labile phosphorus and potassium in leached and typical chernozem was determined by Chirikov's method (GOST 26204-91), nitrate nitrogen content was determined by ionometric method (GOST 26951-86), soil moisture was determined by thermostatic gravimetric method (GOST 28268-89), the doses of mineral fertilizers were calculated by elementary balance method; obtained data was mathematically processed by the method of B.A. Dospekhov (1965) using MS Excel spreadsheet and Snedecor software.

Agricultural machinery in experiment. The main soil treatment was carried out in autumn after harvesting previous crops by PN-8-35 + K-744 plougher to the depth of 22–27 cm. In spring after physical mellowness of soil early-spring tandem disk harrowing was performed by T-150+SP-11+22BZSS-1.0 machine. Summer wheat was sowed on 15-20 of May, the optimal period for forest steppe zone, to the depth of 5-6 cm by John Deere 730 sowing system in combination with New Holland tractor with seeding rate of 6.2M fertile summer wheat seeds of Nobosibirskaya 31 breed. The harvesting was done by direct combining at firm ripe stage with hay chopping.

III. RESULTS

According to agrochemical study on elementary field sectors using satellite navigation systems, there is high variability of nitrate nitrogen content for all the variants (Tables 1 and 2).

In 2015, the diversity of nitrate nitrogen content among the variants was average (87.8%) and large (64%), while in 2017, the control sector contained 92.1%, and after traditional fertilization by ammonia nitrate 95.7%, i.e. insignificant. However, variants with differential offline fertilization by ammonia nitrate had variation coefficient altering from 26.7 up to 137.1%, which testifies the nonuniformity of nitrogen nutrition of summer wheat caused by soil and anthropogenic conditions.

TABLE II. NITRATE NITROGEN CONTENT IN SOIL LAYER OF 0-40 CM BEFORE SUMMER WHEAT SOWING AND FERTILIZATION IN ELEMENTARY FIELD SECTORS (FIELD #67, 2015)

Mineral fertilization method	Elementary sector number	Content of $N-NO_3$ mg/kg of soil	V [%]	Dosage [kg/ha of physical mass]
Control (no fertilizers)	2	8.4	**36.0**	0.0
	7	6.7		0.0
	12	13.2		0.0
	Average	**9.4**		**0.0**
Traditional fertilization	3	7.9	**20.6**	93.0
	8	11.9		93.0
	13	9.8		93.0
	Average	**9.8**		**93.0**
Differential for anticipated crop capacity of 3.0 t/ha	5	12.6	**24.7**	61.0
	10	11.4		76.0
	15	17.9		0.0
	Average	**13.9**		**46.0**
Differential for anticipated crop capacity of 4.0 t/ha	4	9.0	**12.2**	245.0
	9	11.1		222.0
	14	11.3		219.0
	Average	**10.5**		**229.0**
Differential for anticipated crop capacity of 4.0 t/ha + additional fertilizing	1	12.4	**16.2**	252.0
	6	14.2		192.0
	11	17.1		231.0
	Average	**14.5**		**225.0**
HCP_{05}		3.0	-	-

Based on the scale of demand of grain crops for nitrogen fertilizers, depending on $N-NO_3$ content in soil layer 0–40 cm, in spring before sowing on control sector the supply of soil nitrogen to plants in 2017 was very low, 7.1-8.3 mg/kg of soil, in 2015 it was average, 8.4-13.2 mg/kg; no fertilizing. Such supply level allows achieving the crop capacity of summer wheat over two years 2.92 t/ha on average, which testifies high potential fertility and high agricultural expertise in production tests.

Traditional nitrogen fertilization method is distribution of average dose of nitrogen fertilizers along the field (variant) on the basis of $N-NO_3$ content in elementary field sectors. In 2015, the amount of ammonia nitrate was 93.0 kg/ha in physical mass, supply of soil nitrogen was low, 9.8 mg/kg of soil; variability coefficient was 20.6% and increased by 4% by the tillering and stem elongation phase.

Early-spring soil study in 2017 has demonstrated negligible diversity of the marker, 95.7%; the supply of soil nitrogen was low, 9.3 mg/kg of soil; introduction of 109.0 kg/ha of ammonia nitrate increased nitrate nitrogen content in the soil up to 19.6 mg/kg of soil at tillering and stem elongation phase of summer wheat and 8 times increased variability.

Additional fertilization by ammonia nitrate without consideration of soil variability lead to increase by 0.56 t/ha at HCP_{05} – 0.35 t/ha in relation to the control variant of 2015; in 2017, it amounted to 0.31 t/ha at HCP_{05} – 0.35 t/ha.

The content of $N-NO_3$ in the soil layer of 0–40 cm varied from 11.4 to 17.9 mg/kg of soil in 2015 and from 8.1 to 15.5 mg/kg of soil in 2017; the marker diversity was 68.8–75.3%. Differential fertilization by ammonia nitrate for anticipated crop capacity of 3.0 t/ha of summer wheat reduced the introduced amount by 21.1–50.5% with end crop capacity of 3.14–3.80 t/ha. This consequently balances nitrogen-based nutrition regime along elementary field sectors. The surplus to the crop capacity was 0.11-0.13 t/ha in relation to traditional method of ammonia nitrate introduction and 0.42–0.69 t/ha for control variant.

In 2015, there were no substantial discrepancies between variants with differential nitrogen fertilization for anticipated crop capacity of 4.0 t/ha and introduction of additional fertilizers. For instance, the content variability of nitrate nitrogen in soil was 12.2–16.2%, the marker diversity was moderate, the nitrate nitrogen content varied along the sectors from 9.0 to 17.1 mg/kg of soil. The supply was moderate, the rate was 192.0–245.0 kg/ha of ammonia nitrate. However, increased dose has reduced the crop capacity by 16.0–18.8% as compared to anticipated crop capacity of summer wheat and amounted to 3.25 and 3.36 t/ha, correspondingly.

The differential nitrogen fertilization for anticipated crop capacity of 4.0 t/ha lead to a surplus of 0.80 t/ha as compared to control variant, and 0.24 t/ha the traditional fertilization method. Long-term introduction of additional fertilizer had no appreciable surplus from the previous variant, 0.11 t/ha.

Under the conditions of 2017, on the sector with differential fertilization by ammonia nitrate for anticipated crop capacity of 4.0 t/ha the nitrate nitrogen content in the soil was highly contrasting. For instance, the sector #15 contained 109.0 mg/kg of soil, while elementary sector #8 contained 6.2 mg/kg of soil, the variability of soil nitrogen along the variants amounted to 137.1%; ammonia nitrate amount was varied from 0.0 to 247 kg/ha. Such fertilization lead to crop capacity of 3.95 t/ha; the surplus vs. control variant was 0.57 t/ha and 0.26 t/ha in the case of increased amount by 36.7%.

The offline differential additional fertilization for anticipated crop capacity of summer wheat of 4.0 t/ha yielded 4.45 t/ha after fertilization by 217.0-313.0 kg/ha of ammonia nitrate; the surplus after additional fertilization was 0.50 t/ha.

The analysis of economic viability of differential fertilization allows both assessing the income of its implementation and setting the ways of improvement of certain relevant agronomic techniques.

The digitizing of field boundaries is one of the first stages of precision farming. This operation is necessary for determining the precise boundaries and composing electronic map with geographic coordinates. The cost of digitizing depends on the total area of the farm; the specific expenses amounted to 20 RUB/ha; the determination of nutrition elements in one mixed sample costs from 600 to 1000 RUB.

TABLE III. NITRATE NITROGEN CONTENT IN SOIL LAYER OF 0-40 CM BEFORE SUMMER WHEAT SOWING AND FERTILIZATION IN ELEMENTARY FIELD SECTORS (FIELD #63, 2017)

Mineral fertilization method	Elementary sector number	Content of N-NO_3 mg/kg of soil	V [%]	Dosage [kg/ha of physical mass]
Control (no fertilizers)	7	7.9	**7.9**	0.0
	10	8.3		0.0
	11	7.1		0.0
	Average	**7.8**		**0.0**
Traditional fertilization	5	9.8	**4.3**	109.0
	12	9.1		109.0
	14	9.1		109.0
	Average	**9.3**		**109.0**
Differential for anticipated crop capacity of 3.0 t/ha	4	8.1	**31.2**	120.0
	6	12.0		85.0
	13	15.5		53.0
	Average	**11.9**		**86.0**
Differential for anticipated crop capacity of 4.0 t/ha	15	109.0	**137.1**	0.0
	9	11.5		200.0
	8	6.2		247.0
	Average	**42.2**		**149.0**
Differential for anticipated crop capacity of 4.0 t/ha + additional fertilizing	1	14.5	**26.7**	223.0
	2	17.4		217.0
	3	10.0		313.0
	Average	**14.0**		**251.0**
HCP 05		47.3	-	-

TABLE IV. CROP CAPACITY OF SUMMER WHEAT FOR DIFFERENT METHODS AND AMOUNTS OF AMMONIA NITRATE INTRODUCTION, T/HA

Mineral fertilization method	Crop capacity [t/ha]		
	2015	2017	Average
Control (no fertilizers)	2.45	3.38	2.92
Traditional fertilization	3.01	369	3.35
Differential for anticipated crop capacity of 3.0 t/ha	3.14	3.80	3.47
Differential for anticipated crop capacity of 4.0 t/ha	3.25	3.95	3.60
Differential for anticipated crop capacity of 4.0 t/ha + additional fertilizing	3.36	4.45	3.91
HCP 05	0.30	0.35	0.33

In our study, the area of elementary sectors varied from 2.5 to 3.0 ha, which is connected with the configuration of the fields and identification of soil diversity in terms of fertility.

The digitizing of field boundaries and overlay of the grid with elementary sectors is performed once and used for differential mineral fertilization. These expenses cannot be related to additional charges of offline differential mineral fertilization for grain sowing.

On-board navigation system becomes essential element for farming, from early-spring harrowing to harvesting. Linear electric actuator for differential mineral fertilization should be regarded as additional expenses. Considering its cost of 50K RUB and operation life in combination with John Deere 730 sowing combine up to 10 years (with depreciation of 10%) additional charges amount to 2.38 RUB/ha.

The economic efficiency was calculated for costs of 2015. The expenses for field boundary digitizing and agrochemical soil survey amount to 80 RUB/ha; in addition, one should purchase Agronavigator on-board navigation system and linear electric actuator with total cost of 190K RUB.

High level of agricultural machinery and promising fertility of the control variant allow yielding without mineral fertilizers up to 3.0 t/ha on average with production expenses of 14,880 RUB/ha. The profitability is 67.2%.

TABLE V. ECONOMIC EFFICIENCY OF SUMMER WHEAT GROWING DEPENDING ON THE METHOD OF AMMONIA NITRATE INTRODUCTION

Mineral fertilization method	Production expenses [RUB/ha]			Profitability [%]		
	2015	2017	**Average**	2015	2017	**Average**
Reference (no fertilizer)	15197.0	14562.9	**14880.0**	37.0	97.3	**67.2**
Traditional fertilization	16796.3	16450.9	**16623.6**	52.3	90.7	**71.5**
Differential for anticipated crop capacity of 3.0 t/ha	16113.7	15888.9	**16001.3**	65.6	103.3	**84.5**
Differential for anticipated crop capacity of 4.0 t/ha	18958.4	17050.9	**18004.7**	45.7	96.9	**71.3**
Differential for anticipated crop capacity of 4.0 t/ha + additional fertilizing	18279.3	18488.1	**18383.7**	56.2	104.6	**80.4**

*farm-gate price of summer wheat [RUB/t] 8500

The periods of study (2015 and 2017) were typical in terms of weather conditions; the soil on the two field differed vastly in regard to variability of nitrate nitrogen content in soil layer of 0–40 cm.

The reduction of ammonia nitrate amount by 21.1–50.5% introduced by offline differential method for anticipated crop capacity of 3.0 t/ha lead to reduced production expenses by 562.0-682.6 RUB/ha and achievement of the highest profitability of grain production in 2015 (65.6%0) and in 2017 (103.3%); on average, the profitability over 2 years amounted to 84.5%. With increase of anticipated crop capacity up to 4.0 t/ha with offline differential fertilization by ammonia nitrate the production expenses rose by 17.7 % in 2015 and by 7.3 in 2017. Over the two years, the profitability remained the same as compared to traditional fertilization, 71.1-71.5% with increase to the fertilization amount by 36.6-146.2%.

Maximum profitability was achieved in 2017 with additional offline differential fertilization for anticipated crop capacity of 4.0 t/ha (104.6%) and maximum crop capacity of 4.45 t/ha; the grain production profitability is the same as for differential fertilization for anticipated crop capacity of 3.0 t/ha with production expenses of 18488.1 and 15888.9 RUB/ha, respectively.

IV. Conclusions

The study has proven the economic viability of offline differential fertilization by ammonia nitrate of elementary sectors for anticipated crop capacity of summer wheat of 3.0 t/ha with spatial variability of $N\text{-}NO_3$ content of more than 25.0% in soil layer of 0-40 cm, its low and moderate availability (8.1-17.9 mg/kg of soil) during sowing. The differential fertilization by ammonia nitrate for anticipated crop capacity of summer wheat of 3.0 t/ha reduces the fertilizer amount by 21.1–50.5%; production expenses are reduced by 3.4–4.1% as compared to traditional fertilization (average dose along the field). The differential fertilization by ammonia nitrate for anticipated crop capacity of 4.0 t/ha increases the fertilizer amount from 40 to 136 kg/ha with negligible increase of crop capacity of 0.24–0.26 t/ha versus traditional fertilization. Additional offline differential fertilization for anticipated crop capacity of 4.0 t/ha provides no saving of mineral fertilizers with increased crop capacity.

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