The results of the differential mineral fertilization in the automatic mode according to the task map

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Abstract. Off-line differential fertilization is one of the science-intensive technological processes in the precision farming system. The process ensures the change of the norm during the movement of the device in the field in the automatic mode according to the task map compiled on the personal computer for the elementary parts of the field. In the conditions of Western Siberia, studies have been conducted to identify the effectiveness of a differentiated method of applying nitrogen fertilizers for the planned yield of spring wheat of 3.0 t/ha. Off-line implementation of the technological process allows reducing the rate of fertilizers by 7.7-21.1%, production costs by 1.9-3.4% compared to the traditional method. It is shown that the application of top-dressing in off-line mode increases production costs by 10.2%, the rate of ammonium nitrate - 34.4-68.5% relative to the differential application of 4.0 t/ha to the planned yield of spring wheat.

1. Introduction
The creation of highly productive varieties of spring wheat, a balanced system of fertilizers, scientifically based tillage, a full range of plant protection products in the conditions of Western Siberia allows to obtain stable yields of spring wheat and export grain crops [1].

Comprehensive monitoring of fields with the use of satellite navigation systems in different regions shows the heterogeneity of the maintenance of batteries in elementary areas of the field, which reduces the quality and quantity of agricultural products [4, 5, 6, 10].

Precise farming allows automating the process of grain production reducing production costs and consumption of mineral fertilizers, fuel and lubricants, not influencing the level of yield [3, 9, 11].

In the system of precision farming, the differentiated application of mineral fertilizers in off-line mode is one of the science-intensive technological processes [12]. This is a change in the rate of mineral fertilization during the movement of the device in the field, in automatic mode, according to the task map compiled on a personal computer for elementary parts of the field [7].

The availability of space systems, highly productive computers, and a wide range of software being introduced into agriculture allowed automation of many technological processes [2, 8, 13].

2. Research methods and conditions
The study period was characterized by a variety of weather conditions typical for Western Siberia. In 2017-2018 the sum of active temperatures (> 10 °C) is 1610.0–1964.9 °C; this period lasted 103 days. The amount of precipitation for the growing season in 2017 is 281.5 mm, in 2018 - 247.8 mm, the
hydrothermal coefficient (HTC) was 1.5–1.6, which indicates sufficient moisture, which was favourable for the cultivation of crops.

The soil of the experimental production field is leached chernozem. The content of humus in the topsoil (0-30 cm) varies from 7.65 to 9.05%. The gross nitrogen content in the ploughed layer is 0.43–0.44%, in the layer of 30–50 cm — 0.18–0.21%, which indicates a sharp differentiation of the profile according to this indicator. The high amount of exchange bases in the topsoil is 31.4-34.0 and the hydrolytic acidity is 3.5-3.8 mg-eq / 100 g of soil. The density of the arable layer of leached chernozem is 1.07-1.25 g / cm³.

The technology of off-line differentiated mineral fertilization when sowing crops implies a number of sequential operations. They include the digitization of the field borders with the creation of an electronic map of the fields, a breakdown into elementary areas with further export to “Agronavigator +” on-board navigation complex (hereinafter referred to as OBNC); conducting annual monitoring of fields by an automated sampler designed by the State Agricultural University (SAU) of the Northern Zauralye; creating a task map with the rates of mineral fertilization for each elementary area of the field with reference to geographic coordinates, with subsequent export to “Agronavigator +” OBNC; establishment of a linear electric actuator into the tractor “Agronavigator +” OBNC and the sowing reducer of the sowing complex with further calibration of the equipment.

The research and production experiment was conducted on two fields with one type of soil. This is due to the fact that the studies were carried out in a crop rotation, which is deployed in time and space on the fields of the training and experimental farm of SAU of the Northern Zauralye. The experiment was carried out in the typical for the northern forest-steppe crop rotation: corn - wheat - wheat. The area of the field No. 76 is 36.1 hectares (area of experience is 22.5 hectares), No. 67 is 57.8 hectares (area of experience is 45.0 hectares), and the area of elementary plots varied from 1.5 to 3.0 hectares. Evaluation of the effectiveness of the differentiated application of mineral fertilizers using the navigation system was carried out on 5 variants, which were divided into elementary areas. The scheme of the experiment is presented in the tables.

The agrochemical properties of the soils were determined by standard methods used in the agro-chemical service of Russia: the reaction of the soil environment in salt extract (GOST 26483-85), the content of mobile forms of phosphorus and potassium in leached chernozem and typical - according to the method of Chirikov (GOST 26204-91); the content of nitrate nitrogen by the ionometric method (GOST 26951-86); calculation of doses of mineral fertilizers was performed by the method of elementary balance; Mathematical processing of the data was performed according to B.A. Dospekhov (1965), as well as by using Excel and Snedecor computer programmes.

Agricultural machinery in the experiment. The main tillage was carried out in the autumn after harvesting the previous crop by PN-8-35 + K-744 plough to a depth of 22-27 cm. In spring, when physical maturity of the soil occurred, early spring harrowing was carried out in two tracks by the T-150 + SP-11 + 22BZSS-1,0 device. Spring wheat was planted in the optimum for the forest-steppe zone in the period of May 15-20 to a depth of 5-6 cm using the John Deere 730 sowing complex in a unit with a New Holland tractor with a seeding rate of 6.2 million viable seeds of spring wheat of the Novosibirsk 31 sort. Crop feeding was carried out in the tillering stage of spring wheat on the basis of tissue diagnostics. Ammonium nitrate was differentially introduced in off-line mode with a mounted mineral fertilizer spreader “Amazone-500” by YuMZ-6 tractor using satellite navigation systems. Harvesting was carried out by direct combining into the phase of full ripeness with chopping straw.

3. Results and discussions
Based on the results of an agrochemical survey of fields for elementary areas using satellite navigation systems (GPS, GLONASS), doses for local application of nitrogenous fertilizers (ammonium nitrate) were calculated taking into account the test pattern and the heterogeneity of nitrate nitrogen content in the soil layer 0-40 cm (table 1, 2).

A.E. Kochergin developed a scale of the needs of grain crops for nitrogen fertilizers, depending on its content in the soil layer of 0-40 cm before sowing for the regions of Western Siberia. Early spring
soil testing (10 days before sowing) on monitoring N-NO₃ showed that availability was very low in 2018: 4.7 mg / kg, soil evenness - 76.7%, and in 2017 it was low: 7.8 mg / kg soil, with characteristic evenness of 92.1% fertilizers were not applied. Agro-climatic conditions allow getting the yield of spring wheat without the use of nitrogen fertilizers 3.38-3.43 t / ha.

**Table 1.** The content of nitrate nitrogen in the soil layer of 0-40 cm before sowing spring wheat and the dose of application for elementary plots of the field (field No. 63, 2017).

| Fertilizing method | Elementary field | Content of N-NO₃ mg / kg in soil | V, % | Dose, kg / ha physical mass |
|--------------------|------------------|----------------------------------|------|----------------------------|
| Control (without fertilizing) | 7 | 7.9 | 7.9 | 0.0 |
| | 10 | 8.3 | 0.0 |
| | 11 | 7.1 | 0.0 |
| | Medium | 7.8 | 4.3 | 109.0 |
| Traditional fertilizing | 5 | 9.8 | 109.0 |
| | 12 | 9.1 | 109.0 |
| | 14 | 9.1 | 109.0 |
| | Medium | 9.3 | 109.0 |
| Differential fertilizing for the planned harvesting of 3.0 t/ha | 4 | 8.1 | 31.2 | 120.0 |
| | 6 | 12.0 | 85.0 |
| | 13 | 15.5 | 53.0 |
| | Medium | 11.9 | 86.0 |
| Differential fertilizing for the planned harvesting of 4.0 t/ha | 15 | 109.0 | 137.1 | 0.0 |
| | 9 | 11.5 | 200.0 |
| | 8 | 6.2 | 247.0 |
| | Medium | 42.2 | 149.0 |
| Differential fertilizing for the planned harvesting of 4.0 t/ha + “Feeding” | 1 | 14.5 | 26.7 | 223.0 |
| | 2 | 17.4 | 217.0 |
| | 3 | 10.0 | 313.0 |
| | Medium | 14.0 | 251.0 |
| HCP₀₅ | 47.3 | - | - |

Mineral fertilizing without taking into account the content of nutrients in the soil, and without the use of navigation equipment is considered traditional technology. For 2 years, the coefficient of variation on the studied variant did not exceed 10.0% (4.3 in 2017; 8.8 in 2018), therefore, the diversity of the feature is insignificant, and the uniformity is significant. The average yield of spring wheat in two fields is 4.06 t / ha, an increase relative to the control variant is 0.65 t / ha. Unequal spring-autumn weather conditions contributed to uneven accumulation of nitrate nitrogen in the soil layer 0-40, so in 2017 the N-NO₃ content was 9.3 mg / kg of soil; the rate of ammonium nitrate - 109.0 kg / ha in physical mass, in 2018 - 4.1 mg / kg of soil; the norm of 155.0 kg / ha. The decrease in N-NO₃ in the soil layer of 0-40 cm in 2018 increased the application rate of ammonium nitrate by 46.0 kg / ha relative to 2017. This increase in the norm contributed to an increase in yield by 0.73 t / ha with NSR₀₅ - 0.35.

Differential use of nitrogen fertilizers for the planned yield of 3.0 t/ha reduces the rate of application of ammonium nitrate by 7.7-21.1% relative to the traditional method, since fertilizers are applied based on the planned yield with regard to the content of nitrate nitrogen in the soil and the use of satellite navigation systems. The N-NO₃ content in the soil layer of 0–40 cm in 2017 varies from 8.1 to 15.5 mg / kg of soil, the variation coefficient is 31.2%, the evenness is low — 68.8% yield — 3.80 t / ha, which is higher than the traditional method by 0.11 t / ha with HCP₀₅ - 0.35, and the planned yield by 26.7%, in 2018 the N-NO₃ content is from 4.4 to 6.3 mg / kg of soil. The sign's diversity is significant 17.9% (evenness 82.1); yield is 4.69 t / ha, which is higher than the traditional method by 0.27 t / ha with NSR₀₅ - 0.35, and the planned yield by 56.3%. An average increase over 2 years was obtained from the
control and traditional options of 0.84 and 0.19 t/ha, respectively, and an increase in the planned yield by 41.6%.

Table 2. The content of nitrate nitrogen in the soil layer of 0-40 cm before sowing spring wheat and the dose of making the elementary areas of the field (field N 76, 2018).

| Fertilizing method                          | Elementary field N | Content of N-NO3 mg/kg in soil | V, % | Dose, kg/ha physical mass |
|--------------------------------------------|--------------------|--------------------------------|------|--------------------------|
| Control (without fertilizing)              |                    |                                |      |                          |
|                                            | 7                  | 4.0                            | 23.3 | 0.0                      |
|                                            | 5                  | 6.0                            |      | 0.0                      |
|                                            | 14                 | 4.2                            |      | 0.0                      |
|                                            | Medium             | 4.7                            |      | 0.0                      |
| Traditional fertilizing                    |                    |                                |      |                          |
|                                            | 11                 | 4.4                            | 8.8  | 155.0                    |
|                                            | 2                  | 4.2                            |      | 155.0                    |
|                                            | 15                 | 3.7                            |      | 155.0                    |
|                                            | Medium             | 4.1                            |      | 155.0                    |
| Differential fertilizing for the planned harvesting of 3.0 t/ha | 3                  | 4.4                            | 17.9 | 153.0                    |
|                                            | 13                 | 6.3                            |      | 136.0                    |
|                                            | 12                 | 5.8                            |      | 140.0                    |
|                                            | Medium             | 5.5                            |      | 143.0                    |
| Differential fertilizing for the planned harvesting of 4.0 t/ha | 4                  | 5.4                            | 0.0  | 254.0                    |
|                                            | 6                  | 5.4                            |      | 254.0                    |
|                                            | 10                 | 5.4                            |      | 254.0                    |
|                                            | Medium             | 5.4                            |      | 254.0                    |
| Differential fertilizing for the planned harvesting of 4.0 t/ha + “Feeding” | 1                  | 5.4                            | 41.9 | 354.0                    |
|                                            | 8                  | 3.8                            |      | 368.0                    |
|                                            | 9                  | 8.7                            |      | 325.0                    |
|                                            | Medium             | 6.0                            |      | 349.0                    |
| HCP05                                      | 2.37               | -                              | -    | -                        |

In 2018, in the variant with differentiated introduction of ammonium nitrate, the planned yield of 4.0 t/ha, the N-NO3 content in the soil layer of 0-40 cm was levelled by 100% - 5.4 mg/kg of soil, the rate of ammonium nitrate in all elementary areas was 254.0 kg/ha, yield 4.77 t/ha, in comparison with the traditional method of use, the rate increased by 63.9%, and yield by 7.9% or 0.35 t/ha with HCP05 - 0.35. In the conditions of 2017, in the field N 67 in a similar variant, the content of nitrate nitrogen was highly contrasting, at field N 15 - 109.0 mg/kg of soil, and at elementary field N 8 - 6.2 mg/kg of soil, variability of soil nitrogen was, according to the variant, 137.1%, ammonium nitrate norms varied from 0.0 to 247.0 kg/ha, differentiated introduction allowed to get spring wheat yield of 3.95 t/ha, an increase relative to the control variant and the traditional method of introduction of 0.57 and 0.26 t/ha, respectively, at NDS05 - 0.35, the increase in the rate was 36.7%.

Differential feeding in the off-line mode during the tillering of spring wheat increases the spread rate by 37.4-68.5% relative to the variant without feeding. In 2017, the N-NO3 content varied from 10.0 to 17.4 mg/kg of soil, the coefficient of variation — 26.7%, 73.3% evenness — the average norm for the variant is 251.0 kg/ha of ammonium nitrate. Differentiated application made it possible to obtain the yield of spring wheat 4.45 t/ha, an increase relative to the control variant and without adding top dressing 1.07 and 0.50 t/ha, respectively, with HCP05 - 0.35, the increase in the norm was 68.5%. In 2018, the availability of nitrate nitrogen is low 6.0 mg/kg of soil, the minimum N-NO3 content is 3.8 mg/kg of soil in the elementary area No. 8, the maximum number 9 is 8.7 mg/kg of soil, the variation coefficient is 41.9%, the average rate is 349.0 kg/ha. The yield of spring wheat 4.76 was obtained with HCP05 - 0.35, the application of top dressing did not give an increase.
Based on the results of monitoring nitrate nitrogen in the soil layer of 0-40 cm in the early spring period, analysis of the uniformity and variegation of the trait, as well as the economically justified planned yield of spring wheat under production conditions, a task map was created with the numbering of elementary plots and the application norm in the “tbl” format. The created map with numbered elementary sections is exported in the "KML" format. The third navigator file is "pnk". All listed files are exported to "Agronavigator +" OBNC.

The creation of a task map for off-line differentiated mineral fertilization includes digitizing the boundaries of farm fields (price from 20 rubles / ha), followed by division into elementary areas depending on the configuration of the fields of agricultural machinery width, variegation of soil fertility under production conditions. The work has been carried out once. These costs can not be attributed to additional costs for the differential mineral fertilization. Monitoring of agricultural land on a compiled map scheme is carried out annually to collect soil samples and determine nutrients in one mixed sample (price from 600 to 1000 rubles / piece). It is necessary to calculate the exact doses of nitrogen fertilizers for the planned yield of spring wheat. On average, the cost of digitizing the boundaries of fields and the division into elementary areas, including agrochemical analysis of the soil constitute 80.0 rubles / ha.

The on-board navigation complex "Agronavigator +" (cost 140,000 rubles) in agro-industrial enterprises is used from early spring harrowing to harvesting. Its mobility allows quick reinstalling to any agricultural equipment, the acquisition of a linear electric actuator is additionally required. A linear electric actuator should be considered as an additional cost, at a cost of 50,000 rubles. The service life of the sowing complex John Deere is up to 10 years (depreciation deduction 10%), additional costs will amount to 2.38 rubles / ha.

The high potential fertility on the control variant allows to get 3.41 t / ha on average over 2 years, with production costs of 14,567.0 rubles / ha, a profitability of 98.7% (table 3).

Table 3. The economic efficiency of the cultivation of spring wheat, depending on the method of ammonium nitrate fertilization (prices of 2017).

| Fertilizing method | Production expenses, rub/ha | Profitability, % |
|--------------------|-----------------------------|-----------------|
|                    | 2017 | 2018 | Medium | 2017 | 2018 | Medium |
| Control (without fertilizing) | 14562.9 | 14577.0 | 14567.0 | 97.3 | 100.0 | 98.7 |
| Traditional fertilizing | 16450.9 | 17267.6 | 16859.3 | 90.7 | 117.6 | 104.2 |
| Differential fertilizing for the planned harvesting of 3.0 t/ha | 15888.9 | 16940.0 | 16414.5 | 103.3 | 135.3 | 119.3 |
| Differential fertilizing for the planned harvesting of 4.0 t/ha | 17050.9 | 18756.2 | 17903.6 | 96.9 | 116.2 | 93.1 |
| Differential fertilizing for the planned harvesting of 4.0 t/ha + “Feeding” | 18488.1 | 20972.1 | 19730.1 | 104.6 | 92.9 | 98.8 |

Differential fertilization of ammonium nitrate to the planned yield of 3.0 t / ha according to the task map reduces the rate compared to the traditional method by 7.7-21.1%, costs by 327.6-562.0 rubles / ha. On average, the profitability of grain production for 2 years amounted to 119.3% in 2017 - 103.0%, and in 2018 - 135.3%. The increase in the planned yield of spring wheat to 4.0 t / ha and the differential fertilizer application in off-line mode reduces profitability by an average of 11.1%, an increase in costs by 600.0-1488.6 rubles / ha in absolute values relative to the traditional method of fertilizer application.

Additional feeding in the tillering phase of spring wheat in a differentiated way for the planned yield of 4.0 t / ha in off-line mode increases the average cost for 2 years by 10.2%, the increment from top dressing is 0.25 t / ha, and the yield review by years showed no increase. The profitability of this technology is on par with the control variant 98.8%, while the costs are 27.0-43.9% less.

4. Conclusion
Differential nitrogen fertilization in the off-line mode for the planned yield of spring wheat of 3.0 t / ha reduces the rate of use, production costs by 7.7-21.1% and 1.9-3.4%, respectively, relative to traditional
technology, if the spatial variability is in the range of 17.9-31.2%, and the content of nitrate nitrogen is in the range of 4.4-15.5 mg / kg of soil.

Differential feeding in the off-line mode in the tillering stage of spring wheat increases the spread rate by 34.4-68.5%, production costs on average for 2 years by 10.2% relative to the variant without feeding, and profitability at the level of the control option - 98.8%.

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