Prerequisites and effectiveness of the introduction of precision farming elements in the sowing of grain crops in the Leningrad region

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Abstract. Effective farming is the basis of Russia's food security. At the present stage, the agricultural industry, and in particular crop production, is experiencing a constant shortage of qualified machine operators, high-performance equipment, there is no developed infrastructure, etc. The main direction of agricultural production in the North-Western region of the Russian Federation should be resource conservation and technological modernization, including through the use of "precision agriculture" (PA). It has been revealed that there are prerequisites for this: there are enterprises in the Leningrad Region where PA elements have been introduced. The analysis of the sowing campaign on a specific example of an enterprise for soil preparation and sowing of grain crops revealed factors affecting the productivity of aggregates and additional costs. The prerequisites for the introduction of PA elements in the sowing of grain crops were: large overlap on the aisles of the units, work on the incomplete width of the guns, curved movement of the units across the field, incorrect rotation scheme of the unit with manual control. Fuel overspending on soil preparation and sowing of grain crops in monetary terms amounts to 513632 rubles with manual control of the units, and with an automatic control system of 2.5 cm and an RTK station will amount to 20496 rubles.

1 Introduction

"Precision Agriculture is a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production." This Precision Agriculture (PA) definition has recently been recognized by the Board of directors as the official definition of the International Society for Precision Agriculture (ISPA) (January 2021).

Precision agriculture offers environmental, practical and economic benefits. Precision farming potentially increase yields, reduce investment, decrease pollution, enhance economic efficiency, leading to better control in the production process and more productive work time will result in higher profits. Precision agriculture was adopted a bit slowly because of the

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equipment replacement cycle problems. The adoption of precision agriculture was also profit-oriented [1].

Precision farming technology includes global positioning technologies (GPS), geographic information systems (GIS), yield monitor technologies, Variable Rate Technology (VRT) and Earth remote sensing technologies [2 – 4].

Algorithms [5] were developed to predict spatial variation of yield and quality within winter wheat crops intended for bread-making. Bayesian networks were used to predict spatial probability maps of yield and quality based on data sources including yield maps, fertiliser applications, soil variables and Sentinel 2 satellite data. Results presented here for five UK fields show that there was a 65% likelihood of achieving a grain protein premium with variable rate nitrogen application compared to 50% with uniform N. Achieving this premium would increase revenues by £150/ha. A similar comparison for five German fields did not demonstrate a higher probability of profit.

By the beginning of 2022, the Cognitive Agro Pilot system was installed in more than 500 domestic agricultural farms in 30 regions of the country. By this time, the number of installations in Russia of foreign parallel driving systems based on satellite navigation, such as Trimble, TopCon, AgLeader and others, according to Interagrotech, amounted to about 150 thousand.

Unlike "blind" foreign systems using satellite navigation, the Russian Cognitive Agro Pilot system has serious advantages [6]: it allows the technician, as a person, to see and understand the situations taking place on the field and make the necessary decisions. This helps smart technology to avoid incidents with collisions with obstacles, off-field trips, etc., characteristic of navigation solutions, she added.

On October 25, 2022, Cognitive Pilot announced the implementation of a navigation module including a satellite receiver and an inertial navigation system in the Cognitive Agro Pilot autonomous control system for agricultural machinery. Experts in the field of autonomous control call the navigation system a vestibular device of robotic technology. Its task is to assess the change in the position of the machine in space, acceleration and direction of its movement. "The inertial navigation system, like the vestibular apparatus in the inner ear of a person, allows you to determine the position of the harvester in space. It consists of three accelerometers measuring acceleration along three axes and three gyroscopes measuring angular velocity. The system, among other things, allows you to find the orientation angles of the equipment — roll and pitch. This helps to compensate for the swinging of the combine on bumps, as well as the slope of the field. Without taking into account the roll and pitch, it is simply impossible to achieve our navigation accuracy of 2-3 cm," said Anton Yemelyanov, technical director of Cognitive Pilot. This statement is very important for understanding the management of agricultural aggregates in the conditions of the North-Western region. In the region, the fields are small in area, irregular configuration, with many power transmission poles, steep slopes, and poor alignment [6].

In Russia, it is possible to increase soil fertility and get the highest possible yields through the use of precision farming technologies, which have been used for several years by such large agricultural holdings as EkoNiva, Tkachev Agrocomplex, Kuban agroholding, Belaya Dacha Farming and others [7, 8].

Many agricultural enterprises are implementing separate components of this system, in particular Green Seeker and Weed Seeker – modern Western developments that have proven themselves well in Russia. Also, leading scientific associations are developing domestic devices, software and technologies that take into account the conditions of individual climatic zones and regions [9 – 11].

Measurements with the help of N-tester are point-based and cannot fully characterize the spatial variation of the sowing biomass in the field, which is required in precision farming for fertilizing using on-line technology. It should be noted that the calibration tables built into the device are suitable for the varieties and conditions of the sensor's country of origin and should be specified for specific soil and climatic conditions, varieties, and the phase of plant development [10, 12].

Technologies of differentiated fertilization of plants with nitrogen fertilizers have been developed and have been used for several years in the experimental fields of the GNU AFI branch. The calculation of nitrogen fertilizer doses is based on the optical characteristics of spring wheat crops, which are measured using a nitrogen Hydro-N-Sensor and task maps developed on the basis of decryption of aerial photographs of crops. At the same time, the adjustment of the N-sensor for the implementation of technological impacts in on-line mode was carried out on the basis of calibration data obtained directly on crops, as well as on test sites using a portable N-tester device. In comparison with the traditional technology of fertilization, the most effective option was the differentiated application of nitrogen fertilizers according to task maps created on the basis of decryption of aerial photographs of crops using optical characteristics of test sites [13].

In order for the proposed precision farming system to be implemented in an agricultural organization, at the first stage, in order to justify the scale and timing of the introduction of system elements, it is necessary to conduct a comprehensive assessment of the economy, which includes agrotechnical, economic and soil-climatic analysis. As for the Vologda Region, such a comprehensive assessment has not been carried out in any agricultural enterprise [14].

The introduction of precision farming technology requires a fairly balanced economic approach. It is expensive and economically impractical to implement everything at once, the implementation should be carried out in stages, while each stage should be calculated separately.

The number of farms using precision farming elements in the regions of Russia is given in [15] for 2019, including in the North-Western region. The area where precision farming elements and other indicators are used is also reflected (Table 1).

Table 1. Farms using precision farming elements in the Northwest region (2019) [15].

Region	Number of farms	Land area, ha	Digitized fields	Parallel driving	Differentiated seeding
Arkhangelsk	11	23593	1		8
Vologda	45	161651	5	11	8
Leningrad	16	27958	5	6	3
Novgorod	0	0			
Pskov	17	50079	2	1	6

The Vologda region is the leader in all these indicators. For example, in the south of Russia, these indicators are 10 times higher. There are no elements of precision agriculture except in the Novgorod region and in the Republic of Karelia.

Many managers and specialists of agricultural organizations are reserved about precision agriculture technologies because of doubts about their advantages in the economic aspect (35%), especially at the initial stage of implementation. There is an obvious need to improve the skills of most employees of the organization, starting with the management [16].

The purpose of the study is to identify the need to introduce elements of precision agriculture when sowing grain crops in the North-Western region of Russia.

Research objectives: To analyze the literature and interview grain producers in the North-Western region of Russia for the use of PA technology elements in their organizations; to identify factors and shortcomings in the technology of sowing grain crops with "manual control" of the unit on the example of an agricultural organization characteristic of the above conditions; to give options for using PA technology elements when sowing grain crops.

2 Material and methods

The study is based on the analysis and generalization of conclusions and theoretical approaches available in the scientific literature, as well as materials from the Forecasting and Monitoring Center of the Kuban State Agrarian University and a specific agricultural producer from the Leningrad region [14, 17 – 20]. Interviewing was used - a survey of agricultural producers associated with the production of grain crops for livestock feed and seeds.

A relatively large, fairly well-equipped agricultural enterprise in the southern part of the Leningrad region on the border with the Pskov region was selected for research.

The sown area occupied by grain crops is 1,450 hectares, including spring grain crops – 900 hectares, winter grain crops - 550 hectares.

Aggregates that participated in the research.

For pre - sowing tillage were used:

Tractor JD 6195M + disc harrow Lemken Rubin 9/500 KA (2 units);

Tractor RSM 2375 + disc harrow Format Softer 8 PS.

For sowing grain crops were used:

Tractor NH T7090 + seeder Amazone Citan 8000;

Tractor Claas Axion 850 + seeder Amazone Citan 6000.

The study used the instruments listed in Table 2.

Table 2. List of instruments used in the study.

Instrument and Trademark	Measurement limits and accuracy
Weather station with soil moisture sensors, Davis Vantage Pro2 Sensor Suite with Sentek Drill & Drop 900 mm	Temperature range -40 °C to 65 °C, Temperature accuracy ±0.5 °C; Rain fall range 0 to 6553 mm, Rain fall accuracy – greater of 4% or 1 tip
Metallic ruler, Ruler-500 State Standard 427-75	0–500 mm, ±0.15 mm
Steel measuring tape	0–10 m

A preliminary analysis of the sowing campaign revealed factors affecting the performance of aggregates and additional costs for fuel, materials, time per hectare of area due to the following reasons:

a. Large overlap on adjacent aisles.
b. Work on an incomplete width of capture.
c. Curvilinear movement of aggregates on the field.
d. The scheme of the turn at the end of the rut using the "figure eight" technique.
e. Organization of movement on the field.

Let's consider the listed reasons in more detail.

3 Results and discussion

The listed reasons (a) are a - Large overlap on adjacent aisles and (b) - Work on an incomplete width of capture can be determined experimentally.

Pre-sowing soil preparation:

When processing for spring grain crops with aggregates on an area of 900 hectares, the area treated twice was 169 hectares or – 18%.

- Tractors JD 6195M + disc harrow Lemken Rubin 500 KAU (design width of 5 m). The double overlap ranged from 60 to 100 cm. Effective gripping width – 4.0 – 4.4 m (Fig. 1).

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Fig. 1. Area treated twice with JD 6195M + Lemken Rubin 500 KAU aggregates.

- Tractor RSM 2375 + disc harrow Farmet Softer 8 PS (design width of 7.65 m). The double overlap ranged from 80 to 120 cm . Effective grip width – 6.45 – 6.85 m (Fig. 2).

Fig. 2. The area processed twice by the unit RSM 2375 + Farmet Softer 8 PS.

Sowing:

When sowing spring grain crops with aggregates on an area of 900 hectares: the area sown twice is about 70 hectares or – 8%.

- Tractor NH T7090 + seeder Amazone Citan 8000 (design width of 8 m, row spacing - 12.5 cm). Double overlap or with a blemish - 50 cm . Effective gripping width – 7.5 m (when overlapping) (Fig. 3).

Fig. 3. The area sown twice by the aggregate NH T7090 + Amazone Citan 8000.

Tractor Claas Axion 850 + pneumatic seeder Amazone Citan 6000 (grip width 6 m, row spacing - 12.5 cm). Double overlap - 50 cm. Effective grip width – 5.5 m (Fig. 4).

Fig. 4. The area sown twice by the aggregate Claas Axion 850 + Amazone Citan 6000.

The cost overruns for pre-sowing tillage and sowing 900 hectares with manual control of the units are presented in Table 3.

Table 3. Cost overruns for pre-sowing tillage and sowing with manual control of aggregates.

Expenses	Pre-sowing tillage	Sowing
Area treated twice, ha	169	70
Fuel consumption, l/ha	22	15
Fuel price, rub/l	49	49
Seeding rate, kg/ha		200
The cost of seeds, rub/kg		20
Area treated twice, ha	182182.0	51450.0
Fuel consumption, l/ha		280000.0

The cost overruns for pre-sowing tillage and sowing 900 hectares when using Autopilot navigation with an accuracy of 15 cm and 2-3 cm are presented in Table 4. .

Table 4. Cost overruns for pre-sowing tillage and sowing when controlling the units with the Autopilot system with varying accuracy.

Expenses	Navigation with an accuracy of 15 cm		Navigation with an accuracy of 2-3 cm	
	Pre-sowing tillage	Sowing	Pre-sowing tillage	Sowing
Area treated twice, ha	45	48	3.2	3.6
Funds spent on fuel, rub.	48510.0	36280.0	3450.0	2646.0
Funds spent on seeds, rub.		192000.0		14400.0

Table 4 shows that with the accuracy of driving with an Autopilot of 15 cm, the cost overruns will amount to 276790 rubles, and with an accuracy of 2-3 cm – 20496 rubles, unlike manual control - 513632 rubles.

Consider point (c) of the previous section - Curvilinear movement of aggregates on the field. This value is difficult to calculate in numerical terms, but the following should be noted (Fig. 5):
- increased path length traveled by the unit;
- additional power costs in the tractor transmission;
- physical load on the mechanic by turning the steering wheel.

Fig. 5. Curvilinear movement of aggregates across the field with manual control.

Let's consider points (d) and (e) of the previous section - The scheme of the turn at the end of the rut using the "figure eight" technique; - Organization of movement on the field (Fig. 6). Automatic rotation allows the tractor with the Autopilot system installed to calculate the most optimal route of turning and exiting to the next pass.

Fig. 6. The scheme of turning at the end of the rut using the "figure eight" reception with manual control.

We will present several technical and technological solutions for completing one agricultural unit with elements of precision farming, at least for automatic driving. It should be noted that telephone and Internet communication in most farms does not work well away from major highways.

We have to hope for the use of satellite communications. Here are some use cases: Trimble RP RTX with an accuracy of 15 cm – 65,000 rubles per year, Trimble CP RTX with an accuracy of 2-3 cm – 120,000 rubles per year; JD SF3 with an accuracy of 2-3 cm – 20,000 rubles per month. These prices were at the beginning of 2022. Russian providers also offer some solutions: NTRIP for one month for 4800 rubles, EFT CORS – 48,000 rubles per year.

Technically, the system installed on the tractor consists of a display, antenna, sensors and a thruster [4, 10, 21]. For example, the Trimble GFX-750 system costs 1.6 million rubles, the FJD system costs 500,000 rubles and the RTK station costs 500,000 rubles to achieve an accuracy of 2.5 cm at a range of 15 km.

In late 2022 and early 2023, other solutions based on Russian and Chinese technical and technological solutions are proposed [22 – 24].

For example, Shanghai AllyNav Technology offers an automatic AF-305 control system at a price of 500,000 rubles (Fig. 7). It is important to note that the system uses the latest GPS receiver with a built-in gyroscope and radio modem instead of a dual GNSS antenna. The RTK AllyNav base station with a radius of up to 30 km costs 350,000 rubles. The purchase of the station is necessary in one or two copies.

Fig. 7. Elements of the automatic control system.

The FJ Dynamics navigation system costs 460000 rubles per tractor unit and provides the same characteristics as most well-known brands.

Returning to our option of carrying out pre-sowing treatment and sowing of grain crops, at least five units of systems, an RTK station, communication payment for five units of equipment for a month are required (usually paid for the whole year to track the location of equipment and perform other work on mowing grasses, fertilizing). Installation and technical support of these systems requires a specialist and staff training. At the suggestion of dealers, such an offer will cost the company 3.3 million rubles. Additionally, every year you need to pay for communication and maintenance of five units of the system in the amount of 300,000 rubles.

As we have already found out, the overspending of fuel and seeds is 513632 rubles with manual control of the units, and with a 2.5 cm control accuracy system and an RTK station it will amount to 20496 rubles. The payback of the automatic control system for the spring sowing of grain crops will be six years. It is worth noting that the systems can also be used in other agricultural work [4, 8, 15].

4 Discussion

The use of automatic driving on tractors during sowing gives a number of noted advantages [2, 9, 22, 24]: the overlap on adjacent aisles is reduced due to the rectilinear, accurate and stable control of the unit; fuel and seed consumption is reduced in this case; the length of the path traversed by the unit across the field in direct mode is reduced movement; increases the productivity of the unit; increases accuracy and consistency when working with several sowing units in the same field; frees the operator from a lot of physical stress during the shift; work accurately at night and in poor visibility.

Not all managers and specialists of medium and small enterprises see the financial effect of using elements of "precision farming" [6, 14, 25, 26], including the managers of the large enterprise in question for the conditions of the North-Western region of Russia.

5 Conclusions

Analysis of literature sources and a survey of managers and specialists (agronomists, engineers) of agricultural organizations showed that they are reticent about the introduction of precision agriculture technologies due to doubts about the advantages of the economic aspect (35% [16]), especially at the initial stage of implementation. It is necessary to raise awareness and qualifications of the majority of employees of agricultural enterprises in the North-Western region Russia (director, owner of the enterprise, agronomists, engineers, machine operators).

The analysis of technological processes of soil preparation and sowing revealed factors affecting the productivity of aggregates and additional costs for fuel, materials for the following reasons: large overlap on adjacent passages during tillage up to 120 cm and 50 cm during sowing; work on the incomplete width of the unit; curvilinear movement of aggregates across the field; a U-turn scheme at the end of the rutting season irrational.

The options for installing and using an automatic control system with an accuracy of 2.5 and 15 cm control units are proposed, which will ensure the absence or minimize the negative factors of "manual control".

In a concrete example, the overspending of fuel and seeds on soil preparation and sowing of grain crops in monetary terms amounts to 513632 rubles with manual control of the units, and with a 2.5 cm control accuracy system and an RTK station will amount to 20496 rubles.

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