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Yield mapping using satellite navigation systems

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Yield mapping using satellite navigation systems

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Abstract. The paper presents the results of research and production experiments of spring wheat yield mapping. Five clusters were identified in terms of yield with an interval of 0.2 t/ha. With an average yield of spring wheat of 2.23 t/ha over an area of 13.7 hectares, it ranged from 1.91 t/ha to 2.71 t/ha. The reason for the heterogeneity of the spring wheat yield on this fragment of the field is a variety of soil cover. Detailing of soil fertility factors showed that in the low productivity area there was the lowest humus content (3.4%) in the 0-30 cm layer, nitrate nitrogen 5.1 mg/kg soil, mobile phosphorus - 46 mg/kg, exchangeable potassium - 55 mg/kg and pH - 4.2. The obtained data of yield mapping and detailed analysis of soil fertility factors in problem areas served as the basis for a technical solution with software for the differential application of mineral fertilizers in elementary areas in off-line mode.

1. Introduction

The digitization of agricultural technologies facilitates and serves as the basis for the transition to precision farming, which predetermines a systematic approach to solving the set tasks of optimizing the conditions for the growth and development of plants [1-3]. Geographic information systems (GIS) allow to collect a wide range of data on space and terrestrial factors of agro-ecosystem production, make a deep analysis of their importance in the formation of plant productivity and develop crop cultivation technology for the field and a particular plot, taking into account the state of soil fertility and plant requirements.

The technology of the new generation, a wider range of plant protection products, fertilizers, new high-yielding varieties allow for high-tech cultivation of crops [4-8]. At the same time, the attitude to the main means of production - the soil remains at the same level. Soil fertility is estimated by average productivity, which forms a distorted picture of the state of fertility inside the field. The result is an ambiguous agro-economic effect of a technological event.

For successful implementation of digital technologies in production, one should possess information on the soil fertility status not on the average across the field, but on its micro-sites. Using special technical tools and software, initial information can be obtained when mapping crop yields.

2. Objects and methods of research

Studies have been conducted in the northern forest-steppe of Western Siberia since 2006. The climate of the zone is characterized by long winters and short, moderately hot summers. The unobstructed penetration of cold arctic air from the north and dry air from Kazakhstan causes sharp changes in the weather and leads to its overall instability. The annual rainfall is 374 mm, of which 232 falls during the growing season. The sum of temperatures above + 5° C and it varies between 185° - 205°, and



above + 10° C - 1800° - 1940°. The duration of the period with temperatures above 0° C is 194 days. The steady snow cover is established on November 11, and melts on April 10, its maximum height is formed in March of 31 - 27 mm, with water reserves in snow of 93 mm. The depth of soil freezing is 113 mm.

This paper examines the experimental materials obtained on grey forest soils. They have relatively favourable physico-chemical properties. The absorption capacity is of up to 20 - 30 m-Eq/100g of soil. Calcium predominates in the composition of absorbed bases, the hydrolytic acidity is low, and the pH of the soil is classified as slightly acid. The humus content in the plow layer is 3.3–4.9%. The provision of soil with mobile forms of phosphorus and potassium is at a low level. The humus horizon has a low density of 0.93 - 1.02 g/cm³ and a high total porosity. Dead moisture is small and amounts to 11.1 - 11.8%. The field capacity is rather high and makes up 60% of the total capacity.

Yield mapping was performed by NewHolland combine harvesters equipped with a GPS receiver, an on-board navigation computer, a header lifting and lowering sensor, optical sensors, and sensors for determining the moisture content of grain. Cleaning was performed by direct combining, the results were processed using software in the electronic computing module.

3. Results and discussions

The practical use of elements of precision farming is carried out in a certain sequence, which reflects the phasing of the transition to innovative technologies, and in general forms the consistency of production processes using satellite navigation systems.

First, we set the boundaries of the fields (digitization) by means of information technologies, including space imagery. The use of the GPS made it possible to determine the actual field boundaries with sub-meter accuracy. The electronic image of the field was recorded on a mobile technical carrier - a chip card.

The results of the positioning work performed by us showed the location of the selected site in the farm and the district, its size and configuration. Field mapping accurately determines the actual areas of crops of land users, and this makes it possible to realistically assess the situation in the agro-industrial complex and develop the correct technologies for the cultivation of agricultural crops.

The dual-frequency GPS-receiver also allowed us to build a digital model of the relief of this field, which in the conditions of Zavodoukovsky district shows the relative alignment of the site with minor declines and a north-western slope, which should be considered when developing accurate farming (figure 1).

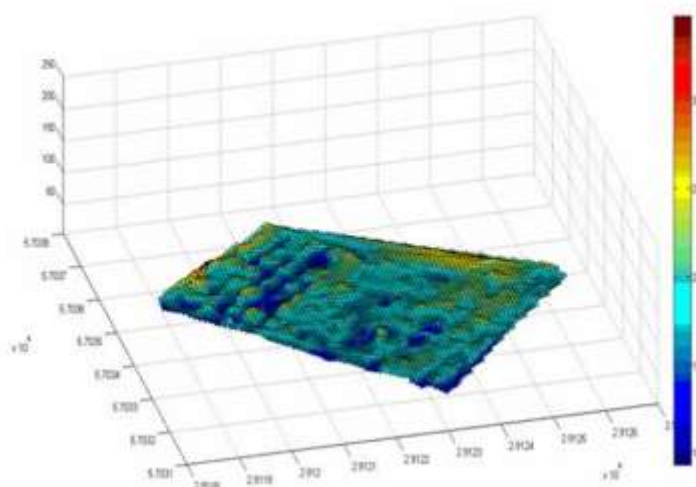


Figure 1. Digital elevation model of the field (Zavodoukovskaya agro-industrial company).

The crop yield map makes it possible to identify problem areas of the field on which agrocenosis with low productivity is formed. The method was based on certified level sensors for bulk materials. For their implementation, we performed a bulk model of the combine bunker.

Using a mapping system, data were obtained on the yield of spring wheat and oats with an accurate reference to the coordinates of each individual area on the field and a reflection of the trajectory of the combine. Such a map creates an objective picture of the variation of soil fertility on the field. The on-board computer with the developed program made it possible to reflect the work of the yield sensor: the nature of the filling of the combine's bunker with grain and the unloading of grain into trucks. The recorded dynamics of filling the bunker with grain on electronic media showed that the grain distribution in the bunker was uniform, so the use of the applied system for mapping the yield of grain makes it possible to obtain comparable data on elementary areas. The mapping of grain yield during the day should be accompanied at least three times (morning, afternoon, evening) by calibrating the sensors: after determining the nature, moisture content and grain debris.

When using one-minute discreteness, the amount of information received is cumbersome and difficult to analyze, therefore, the establishment of optimal discreteness will depend on the characteristics of the soil cover, size and geographical location of the farm.

In terms of the yield of spring wheat inside the field, they were grouped into relatively homogeneous clusters (zones), which have different intervals. An example is a report on the work of a single combine (figure 2, table 1).

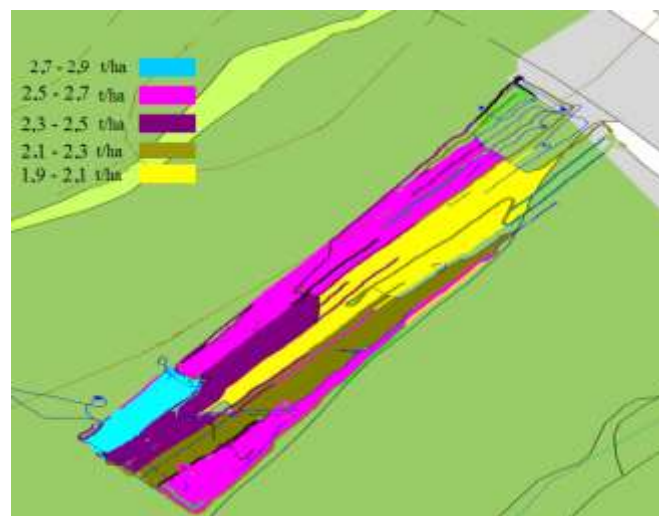


Figure 2. Spring wheat yield map.

Table 1. Report on the work of the combine harvester (h:min:s).

Bunker No	Start time of filling in the bunker	End time of filling in the bunker	Full time of filling in the bunker	The end time of the unloading of grain	The distance travelled during the filling of the bunker, m	Harvested area, ha
1	12:14:21	12:59:30	0:45:09	13:03:02	2726	1.6
2	13:06:10	13:30:56	0:24:46	13:36:57	2475	1.5
3	13:40:46	14:05:00	0:24:14	14:09:31	2441	1.5
4	14:13:26	14:35:57	0:22:31	14:38:29	2239	1.3
5	14:42:17	15:12:14	0:29:57	15:15:19	2907	1.7
6	15:21:12	15:50:55	0:29:43	15:53:57	2915	1.7
7	16:01:56	16:26:56	0:25:00	16:29:48	2419	1.5

8	17:11:28	17:40:52	0:29:24	17:43:10	2885	1.7
9	18:50:56	19:20:39	0:30:43	19:31:05	2022	1.2
					23029	13.7

Five areas (zones) with different productivity of cultivated plants were identified: with an area of 1.6 hectares, respectively; 4.5 ha; 1.3 ha; 1.2 ha and 5.1 ha. We believe that in the studied fragment there are 3 problem areas with a total area of 6.1 hectares, which is 44.5% of the total area of the field fragment.

The yield of spring wheat in these areas amounted to 1.91 t/ha with a gross yield of 9.74 t. The maximum yield was 2.71 t/ha from an area of 2.5 ha with an average yield of 2.23 t/ha in an area of 13.7 ha

For the compilation of the yield map, a site was chosen that was not uniform in terms of visual assessment of the condition of crops. This area was characterized by heterogeneity of the soil cover, where, against the background of gray forest soil, there was a pronounced area of solodization.

It recorded the lowest productivity (1.9 - 2.1 t/ha) of spring wheat. Agrochemical analysis of the soil showed that this area has a low level of fertility compared to the others (table 2). The content of nitrate nitrogen in a layer of 0-30 cm before sowing spring wheat here was lower by 1.5-5.2 mg/kg of soil relative to clusters with yield 2.3-2.5; 2.5-2.7 and 2.7-2.9 t/ha. Humus in this area was lower by 1.1-1.7% than in other variants and amounted to 3.0%.

Table 2. Agrochemical indicators of fertility in areas with different yield of spring wheat.

Yield Cluster, t / ha	Soil N-NO ₃ , mg/kg	P ₂ O ₅ , mg/kg	K ₂ O, mg/kg	pH	Humus, %
1.9-2.1	5.1	46	55	4.2	3.0
2.1-2.3	5.0	49	60	4.7	4.1
2.3-2.5	6.6	54	59	4.7	4.5
2.5-2.7	9.2	54	73	5.6	4.4
2.7-2.9	10.3	82	94	5.5	4.7
HPC 0.5	1.4	7	4	0.3	0.6

One of the most optimal systems for mapping grain yield is considered to be the mechanism of optical determination of the volume and mass of grain entering the combine bunker. This set of yield accounting systems includes: optical sensors 1 (figure 3), which are mounted on the body of the grain elevator against each other. When a combine harvester is working, a grain conveyor chain with scrapers is fed to the grain chamber of the combine bunker auger. In the grain bunker, a sensor 2 for determining the grain humidity that constantly passes through it is installed on the filling auger. A navigation system is provided in the yield mapping system, with the help of which the location of the unit is determined in a certain part of the field. An antenna 3 is installed on the combine cab to receive GPS or GLONASS communication signals.

The entire mapping system turns on the header position sensors 4. When the header is lowered to a specific height, and when the header is raised, it turns off. All used sensors of the mapping system are connected to the on-board computer, and its display shows information about the system's performance, the actual yield and moisture content of the threshed grain.

However, the use of optical sensors for recording the grain entering the bunker requires further work, since under production conditions the dusty environment can distort the accuracy of their readings.

The data obtained by the crop accounting system can be processed in a special GIS program, where, according to legend, the actual yield in certain areas of the field, the speed of the combine during operation, grain moisture and many other indicators can be observed.

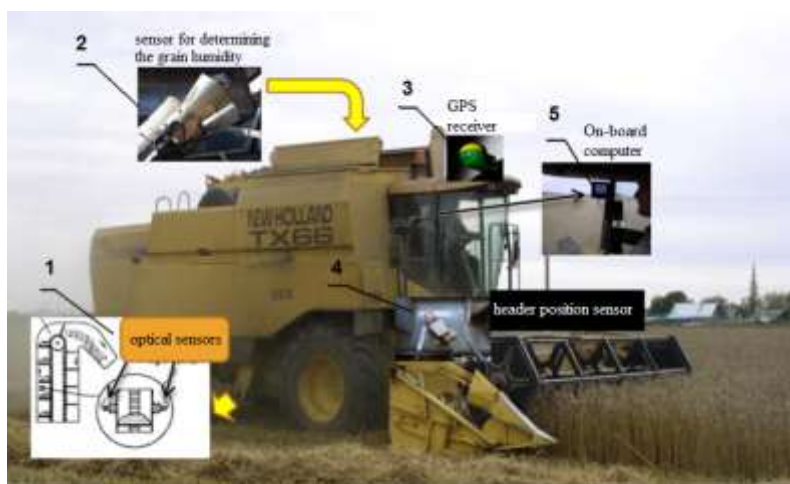


Figure 3. Grain yield mapping.

Thus, the results of the mapping allowed us to determine the causes of the heterogeneity of the yield of spring wheat on this fragment of the field, which are of a constant nature and are associated with the type and variety of soil cover. Mapping and identifying the causes of heterogeneity of crop yield in the fields of crop rotation is the starting point for introducing elements of precision farming in the first stage. Subsequently, there is a detailed elaboration of soil fertility factors inside problem areas, which may be the reasons for the decline in productivity of agrocenoses. A detailed map is compiled of the elementary sections of the provision of cultivated plants with one or another means of livelihood and a computer program for the differential implementation of agricultural practices in order to optimize soil fertility indicators.

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