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Estimation of the spatial distribution of spring barley yield using ground-based and satellite spectrophotometric data

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Abstract. The article presents a method for estimating the spatial distribution of spring barley yield, based on the use of optical ground and satellite spectral data (PlanetScope data with a spatial resolution of 3 meters). This approach is highly relevant for the development of precision agriculture technologies. Yield mapping is carried out on the basis of data on the spatial distribution of the actual yield and the spatial distribution of the spectral optical characteristics. The method's characteristic feature is the use of the integral values of vegetation indices (NDVI, MSAVI2, ClGreen) at various stages of crop development. The method was tested on the basis of stationary field experience, where traditional agriculture (deep plowing) is compared with resource-saving technologies (subsurface and surface plowing, and direct seeding with zero tillage).

1. Introduction

Yield mapping is an element of the precision agriculture system, making it possible to determine the heterogeneity of one of the most important indicators - crop yield [1]. A map of crop yield is the basis for the differentiated application of fertilizers in precision agriculture [2] It can be used to identify areas with low yield for a focused study of the causes of its decrease in this area of the field and taking appropriate measures to solve this problem [3].

The creation of digital field maps is possible using satellite data of high spatial and temporal resolution. Currently, continuous monitoring of crops with high spatial resolution (3 meters) and daily measurements are provided by the world's largest satellite constellation PlanetScope of the Planet company [4]. The system provides data making it possible to evaluate the condition of crops during the entire growing season.

The purpose of the study is to develop a method for constructing yield maps using PlanetScope satellite data.

2. Research object and methods

Studies were conducted on the lands of the Minderlinskoye Instructional Farm LLC, located in Sukhobuzimsky District, Krasnoyarsk Territory, during the growing season of 2018. The experimental field consists of 5 strips. Their average length is 650 meters. The strips are located from west to east, the width of each strip is 20 m. Fertilizers were applied along the northern part of each strip (10 m wide),

the southern part remained without fertilizers. Each strip was sown with a specific type of crop. The work presents the analysis and results of data processing for strip number 5 sown with "Acha" barley. Barley was sown on May 19th. In 2017, wheat was sown on this strip. All strips were divided into 4 test areas in accordance with four types of soil treatment: "A" — plowing (pickup plow PN-5-35, 20–22 cm); "B" — subsurface treatment (subsurface cultivator KPSHK-3.8, 20-22 cm); "C" — surface treatment (disk header BDShCh-5.6, 8-10 cm); "D" — direct sowing at zero tillage (Agrator 4.8).

For the purity of the experiment, all test areas were separated from each other by protective strips 5 meters wide. Field spectrometry was performed 5 times during the growing season 2018. The distance between measurements was about 50 meters.

When carrying out field spectrometry, the Spectral Evolution PSR-1100F spectroradiometer was used. The data obtained were the spectral brightness coefficients of the object in the range from 320 to 1100 nm.

The study is based on PlanetScope satellite data with a spatial resolution of 3 meters. At the preprocessing stage, the atmospheric correction of the PlanetScope data was performed. Correction factors for each channel are present in the metadata of each scene.

The satellite and ground-based spectrophotometric data were used to calculate the following spectral indices: NDVI (Normalized Difference Vegetation Index) [5], VARI (Visible Atmospherically Resistant Index) [6], MSAVI2 (Modified Soil Adjusted Vegetation Index) [7], and ClGreen (Green chlorophyll index) [8].

3. Results and discussion

The environmental conditions for the formation of barley yield in the year of research differed from the long-term average annual data. The vegetation period of 2018 was distinguished by an extremely uneven distribution of precipitation and increased average monthly air temperature in June and August. In general, the growing season 2018 was characterized as unfavorable for the cultivation of crops.

The variability of the actual barley yield changes depending on the availability of fertilizer background and the treatment method. The highest yield of barley was recorded in the variant with mouldboard plowing (25.9 centner/ha (fertilized background) and 23.7 centner/ha (non-fertilized background), the lowest — in the variant with surface treatment (19.7 centner/ha (fertilized background) and 15.8 centner/ha (non-fertilized background). For all types of treatment, the application of mineral fertilizers led to an increase in the yield of barley grain.

Evaluation of the actual yield on the field is an important indicator of the efficiency of agricultural production. Determination of the spatial distribution (cartograms) of yield is more informative, making it possible to reveal the heterogeneity of the yield level within one field. Vegetation indices, including NDVI, MSAVI2, ClGreen, are a quantitative characteristic of the state of crops. A number of papers have confirmed a stable correlation between NDVI and yield [9-12]

The use of PlanetScope satellite information helps to identify areas with persistently low or high values of phytomass at separate phases of plant growth and development. Creation of high spatial resolution maps of the spatial distribution of index values during the growing season is an integral part of precision agriculture.

The basic characteristic used in the work is the growth dynamics of the plant agrobiocenosis during the vegetative period. The main parameter used in further work is NDVI. During the growing season, the NDVI value undergoes significant changes from 0.1 to 0.8. The typical NDVI curve during the growing season looks as follows: growth at the beginning of the period, the maximum values in the middle, and decrease at the end of the growing season. Such form of representation of this value makes it possible to calculate the integral of the vegetation index curve.

For practical purposes, it is possible to use not the complete integral from the beginning to the end of the growing season, but its initial part. The earlier the yield forecast is made, the more significant it is for practical purposes. It means that it is necessary to find the optimal date to calculate the integral of the vegetation period, which also ensures sufficient accuracy of the forecast.

The calculation of the curvilinear integral of the studied indices was carried out according to the formula:

$$I = \sum_{k=1}^{n}\left(\frac{V_k + V_{k+1}}{2}\right) * (d_{k+1} - d_k) \tag{1}$$

The analysis of the relationship between the yield and the integral value at different vegetation periods showed that starting from mid-July, the value r increased considerably (more than 0.7) for the NDVI, MSAVI2, and ClGreen indices. The maximum values were achieved by early August. The correlation coefficients calculated from July 2nd to September 5th are reliable at a significance level of 0.05. Thus, it was shown that the use of integral indicators allows one to perform a forecast of barley yield at the stage of flowering — milky ripeness. The VARI index showed a rather low correlation with the yield and could not be used for forecasting purposes.

Figure 1 shows the cartograms of the NDVI integral values of barley crops during the growing season from June 4th to September 5th, 2018, obtained on the basis of the PlanetScope data.
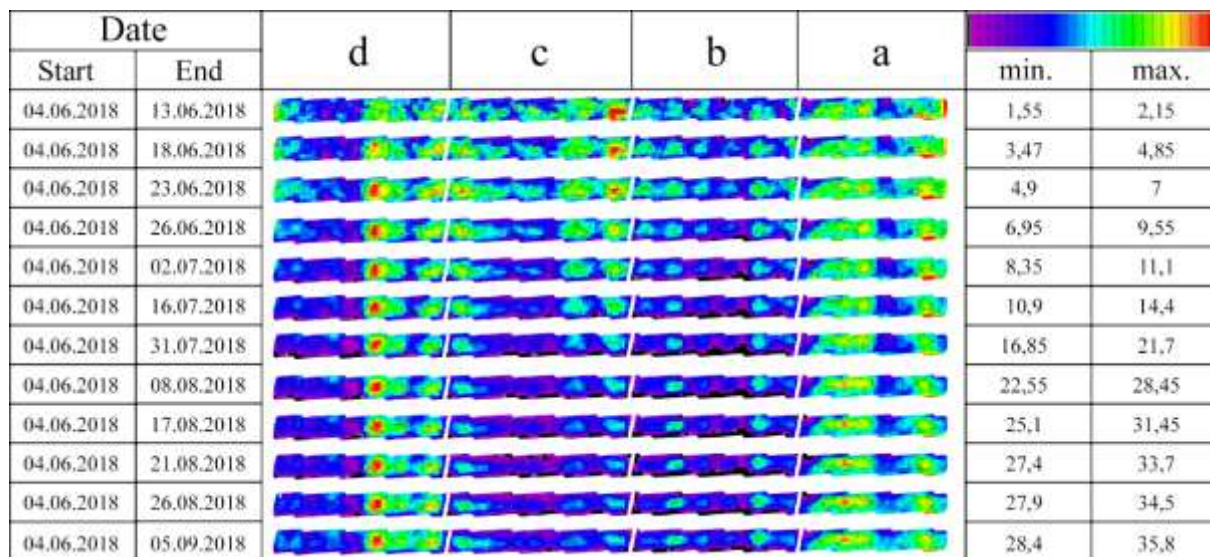

Date		d	c	b	a	min.	max.
Start	End						
04.06.2018	13.06.2018					1,55	2,15
04.06.2018	18.06.2018					3,47	4,85
04.06.2018	23.06.2018					4,9	7
04.06.2018	26.06.2018					6,95	9,55
04.06.2018	02.07.2018					8,35	11,1
04.06.2018	16.07.2018					10,9	14,4
04.06.2018	31.07.2018					16,85	21,7
04.06.2018	08.08.2018					22,55	28,45
04.06.2018	17.08.2018					25,1	31,45
04.06.2018	21.08.2018					27,4	33,7
04.06.2018	26.08.2018					27,9	34,5
04.06.2018	05.09.2018					28,4	35,8

Figure 1. The cartograms of the NDVI integral values of barley crops during the growing season (from June 4th to September 5th, 2018) obtained on the basis of the PlanetScope data. White lines indicate the division into the types of soil treatment (a, b, c, d). The cartograms were colored using a single color scale for all of the research dates. The minimum and maximum values of the color scales are presented in the table — opposite the corresponding cartogram.

The presentation of information in the form of the accumulated values of NDVI integrals shows that, compared with the spatial variation of direct NDVI values, a stable structure appears over time in certain types of treatment (d and a). At the same time, there is a clear dependence of the change in the spatial structure of NDVI integrals during b and c type treatments. In type c treatment, the integral pronounced value decreases from June 4th to 13th, by August 8th it disappears, and the whole area becomes almost uniform. The same happens in type b treatment, but the difference between the beginning and the end is less than in type c treatment.

To predict barley yield at the end of July (flowering), a linear regression model was constructed, using the NDVI curve integral values at different periods as parameters. The multiple linear model for predicting barley has the following form with 7 variables (the coefficient of determination is 0.73; the root-mean-square error is 1.5):

$$Y = -1,71 + 20,72 \times NDVI_1 - 36,28 \times NDVI_2 + 62,82 \times NDVI_3 - 153,74 \times NDVI_4 + 156,75 \\ \times NDVI_5 - 62,03 \times NDVI_6 + 15,44 \times NDVI_7 \tag{2}$$

The calculations made it possible to construct a cartogram of the yield of the studied area. Figure 2 (I) shows the actual yield distribution. A yield map was constructed for each area, taking into account the type of treatment and the background (fertilized/non-fertilized), by interpolating direct measurements (6 points) obtained during harvesting. Figure 2 (II) shows the spatial distribution of the yield at the study area, obtained on the basis of the model calculation results.
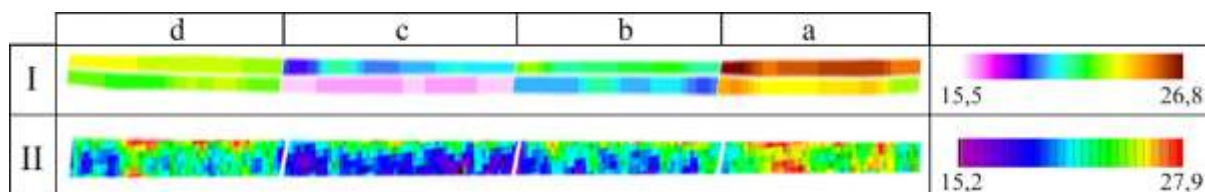

Figure 2. The map of the barley field yield obtained from ground data (I) and model calculation results (II).

Comparison of the obtained cartograms (I and II) shows similarity in the spatial distribution of the yield. In the future, it is planned to use the obtained maps for the differential application of fertilizers and selection of soil samples. Differential fertilization will improve the efficiency of fertilizers used and level the crop yields within a field.

4. Conclusion

The use of yield maps makes it possible to identify areas with low yield. It was established that the integral calculated under the index curve (variability of the area under the curve) can be considered as a parameter related to the yield. The analysis of the relationship between the yield and the integral value at different vegetation periods showed that starting from mid-July, the value r increased considerably (more than 0.7, at a significance level of 0.05) for the NDVI, MSAVI2, and ClGreen indices. The maximum values were achieved by early August.

As a result of the studies performed, the spatial variation of the NDVI values of the barley field from June 2nd to September 20th, 2018 was built using satellite and ground data. The spatial variation of the NDVI integral values of the barley field during the growing season (from June 4th to September 5th 2018) was obtained on the basis of satellite data.

A method was developed for estimating the spatial distribution of the yield of spring barley, based on the use of optical ground and satellite spectral data (PlanetScope data with a spatial resolution of 3 meters).

The barley yield at the end of July was predicted on the basis of a linear regression model using the NDVI curve integral values at different periods as parameters. The type of a multiple linear model was established for barley prediction with 7 variables (coefficient of determination 0.73; root-mean-square error 1.5).

The spatial distribution (map) of barley yield was built using satellite (PlanetScope) and ground data. The resulting yield maps will be used when planning the next year's agricultural work.

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