The use of the data derived from the PlanetScope satellite and unmanned aerial vehicles to estimate crop yield as dependent on the amount of nitrogen fertilizer applied

N O Malchikov¹,³, T I Pisman¹, I Yu Botvich¹, D V Emelyanov¹, V V Vagner² and A P Shevyrnogov¹

¹Institute of Biophysics, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, Russia
²Kuragino RF, FRC KSC SB RAS, Kuragino, Krasnoyarsk Krai, Russia
³E-mail: show.mno@mail.ru

Abstract. The purpose of the present study is to show the usefulness of the satellite data and the data derived from unmanned aerial vehicles (UAVs) for estimating the relationship between cereal grain crop yield and the amount of nitrogen fertilizer applied. The study was conducted on the land of the Kuraginskoye Research Farm. The study material was spring barley cv. Biom. Three test plots were studied; mineral fertilizer, urea, was used in different quantities for foliar application in June; applications were performed at equal intervals. Multispectral images were based on PlanetScope satellite data, with the 3 m spatial resolution, and the data derived from the DJI Phantom 4 Multispectral UAV, with the 10 cm resolution. The satellite and UAV data were used to calculate spectral vegetation index (NDVI) (Normalized Difference Vegetation Index). A high correlation was obtained between the NDVI values calculated using satellite data and UAV data. The satellite data provided the basis for assessing barley crop yield as dependent on the amount of foliar-applied urea during the growing season. Maps of the spatial distribution of barley NDVI were constructed using the Phantom UAV data; they showed that the third foliar application of the fertilizer was not economically justified.

1. Introduction

A major task of agricultural science is to evaluate the state of cereal grain crops and their crop yields. Unlike most plants, crops are characterized by the highly variable reflectance during all stages of their development, and this property can be used in remote sensing to obtain reflection spectra and to analyse the state of crops and predict crop yields [1].

The rapid development of remote sensing in the last decades has opened up new opportunities for online monitoring of crops [2]. An important direction in monitoring agricultural lands is using spectral (vegetation) indices – a tool to perform automated mapping, study crop development dynamics, and predict crop yields. The index commonly used for this purpose is NDVI (Normalized Difference Vegetation Index).

The main advantages of remote sensing techniques are the high reliability and optimal frequency of acquisition of the data and the possibility of gathering information from large areas. Remote sensing
techniques, though, have certain limitations, and the most significant of them are low spatial resolution of satellite images and errors associated with definite environments and climates [3].

At present, unmanned aerial vehicles (UAVs) can be used to overcome these limitations [4]. Regular data collection and visualization of the crops using UAVs facilitate monitoring crops and changes occurring in them [5, 6].

There are studies showing that crop biomass monitoring can be combined with yield assessment. Biomass is the crop parameter that can be used to determine the need for foliar application of fertilizers. Moreover, data obtained using UAVs can serve as the basis for creating spatial digital crop maps.

The purpose of the present study was to assess barley crop yield on the fields of the Kuraginskoye Research Farm (Krasnoyarsk Krai) as dependent on the number of foliar applications of urea, based on the data obtained from the PlanetScope satellite and a DJI Phantom 4 Multispectral UAV.

2. Materials and methods
The study was conducted on the land of the Kuraginskoye Research Farm (figure 1). The Kuraginskoye Research Farm is situated in the Kuraginski District of Krasnoyarsk Krai. The study area was 270 ha. The study material was spring barley cv. Biom (sown on 29 May). Barley crop yield was determined on 21 August using the classical method [7]. Three test plots (No 1, No 2, and No 3) were studied. Mineral fertilizer, urea, was used in different quantities for foliar application in June; application was performed at equal intervals at a rate of 3 kg urea/ha (table 1). The first application was performed on all plots, the second – on plots No 2 and No 3, and the third – on plot No 3.

![Figure 1. Test plots on the land of the Kuraginskoye Research Farm. Plots No 1, 2, and 3 with different amounts of foliar-applied urea.](image-url)
Table 1. Crop yields on test plots as dependent on the amounts of foliar-applied urea.

| Plot   | Number of foliar applications of fertilizer | Crop yield, tons/ha |
|--------|------------------------------------------|---------------------|
| No 1   | 1                                        | 2.46                |
| No 2   | 2                                        | 3.386               |
| No 3   | 3                                        | 3.361               |

Multispectral images were based on PlanetScope satellite data, with the 3 m spatial resolution, and the data derived from the DJI Phantom 4 Multispectral UAV, with the 10 cm resolution (the altitude was 150 m). The barley fields were examined during the growing season, at different stages of barley development (before sowing, at tillering, heading, and ripening stages).

The satellite and UAV data were used to calculate spectral vegetation index, NDVI (Normalized Difference Vegetation Index).

$$NDVI = (NIR - RED) / (NIR + RED)$$

where NIR is reflectance in the near-infrared spectral region; RED is reflectance in the red spectral region; Averaging was done for each plot.

3. Results

NDVI is a well-known indicator of spatial and temporal changes in the plant state and productivity. There are many studies reporting the use of satellite data to estimate crop yield. Those studies, however, were based on the data with low spatial resolution and for large areas. Moreover, there are certain limitations of using NDVI for this purpose, weather conditions being among them. Therefore, the accuracy of assessing crop yield based on satellite data with low spatial resolution is reduced.

In an attempt to overcome these limitations, PlanetScope satellite data, with the 3 m spatial resolution, and the data derived from the Phantom UAV, with the 10 cm resolution, were used to assess barley crop yield. First, the data obtained by the PlanetScope satellite were correlated with the data of the Phantom UAV (figure 2). The resulting correlation between the NDVI values calculated using the PlanetScope and Phantom UAV data was rather high (0.79 – 0.82).

Figure 2. The relationship between barley NDVI and the amount of foliar-applied urea based on the PlanetScope satellite data and the Phantom UAV data for the 2020 growing season. Plot No 1 – one foliar application of urea; No 2 – two applications; No 3 – three applications.

Owing to the high temporal resolution of satellite data, NDVI and, hence, photosynthesizing biomass can be closely monitored throughout the growing season (figure 3). The barley NDVI
dynamics on plot No 1 (with one foliar application of urea) differed from the NDVI dynamics on plots No 2 and 3 (two and three urea applications, respectively). In July, NDVI values were higher on plots No 2 and 3 than on plot No 1. The similar NDVI dynamics on plots No 2 and 3 suggest that the third foliar application of the fertilizer did not increase NDVI and, thus, would not result in a higher crop yield. That conclusion was supported by the ground-based data (table 1).

![Figure 3. Barley NDVI dynamics as dependent on the amount of foliar-applied urea based on the PlanetScope satellite data for the 2020 growing season. Plot No 1 – one foliar application of urea; No 2 – two applications; No 3 – three applications.](image)

Because of spatial heterogeneity of mineral elements in soils, mapping methods should be developed using remote sensing data. NDVI is a useful tool for both mapping and determining the patterns of spatial variations in soil and plant properties [8].

Figure 4 shows maps of the spatial distribution of barley NDVI on test plots based on the Phantom UAV data. The maps and data in figure 3 show that in July, NDVI and, hence, the amount of photosynthesizing biomass were determined by the amount of foliar-applied nitrogen fertilizer. For instance, on 16 July, barley NDVI on plot No 1 (one foliar application of urea) was lower than the NDVI on plots No 2 (two applications) and No 3 (three applications). The NDVI values on plots No 2 and 3 were similar to each other and rather high (about 0.8). The ground-based data on barley crop yields support these results (table 1). Thus, the third foliar application of urea is not economically justified.

![Figure 4. Spatial distribution of spring barley NDVI during the 2020 growing season (June – August) based on the Phantom UAV data.](image)
In addition, the map for 20 June (figure 4) shows intra-plot heterogeneity of NDVI distribution. These data suggest the need for precision agriculture, namely, selective application of nitrogen fertilizer based on the actual distribution of NDVI.

4. Conclusion
The study performed in the Kuraginskoye Research Farm produced the following results and suggested the following conclusions:

- spectral properties of barley cv. Biom were measured at two levels: using the DJI Phantom 4 Multispectral UAV and the PlanetScope satellite data;
- the effect of the amount of foliar-applied urea on the spring barley NDVI was estimated;
- maps of the spatial distribution of barley NDVI, with the 10 cm spatial resolution (DJI Phantom 4 Multispectral UAV), were constructed for the plots with different amounts of foliar-applied urea during the 2020 growing season (June – August);
- barley phytomass and yields on the plots with different amounts of nitrogen fertilizer (urea) were estimated during the growing season by combining the PlanetScope satellite data with high temporal resolution and the UAV data with high spatial resolution;
- intra-plot heterogeneity of NDVI distribution was detected. This finding may be the basis for using precision agriculture. Selective application of fertilizer based on the actual distribution of NDVI becomes possible.

This approach can be used in management of other crop species in different Siberian regions. Based on UAV data, farmers will be able to manage the crops, use the applied resources (e.g., nutrients) effectively, and determine harvest dates.

Acknowledgement
The study was supported by Krasnoyarsk Regional Scientific Foundation within the framework of Project “Development and implementation of the method for early prediction of crop yield in the Siberian region based on remote sensing data”.

References
[1] Xu Y, Yu L, Zhao Y, Feng D, Cheng Y, Cai X and Gong P 2017 Int. J. Rem. Sens. 38 4459-80 doi:10.1080/01431161.2017.1323285
[2] Kouadio L, Newlands N K, Davidson A, Zhang Y and Chipanshi A 2014 Remote Sens. 6 10193-214 doi: 10.3390/rs61010193
[3] Rembold F, Atzberger C, Savin I and Rojas O 2013 Remote Sens. 5 1704-33
[4] Yang S, Yang X and Mo J 2018 Precis. Agric. 19 278-92
[5] Zhang C and Kovacs J M 2012 Precis. Agric. 13 693-712
[6] Tsouros D C, Bibi S and Sarigiannidis P G 2019 Information 10 349
[7] Sidko A F, Botvich I Yu, Pisman T I and Shevyrnogov A P 2017 Field Crop. Res. 207 24-9
[8] Rivero R G, Grunwald S, Binford M W and Osborne T Z 2009 Remote Sens. Environ. 113 2389-402