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APPLICATION OF HYPERSPECTURAL IMAGES AND GROUND DATA FOR PRECISION FARMING

ABSTRACT. Crops, like other plants, clearly react to various changes in both natural and anthropogenic factors (herbicides, pesticides, fertilizers, etc.), which affects the amount of phytomass, its fractional composition, and developmental and physiological state of the plant, and, accordingly, is reflected in the spectral image. Data on spectral characteristics of plants allow users to determine quickly and with a high degree of reliability various indicators of the state of agricultural crops and thus improve the efficiency of agro-technical practices and the use of land resources and facilitate the implementation of the precision farming concept. Reflective properties of plants (and hence crops) carry a large amount of meaningful information about the species, stage of development, and morpho-physiological state, allowing determination of the interrelations between the spectrometric characteristics and temporal physiological parameters.

The paper presents the results of monitoring of the state of winter wheat and corn in experimental fields in southern and central Russia in the spring and summer of 2016.

KEY WORDS: remote sensing data, hyperspectral images, precision farming, spectral characteristics, agricultural crops

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INTRODUCTION

Agriculture is one of the most successfully developing sectors of the Russian economy ensuring domestic needs of the country and success in foreign markets. In modern realities, sustainable development of agriculture is inextricably linked with precision farming and innovative information technologies. Geo-intellectual services enhance the effectiveness of agricultural and related activities. Satellite and aerial monitoring allows assessing the condition of crops and the results of technical and meliorative measures, reduces the cost of production, and increases yield. The effectiveness of hyperspectral remote sensing methods for diagnosing the state and course of various processes in agriculture has been widely discussed in scientific literature in recent years (Borengasser et al. 2007; Thenkabail 2011; Thenkabail 2014; Haboudane 2004; Liebisch 2015 etc.). A new generation of compact, light and relatively inexpensive hyperspectral cameras (Constantin 2017) installed on unmanned aircraft systems (UAS) (Liebisch et al. 2015; Constantin et al. 2015) has emerged. A significant reduction in the cost of these technologies has facilitated the use of hyperspectral remote sensing data (RSD) in precision farming.

Precision farming is a combination of technologies, tools, and decision-making systems in the integrated production and information system of agriculture, aimed at long-term improvement of efficiency and productivity for specific local conditions and minimization of the negative impact on the environment. The concept of precision farming is based on the concept of heterogeneity of plant growth characteristics within a single field. In this regard, various land management activities (e.g., application rates of fertilizers, lime, herbicides, and pesticides, irrigation, etc.) are carried out on each individual small plot. To implement the concept of precision farming, constantly updated high-detail cartographic material is necessary, which can be provided by remote sensing, particularly, UAS and hyperspectral methods. Timely assessment of the agricultural land conditions based on RSD is a key tool in implementing agro-services for regular monitoring of large areas.

The tasks of precision farming in relation to operational monitoring and agro-technical practices can be facilitated by RSD, especially ultra-high resolution imagery based on the analysis of sets of statistically reliable empirical information on the spectral characteristics of agricultural plants. Spectral images of agricultural plants vary depending on the heterogeneity of both natural conditions of the fields (e.g., hydrothermal, soil, geomorphological) and the agro-technical practices (tillage methods, irrigation, use of fertilizers, herbicides, pesticides, etc.) (Yakushev and Petrushin 2013; Thenkabail et al. 2014).

An important element of this crop monitoring system is based on specific identified relationships between the spectral characteristics and physiological parameters of plants in different periods of vegetation growth (Sidko et al. 2009). Such information allows users to determine quickly and with a high degree of reliability the various indicators of the state of agricultural crop and improve the efficiency of agricultural practices and the use of land resources in general (Zimin et al. 2014; Knizhnikov et al.2011).

The purpose of this study is to analyze the results of monitoring of the state of agricultural crops (winter wheat and corn) based on hyperspectral surveying and ground measurements. The following tasks have been addressed:

•ground measurements of the morphometric and spectral parameters and characteristics of winter wheat and corn in different vegetation periods and various applications of agro-technical practices were conducted;

•the technology of agricultural crops monitoring using a miniature hyperspectral camera was tested;

•correlation dependency between ground and aerial data using these quantitative data was obtained; and

•maps for experimental fields, reflecting the current state of agricultural crops, were compiled.

MATERIALS AND METHODS

The crops subjected to various agro-technical practices on the experimental fields of Syngenta company were studied in southern and central Russia in the spring and summer of 2016. In the Krasnodar region, on the experimental fields of winter wheat, the effects of various seed dressing were considered on test sites. To assess the drought resistance of various corn hybrids, three remote sensing surveys and ground-based studies were conducted on experimental fields in the Krasnodar and Stavropol regions of Russia. The ground-based studies included: spectroradiometric measurements (ASD FieldSpec 3 Hi-Res, OceanOptics Flame, and OceanOptics USB2000+ spectroradiometers), identification of the morphometric parameters of plants (height, density of crops, size, the number of ears of wheat or corn, etc.), measurement of the production of green phytomass (wet and absolutely dry weight), determination of the presence of weeds, and collection of samples for biogeochemical analyzes to obtain reference data. Hyperspectral survey of agricultural crops was carried out by a miniature hyperspectral camera Gamaya (41 spectral channels in the range 470-904 nm), installed on the "Geoscan" UAS, in different phenological stages of plants.

Our approach implied the simultaneous acquisition of ground and remote data. The ground-based spectroradiometric measurements were performed using calibration panels to obtain reflectance values. This allowed us to compare material from different studies and to obtain highly reliable results.

For the purpose of calibrating the UAS-obtained hyperspectral survey data, ground-based spectroradiometric measurements were used; these surveys were conducted synchronously on the calibration sites represented by open surfaces with average brightness (homogeneous sections of dirt roads or parts of fields with insignificant projective vegetation cover).

Investigations on winter wheat crops were carried out in an experimental field in the Krasnodar region in April-June, 2016, on six strips where seeds were treated with various dressings. On each of these strips, test plots (Fig. 1) measuring 5x5 m were marked, within which, during the hyperspectral survey (April 8-9, May 6-7, and June 29), ground measurements were taken to obtain obtain the reference data. Ground work included measurements of the morphometric characteristics of vegetation cover, sampling of plants (for further geochemical research and assessment of phytomass and moisture), and vegetation spectroradiometry in natural conditions.

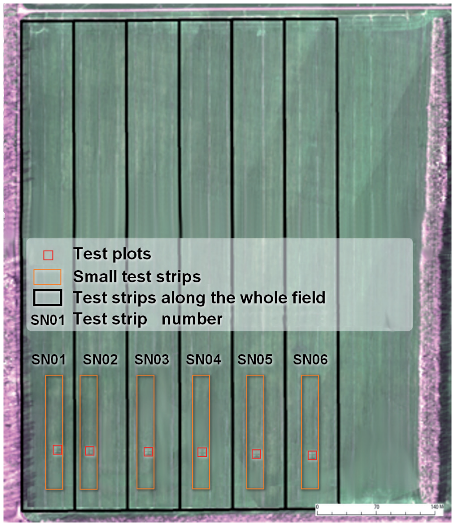

Fig. 1. An orthophotomosaic fragment of Gamaya camera images in natural colors, April 8, 2016, and the schematics of the locations of the test strips and plots

Because of specific characteristics of corn associated with its considerable height, the method of conducting fieldwork was somewhat different from the work with wheat. After the samples were taken, the cut plants were divided into parts (leaf surface, stem, ears) and separate morphometric measurements were conducted. Spectroradiometric studies were carried out only for the leaf surface of corn by placing leaves to create a 100% canopy under natural light conditions.

Thus, based on the combination of ground and remote sensing methods, reliable data have been obtained, which made it possible to identify the interrelationships between the spectral, geochemical, and morphometric characteristics of the studied plant species. The use of a series of integrated field studies is important for describing the correlation dependencies and understanding the relationships between spectral characteristics and vegetation developmental features (Bao et al. 2013; Sidko et al. 2009; Blackburn 1998), which is a reliable indicator of growing conditions (soil characteristics, meteorological conditions, relief, etc.), agro-technical practices, and vegetation stages.

Subsequent processing of the data obtained during fieldwork included spectral index, correlation, and expert approaches in the interpretation of hyperspectral imaging data, and was implemented both at the level of the test plots and strips and, in general, over the area of the experimental fields.

RESULTS AND DISCUSSION

The relative representativeness (wealth) of the information contained in the hyperspectral images compared with the multichannel imagery can be grasped by comparing the image obtained in the visible part of the spectrum, a natural color composite of the red, green, and blue channels, and the composite of the first three principal components for the 41-channel hyperspectral image (Fig. 2). Different colors in the chosen color palette correspond to the properties of the plants and here the difference in the detail of the object of the study, obtained by different types of survey, is clearly visible. The identification of such patterns and relationships of spectral characteristics with the biochemical and morphometric characteristics of the vegetation cover is one of the key directions in solving the problems of precision farming with respect to remote sensing methods and is the subject of such studies.

Hyperspectral imaging data were used to compile NDVI index maps based on two spectral channels (red [R] and near-infrared [NIR]). Fig. 3 clearly shows that when working with a wide spectral range, important differences in the state of plants are averaged and the difference in the values of the NDVI

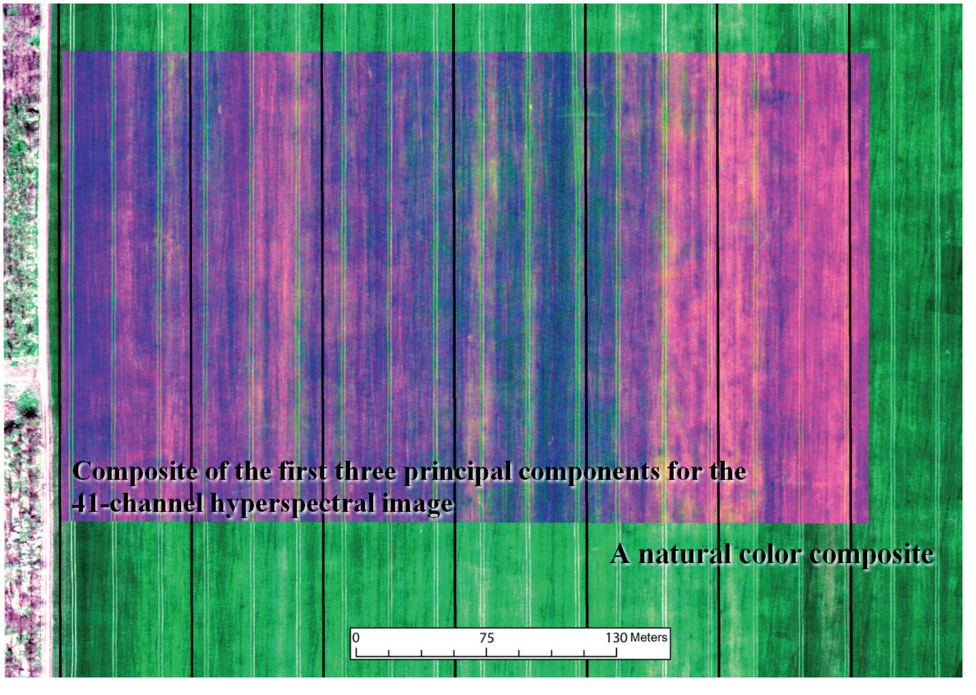

Fig. 2. The composite of the first three principal components for the 41-channel hyperspectral image (the Syngenta field). An enlarged fragment of the southern part of the field (April 9, 2016). of the locations of the test strips and plots

index is minimal. It should also be noted that the NDVI index maps represent only the relative characteristic of the phytomass value. It follows that the assessment of the state and characteristics of the vegetation cover should be based on a large number of narrow-spectral channels, which is realized by hyperspectral surveying.

The ground measurements data (spectral characteristics, phytomass, and nitrogen content in plants) and hyperspectral indices with reference to the survey data were used to compile maps of the green phytomass of the leaves of winter wheat (Fig. 4) and their nitrogen content (Fig. 5).

The maximum errors in assessing the indicators of crops on the compiled maps do not exceed 30% of the range of actually observed values. Based on the statistical processing of the data obtained at the three levels (test plots, small test strips, and test strips along the whole field (approx.1 km long) (Fig. 1), comparative diagrams were constructed (Fig. 6). As of April 8, 2016, the best state of plants was observed in the experiments SN01 and SN02, gradually deteriorating from SN03 to the worst conditions in SN05, and then sharply improving in SN06, almost to the level of SN01 and SN02. The experimental 5x5 m test plots, despite the heterogeneity of the state of the plants within each experiment, were representative for comparing the state of plants in various experiments, although their values were somewhat lower than on wider and longer test strips and the entire length of the strips of each seed dressing in the field.

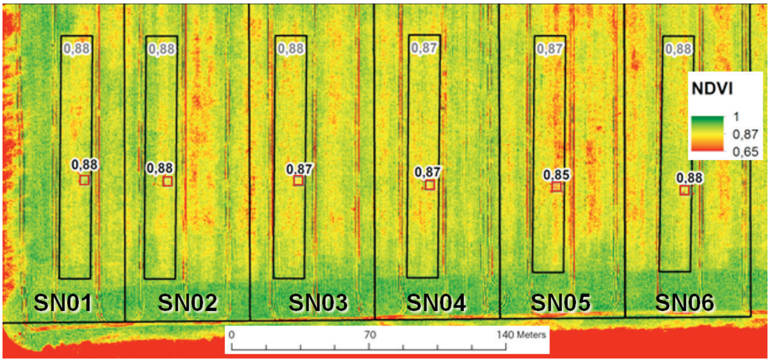

Fig. 3. Map of the NDVI index for the experimental winter wheat field, Yukka variety, April 8, 2016. Dark green, green, yellow, and red shades represent the maximum, medium, low, and zero values, respectively, of green phytomass. The numbers on the map show average NDVI values for the test plots (squares) and the larger strips (rectangles)

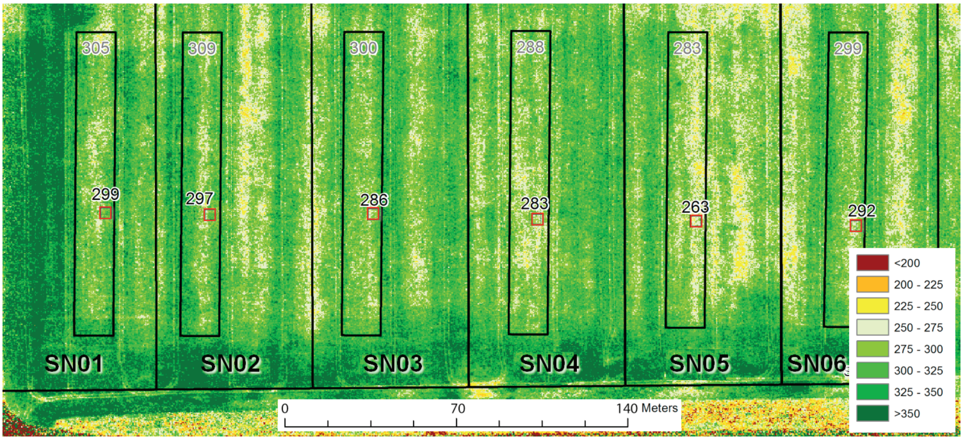

Fig. 4. Map of the green phytomass (g/sq.m.) of Yukka winter wheat leaves, April 8, 2016. An enlarged subset in the southern part of the field. The numbers on the map show the average phytomass values in the test plots (squares) and the larger strips (rectangles)

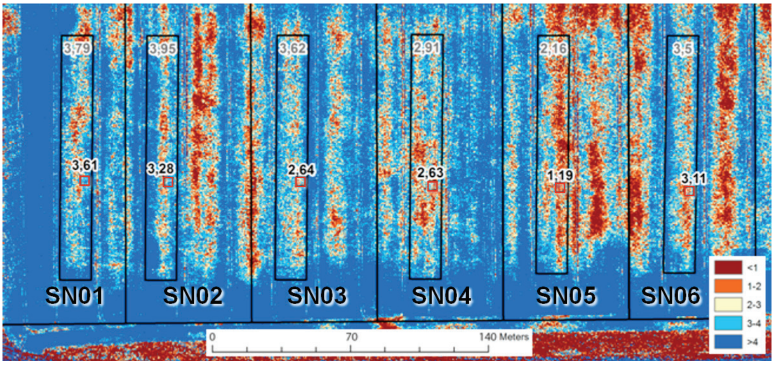

Fig. 5. Map of the nitrogen content (%) for Yucca variety winter wheat, April 8, 2016. An enlarged subset in the southern part of the field. The numbers on the map indicate the average values of nitrogen content of the plants of the test plots (squares) and the larger strips (rectangles)

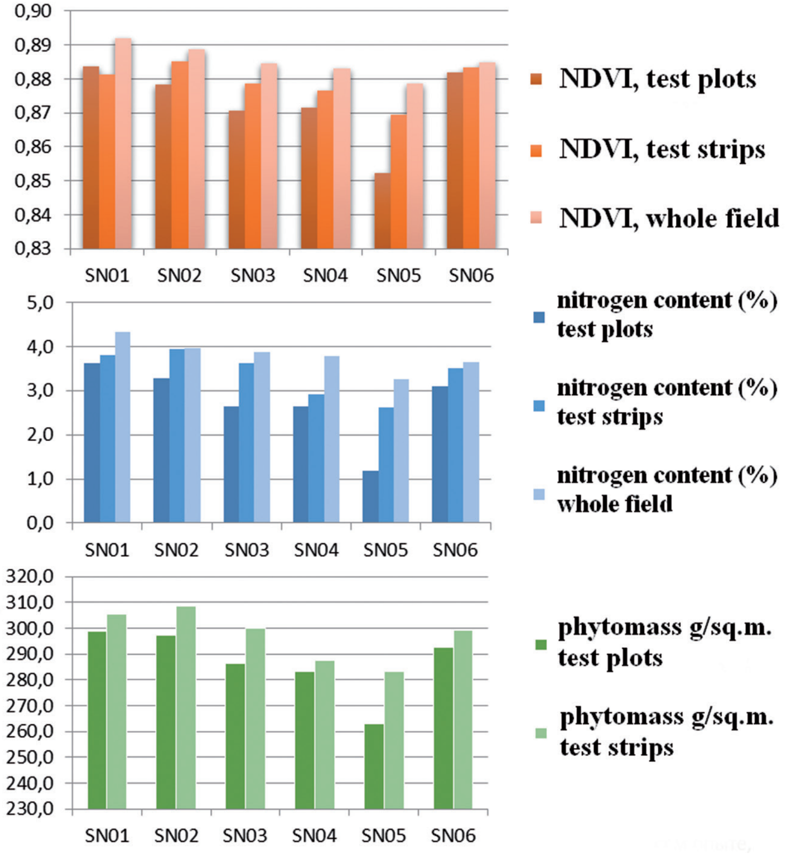

Fig. 6. The indicators of the state of crops obtained from the results of hyperspectral survey on April 08, 2016

Another way to utilize hyperspectral information is to analyze the graphs of spectral reflectance (Fig. 7). The measurements results showed that according to the data for April 8-9, 2016, the test plots SN01 and SN02, with the highest parameters, had a sufficiently high reflectance in the NIR range (greater than 750 nm) (associated with moisture and leaf

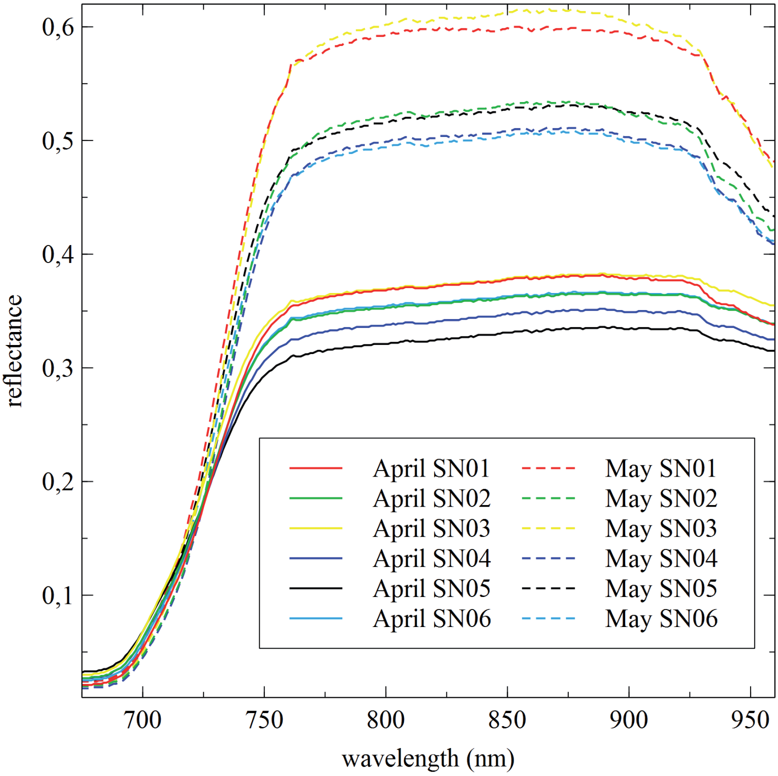

Fig. 7. Comparison of the reflectance graphs from the ground-based spectroradiometry data for Yucca variety of winter wheat. Dotted lines represent the data of April 9, 2016, and continuous lines represent the data of May 6, 2016

structure) and medium (relative to other test plots) reflectance at the red minimum (about 650 nm) (associated with the absorption of chlorophyll). The test plot SN05, with the worst state of plants, had a low reflectance in the NIR range and a high reflectance in the red spectral range. The test plot SN06, with relatively good plant condition indices, had a low reflectance in the NIR range and a low reflectance in the red spectral range, which indicates a sufficiently high chlorophyll content in plants, but poorer general conditions compared to SN01 and SN02.

To analyze the dynamics of wheat development from early April to the end of May, 2016, with the aerial survey data, we compared the results of hyperspectral surveys for April 8-9 and May 30, 2016, for the southern part of the field. Thus, by the end of May, NDVI had already fallen to an average of 0,77 compared with the beginning of April (an average of 0,88) (Fig. 8). At the same time, according to the available data from the Landsat 8 satellite, which is in good agreement with our data, the maximum NDVI was observed on April 23, 2016, and was about 0,9. According to our hyperspectral surveys on May 6, 2016, it reached 0,9-1,0. Thus, the maximum NDVI and green phytomass in the field were achieved in 2016 in late April - early May. By the end of May, the NDVI decreased to 0,77 (which was due to a decrease in the amount of chlorophyll in ripening wheat). On June 20 (according to the Tetracam camera survey), there was a decrease in NDVI to 0,40-0,60. It fell to 0,20-0,40 at the eastern margin of the field. In general, there was a good correspondence between the NDVI maps compiled from the satellite and aerial data, which makes it possible to use both types of sensors for monitoring of the general state of fields. However, NDVI did not provide sufficient differentiation between the experiments, which differ in the values of the index by only 1-2%. This, as already noted earlier, is due to the fact that the NDVI index was calculated from broad spectral bands.

The ground-based dynamics of wheat development from early April to the end of June, 2016, was obtained from the available data of the direct field measurements of spectral images of plants, as well as from the phytomass data. These data allowed analyzing the changes that have occurred in plants over one and three months. Thus, in May, the vegetation became much denser and the phytomass increased significantly, which was reflected in the increase of reflectance in the NIR part of the spectrum (Fig. 7). In May, as in April, the highest NIR reflectance was observed in the test plots SN03 and SN01. Small changes were noted in other test plots. Reflectance in the NIR range of SN02 closely followed the SN03 and SN01 values in April and May; however, in April, the identical values were associated with SN06, while in May, this test plot had the minimum reflectance values close to SN04.

SN05, which had the lowest values in April, became identical to the SN02 spectral image in May. Thus, the test plot SN05, with the strongest dressing treatment, caught up with the test plots that had average and good conditions, while the test plot SN06 (where a standard dressing treatment, as on the adjacent farm fields, was used) has slowed its development. The dynamics of the green phytomass values for the six test plots according to the April, May, and June data, is shown in Fig. 9. The dynamics of the phytomass values of the test plots has changed. In April, the highest values were observed for the test plots SN02, SN04, and SN06 and were approximately equal. The values for the test plots SN01, SN03, and SN05 were smaller and also approximately equal.

In May, there were significant changes visible in the test plot SN04, which had the largest phytomass in April, while the smallest in May. The test plot SN01 had a comparatively

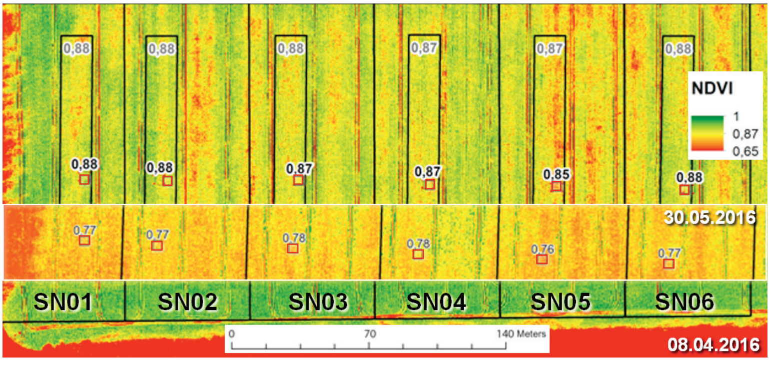

Fig. 8. The NDVI maps for April 8, 2016 and for May 30, 2016 (the enlarged fragment in the figure represent the southern part of the Syngenta filed). The numbers on the map indicate the NDVI values for the test plots (squares)

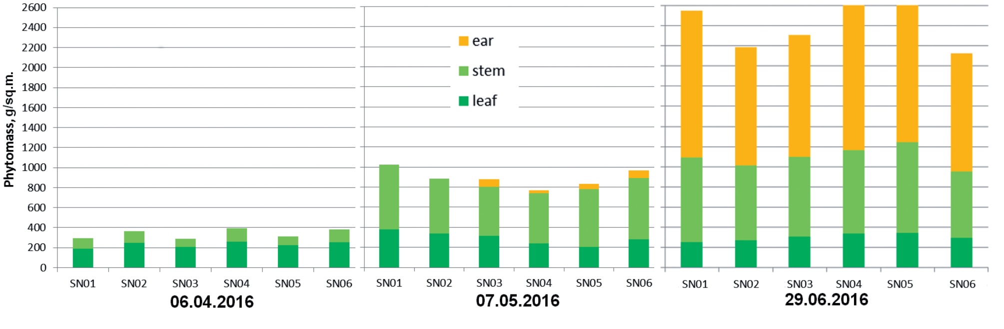

Fig. 9. Comparison of the green phytomass values for Yukka wheat variety in April (April 9, 2016), May (May 7, 2016), and June (June 29, 2016)

low phytomass in April; however, in May, it became the highest (has not yet formed ears of wheat). The test plots SN02 and SN06 that had a high phytomass value in April, retained their position in May, with one difference: ears of wheat did not yet appear on SN02. At the end of June, the situation changed again: SN05, along with SN01 and SN02, took the lead. Thus, despite the low green phytomass in early April, the wheat on SN05, treated with the strongest dressing, gradually increased the phytomass, had a high density of plants (according to the ground count), and yielded high crop, along with wheat on SN01 and SN02.

The second line of research on the assessment of drought resistance of various corn hybrids was carried out in cooperation with Syngenta company under the ARTESIAN project. The work was performed on the fields of the Stavropol and Krasnodar regions using UAS Gamaya hyperspectral survey and ground measurements of the crop state (Fig. 10).

Under conditions of stress, the NDVI index decreased and the corn hybrids differentiated according to their state, depending on the density of the crops and the efficiency of moisture intake through the root system. In addition, there was a clear deterioration in the state of crops from the middle to the end of July, 2016, due to drought (Fig. 10). In the Stavropol region, cultures had a higher green phytomass. Analysis of the crops reflectance confirmed the observed deterioration in the state of crops from the middle to the end of July, 2016, due to drought. In the Stavropol region, however, crops still had a higher green phytomass.

CONCLUSION

The study of the characteristics of spectral images of agricultural crops has enabled us to draw several conclusions. Firstly, to obtain reliable information on the state of crops, ground-based measurements of their morphometric parameters are

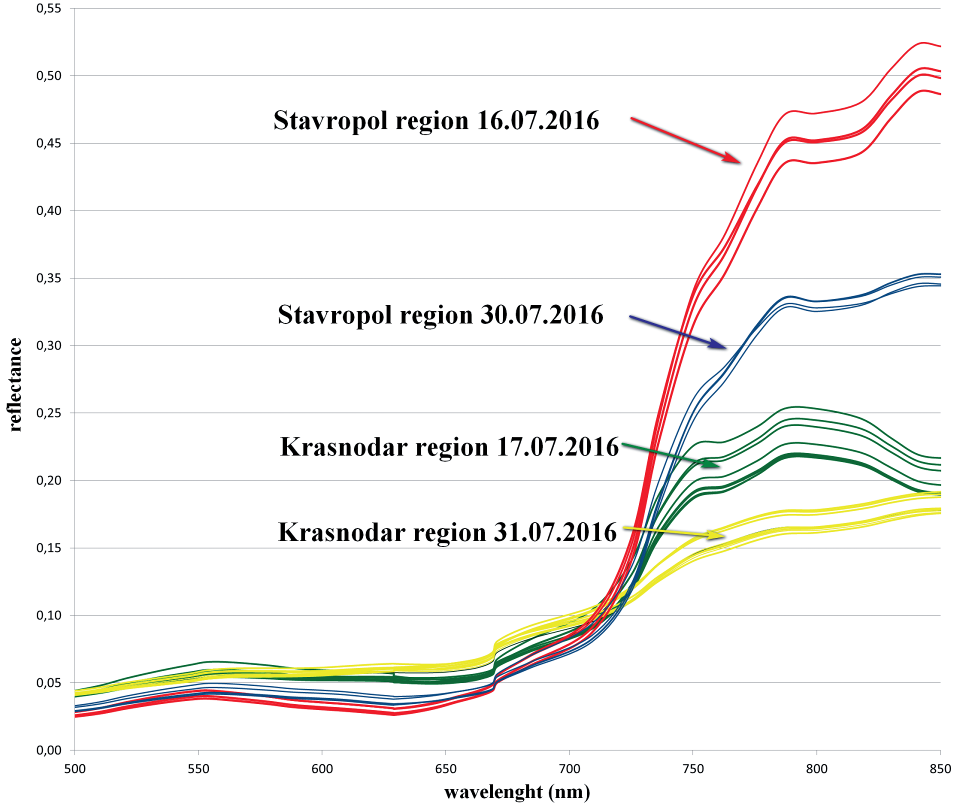

Fig. 10. The reflectance dynamics for various corn hybrids on 16-31 July, 2016, on two fields (Stavropol and Krasnodar regions)

required to obtain quantitative data and establish correlation dependencies between field experiments and hyperspectral survey results. Secondly, hyperspectral indices for the calculation of nitrogen content and plant phytomass are much more sensitive than NDVI. Thirdly, the use of a set of indicators, namely reflectance values, morphometric parameters of plants, and vegetation indices, is effective in interpreting data of aerial hyperspectral surveys and information support for precision farming. The proposed research methodology allows creating maps that reflect the current state of agricultural crops, and recommend the necessary timely agro-technical practices.

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