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The use of remote sensing, ground survey and the yield mapping system in the conditions of northern Kazakhstan for food production and food security

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Abstract

Food security is among the most important aspects of our physical health; it is necessary to live a full and peaceful life. Food security is a wide term that encompasses more than crop production since it necessitates taking into consideration geographical and temporal variability, along with economic and physical availability. Drought and salt stress are two major variables that restrict agricultural yield. These pressures are expected to worsen as a result of climate change, posing even greater threats to global food security. Earth remote sensing (ERS) using unmanned aerial vehicles is operational monitoring of the state of fields, the quality of processing of fallow lands; provides control of the degree of weediness of fields during the period of spring fieldwork, which makes it possible to rationally distribute agricultural machinery for closing moisture, intermediate treatments and pre-sowing chemical treatments sowing quality control; monitoring the vegetation index makes it possible to construct effective schemes for plant feeding, as well as effectively distribute agricultural machinery during the harvesting period, depending on the degree of crop maturation. The yield mapping system allows evaluating the effectiveness of precision agriculture techniques, making it possible to accumulate data on productivity zones, considering the actual yield.

Keywords: precision agriculture; earth remote sensing; UAV; satellite image.

Practical Application: The research results are of practical importance for teachers of higher educational institutions, researchers, managers and specialists of peasant farms and other agricultural enterprises.

1 Introduction

Food security is a severe issue all across the world, with a huge number of food production systems under jeopardy right now. According to estimates, food insecurity is expected to increase to more than 840 million people by 2030 (Chivenge & Sharma, 2019; Ncube et al., 2018). Meanwhile, it is expected that COVID-19, which is currently underway, would exacerbate the global problem of malnutrition (Laborde et al., 2020; Balwinder-Singh et al., 2020). Drought, nutritional, and salinity stress lower production by more than 50% in different regions, aggravating the food security issue. Furthermore, crops are typically stressed by a combination of factors, making food production even more difficult. The impact of these stresses must be evaluated and mitigated to allow for sustainable agricultural output and reduce the possibility of global food shortages (Seleiman et al., 2020). According to the Food and Agriculture Organization of the United Nations, salinity affects 11% of the world's irrigated land (34 Mha). India, Pakistan, United States, and China control more than 60% of the entire land area in the region (21 Mha) (Oruma et al., 2021; Raimi & Sule, 2021). Precision agriculture is a technology-enabled, data-driven approach to farming management that observes, measures, and analyzes the needs of individual fields and crops. Sensors on fields and crops are starting to provide literally granular data points on soil conditions, as well as detailed info on wind, fertilizer requirements, water availability, and pest infestations, which in addition to aerial images captured by unmanned aerial vehicles, or drones, which can patrol fields, can alert farmers to crop ripeness or potential problems and provide early warnings of deviations from expected growth rates or quality (Boubin et al., 2019; Gsangaya et al., 2020; Perakis et al., 2020).

Agricultural remote sensing is a key technology that, with global positioning data, produces spatially varied data and information for agricultural planning and prescription for precision agricultural operations with GIS (Kogan, 2019; Thenkabail et al., 2009; Thenkabail et al., 2012). Agricultural remote sensing data appear in different forms and are acquired from different sensors and at different intervals and scales. Agricultural remote sensing data all have characteristics of big data. The acquisition, processing, storage, analysis, and visualization of agricultural remote sensing big data are critical to the success of precision agriculture. With the most recent and coming advances of information and electronics technologies and remote sensing big data support, precision agriculture will be developed into smart, intelligent agriculture (Thenkabail et al., 2009; Thenkabail et al., 2012).

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Remote sensing with unmanned aerial vehicles (UAVs) is a game-changer in precision agriculture. It offers unprecedented spectral, spatial, and temporal resolution but can also provide detailed vegetation height data and multiangular observations (Jin et al., 2020; Kogan, 2019; Nhamo et al., 2020; Perakis et al., 2020; Yonah et al., 2018).

Satellite multispectral images have been widely used for production management in large areas. However, their observation is limited by the pre-defined and fixed scale with relatively coarse spatial resolution, resulting in limitations in their application (Hardhienata et al., 2008; Karthikeyan et al., 2020; Matejicek & Kopackova, 2010; Temple et al., 2019).

The Normalized Difference Vegetation Index (NDVI) is a commonly used vegetation index for a wide range of purposes. In crop production, NDVI is applied, amongst others, to monitor crop status and vigor, predict yields, and prescript doses of nitrogen fertilizers. The calculation of NDVI requires the reflectance in Near Infrared (NIR) and Red (RED) wavelength bands. These data may be obtained from several sources, e. g. ground sensors, unmanned aerial vehicles, airborne and satellite sensors (Huang et al., 2021; Sbahi et al., 2021; Boori et al., 2020; Sutisna et al., 2021).

Spatially variable field operations depend on various parameters such as in-field variations of soil and crop yield. A yield map can provide local information on nutrient absorption, variability of soil, and effects of special treatment strategies. In order to monitor the spatial variations of yield, the combine harvester has to be equipped at least with data acquisition for locating and measuring grain flow and area productivity. Accuracy of yield mapping can be increased by additional measuring of grain moisture, actual cutting width, and the dynamics of the grain transport within the combine (He et al., 2019; Z. Jin et al., 2019; Sahle et al., 2018).

In particular, monitoring crop yields can inform management interventions, food security efforts, research priorities, and commodity markets (Karthikeyan et al., 2020; Mutanga et al., 2017; Qu & Hao, 2018).

The aim of the work is to determine the effectiveness of the use of precision agriculture elements in Northern Kazakhstan by remote sensing of crops using satellite images and UAVs, as well as ground route surveys, the use of a yield mapping system. The article was prepared within the framework of programme and targeted financing of the Ministry of Agriculture of the Republic of Kazakhstan for 2021-2023 under the scientific and technical programme «Development and scientific substantiation of technical and technological parameters for the adaptation of space sensing technologies and precision farming according to the actual production tasks of the agro-industrial complex entities and the formation of the reference database necessary for this» (IRN – BR10865093).

2 Material and methods

The necessity to feed humanity and enhance the quantity and quality of food products in order to maintain food security from a developmental, environmental, and managerial standpoint has led to the adoption of new agricultural methods and technology (Bullock et al., 2017; Devereux et al., 2020; Wang, 2019). Plant breeding, genetically engineered foods, in vitro planting, and the expansion of closed ecological systems are all used to enhance food accessibility today. In addition to these techniques, precision agriculture, which uses contemporary technology, has been advocated as a means to attain food security (Lim & Lee, 2017; Lubis et al., 2017). Various technologies, including remote sensing and geographic information systems, are used to give early intervention to prevent the development of undesired occurrences, as well as the capacity to monitor crops in all phases of production, from tillage to post-harvest (Mutanga et al., 2017; Seutloali et al., 2018). In addition to the economic and environmental benefits of precision agriculture, social impacts include raising farmer knowledge via the use of contemporary technology and integrating scattered fields to achieve sustainability (Ejikeme et al., 2017). A precision agriculture system is not a strictly defined set of techniques and technical means, but rather a general concept based on the use of satellite positioning technologies (GPS), geographic information systems (GIS), accurate mapping of fields, etc.

The introduction of each of the stages of the precision agriculture system allows for the more economical use of resources involved in agricultural production: labor, equipment, and materials. This is the basis for the economic efficiency of the introduced elements of precision agriculture.

Using a portable instrument N-Tester, the level of nitrogen absorption by the culture was measured to determine its exact need. Work with the N-Tester was carried out by measuring the chlorophyll content in the leaves, directly in the field, without the use of auxiliary means, which is associated with the nitrogen state of the plant. The measurement point should be in the middle of the plate of the first fully developed sheet. Thirty random measurements in the field, performed using the usual «W» pattern, give the average value used to determine the amount of nitrogen a plant needs.

The GreenSeeker handheld system, a portable biomass sensor, is an easy-to-use measurement device that can be used to assess crop health and yield. The sensor displays the measured value in terms of reading the NDVI (Plant Green Index or Photosynthetic Activity Index) in a range of 0.00 to 0.99 on the LCD screen. The strength of the detected light is a direct indicator of the health of the crop; the higher the indicator, the healthier the plant.

For the NDVI and GNDVI indices, Sentinel-2 satellite imagery was used. The range of index values is -1-1. Maps of a qualitative assessment of the nitrogen content in the leaves of GNDVI plants were obtained in the Geoanalysis service. Agros is generated according to Landsat data with a spatial resolution of 30 meters. Temporary resolution: 16 days. The normalized difference Red Edge Index (Normalized Difference Red Edge Index, NDRE) indicator of photosynthetic activity of vegetation used to estimate the nitrogen concentration in the plant leaves using near-infrared (750-1000 nm) and extreme red (690-730 nm) channels. The index is applicable in assessing depressed and aging vegetation. It is effective in assessing the nitrogen content in plant leaves according to multispectral data, which have extreme red and near-infrared spectral channels.

AES «Zarechnoye» LLC purchased a Geoscan 101 unmanned aerial vehicle (UAV) equipped with a Sony A6000 multispectral camera. There is also a parachute that provides a soft landing. A flight task for a drone is created in the Geoscan Planer program, it is enough to select the boundaries of the studied field or download it from a file, and the program will send it to the drone (Figures 1, 2).

The obtained images are processed in the program 'Agisoft Metashape,' the vegetation indices are calculated (Figure 3).

Aerial photography of the investigated area was carried out at an altitude of 300 meters using a MicasenseRed-Edge camera while simultaneously obtaining photographic images of the object in different parts (zones) of the electromagnetic wave spectrum.

The survey was carried out over 19 fields in five spectral ranges: blue, green, red, extremely red, near-infrared. The total area of the rented territory was 3800 hectares. The aerial survey data were processed with specialized photogrammetric software to obtain multichannel (multispectral) field maps and orthophoto maps.

Based on the results of aerial photography for each field, the following products were generated: orthomosaic, dense point cloud, digital surface model (elevation map), processed digital surface model, textured georeferenced model of the territory (3-D model). On the basis of the created orthophoto maps, index maps of vegetation state were built (Figure 4).

Figure 1. Launch of the Geoscan 101 UAV from the catapult, «AES «Zarechnoye» LLC.

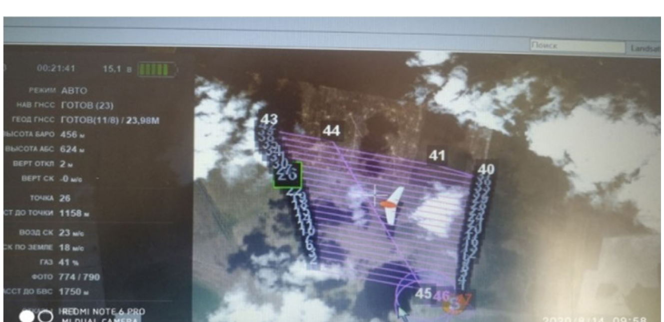

Figure 2. Flight task for the UAV «Geoscan 101», «AES «Zarechnoye» LLC.

At the main stage of image processing and analysis, maps of the normalized vegetation index (NDVI) and normalized vegetation index of greenness (GNDVI) were constructed using the spectral channels of the near-infrared (NIR), red (RED), red edge (REDEDGE), green (GREEN).

NDVI (NormalizedDifferenceVegetationIndex) – Normalized difference vegetation index is a simple quantitative measure of the amount of photosynthetically active biomass (commonly referred to as the vegetation index).

The NDVI calculation is based on the two most stable (independent of other factors) portions of the vascular plant reflectance spectral curve. In the red region of the spectrum, the maximum absorption of solar radiation by chlorophyll of higher vascular plants is manifested, and in the infrared region, there is the region of maximum reflection of the cellular structures of the leaf.

3 Results and discussion

Food security occurs when all people have economic and physical access to adequate, secure, and healthier food that fulfills their dietary needs and food choices for an improved lifestyle, according to the widely recognized definition of food security published by the United Nations in 1996 (Abdullah, 2019; Chen & Yu, 2021). Several variables, including the world population growth, the quantity of arable land available, the availability of water resources, climate conditions, and food accessibility and loss, are putting pressure on global food security. To build a complete picture of the effectiveness of the use of differentiated nutrition at the production testing area, we carried out a set of measures for remote and ground control at the designated plots.

In addition, a targeted effect of nitrogen fertilizers was carried out at the testing area, which implies feeding with liquid forms of mineral fertilizers during the growing season of spring wheat. The basis for foliar feeding is the measurement of the actual level of chlorophyll in the leaves, which is carried out by the portable device for leaf diagnostics «N-tester.»

In the period when spring wheat plants reached the stage of development «4-5 leaves – full tillering», photometric diagnostics of wheat plants with a portable device N-tester «YARA» and analysis of green biomass with a GreenSeeker device were carried out. Determination of the nitrogen status of plants during this period and its timely correction can reduce the impact of unfavorable factors and improve the general condition of plants (Figure 5, 6).

With values for the stubble predecessor below 300-350 units, corresponding to a low level of nitrogen supply to spring wheat plants, and for a fallow predecessor – below 400 units, which also correspond to a low level of plant nitrogen supply, the spring wheat crops were sprayed using the John Deere 4730 sprayer with a liquid mineral fertilizer «Strada N» with a consumption rate of 3.0 l/ha, a working fluid flow rate of 100-150 l/ha, with a wind speed not exceeding 3-4 m/s. This fertilizer is used for foliar feeding plants. The nitrogen concentration in the fertilizer is 27%.

For the purpose of additional diagnostics of the degree of supply of spring wheat plants with nitrogen in the phase of

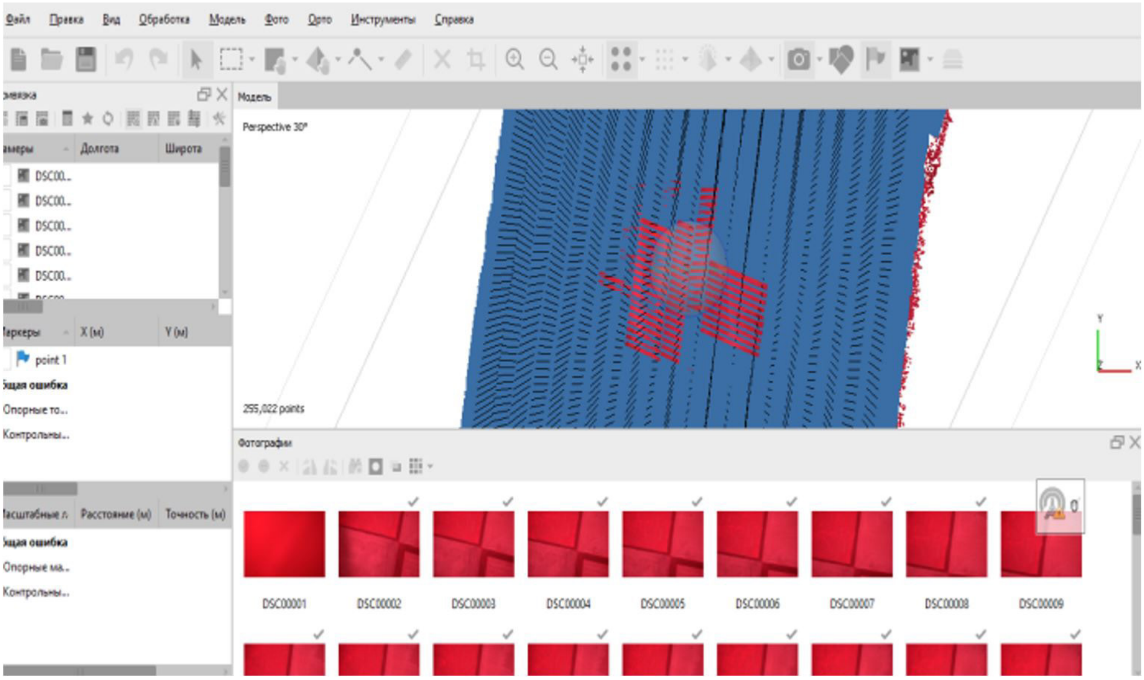

Figure 3. Processing of images from the UAV «Geoscan 101» in the program «Agisoft Metashape,» «AES «Zarechnoye» LLC.

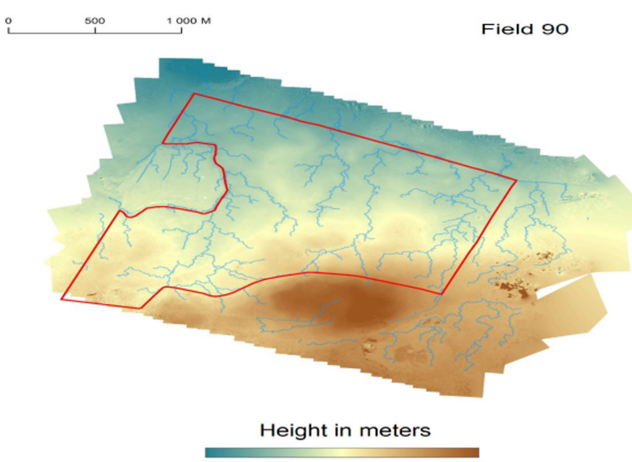

Figure 4. Digital elevation model and watercourses for field No. 90.

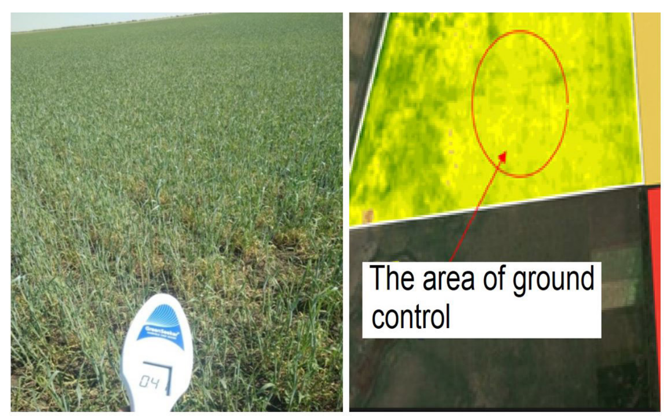

Figure 5. Working with a portable device Greenseeker on field No. 109 accounts. 9, experiment with the introduction of liquid fertilizer «Strada N» on spring wheat according to the stubble predecessor at a rate of 3.0 l/ha, 13.07.2020.

development «4-5 leaves – full tillering», aerial photography by an unmanned aerial vehicle GeoScan 101 was applied. This made it possible to normalize the obtained index GDVI images according to the values of the N-tester according to the data of ground measurements.

The data on the flight of the fields by the unmanned aerial vehicle GeoScan 101 served as the basis for creating a map of the differential application of foliar nutrition. The construction of prescription maps is based on taking into account the state of vegetation (Figure 7).

So, the calculated doses of the liquid mineral fertilizer «Strada N» were experimentally introduced in doses of 1.5, 3.0, and 5.0 l/ha during the tillering period with further tracking of all morphometric parameters.

Considering the readings of the N-tester and the nitrogen content in the leaves of spring wheat plants during the period of "leaf-tube formation-heading," according to the results of applying liquid fertilization, an increase in these indicators can be noted, which indicates a positive dynamic in the nitrogen status of plants. Thus, the increase in the N-tester readings, taking into account the foliar nutrition for the stubble predecessor, was 123 units for the fallow one – 163. The increase in nitrogen content in the leaves of spring wheat in terms of dry matter was 0.22% for the stubble, 0.27% for fallow (Table 1).

Figure 6. Determination of the nitrogen content in the leaves of spring wheat on seed crops with a portable device N-tester, 28.07.2020.

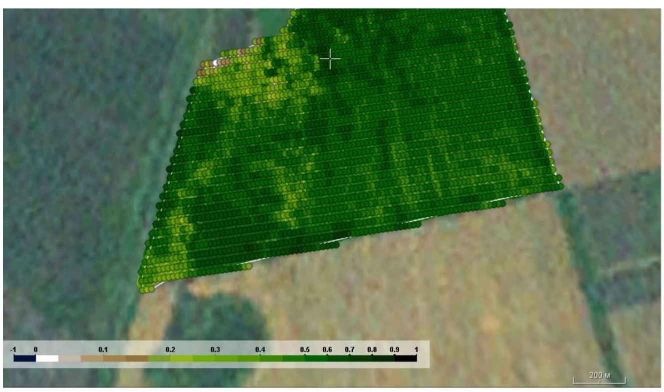

Figure 7. Stages of creating a technological map for the differentiated application of nitrogen foliar nutrition for field No. 109, 2019.

As a result of using the proposed method of cultivating spring wheat with a differentiated foliar application of nitrogen fertilization, the yield of spring wheat according to the stubble predecessor increased by 38.5% compared to the control. According to the fallow predecessor, the increase in yield in the variant with the introduction of liquid fertilizer «Strada N» with a consumption rate of 3.0 l/ha was 24.3% (Table 2).

Aerial photography from a drone gives larger and more detailed data in high resolution (including digital images), allows you to work in any weather (except for the wind), and examines large areas of crops. However, adequate lighting is essential for the camera to function properly.

Survey of agricultural fields using aerial photography allows you to optimize agricultural operations and identify various plant stresses, which helps reduce the economic costs of crop production.

As a result of the aerial photography, the NDVI index was obtained. In the tillering phase, the average NDVI value in field No. 94 ranged from 0.4-0.5; deviation from the average indicated a possible strong weediness of crops (Figure 8). In the course of the ground survey, it was confirmed that these plots had a strong degree of infestation with annual millet weeds. Thus, the use of such data in agriculture is highly justified.

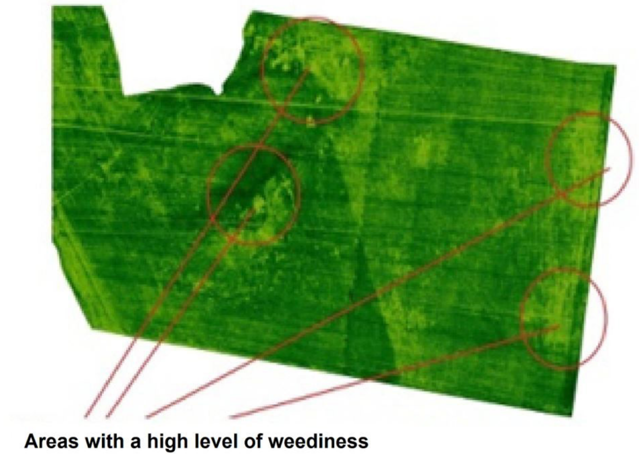

Figure 8. Detection of areas with a high level of weediness using UAVs, «AES «Zarechnoye» LLC

Table 1. Data on the change in the nitrogen status of spring wheat plants by the period «leaf-tube formation – heading» depending on the use of foliar nutrition.

Variants	Nitrogen content	
	increase in instrument readings (N-tester coefficient)	nitrogen growth (Dry matter), %
Control (no treatment)	–	–
Foliar feeding, according to stubble predecessors	+123	0.22
Foliar feeding, according to fallow predecessors	+163	0.27

Table 2. The effectiveness of the use of differentiated foliar nutrition of spring wheat plants.

Variants	Increase in yield, %
Control (no treatment)	–
Foliar feeding, according to stubble predecessors	38.5
Foliar feeding, according to fallow predecessors	24.3

Similar work was carried out on field No. 107. It also showed a high level of millet infestation (Figure 9), which was confirmed by a ground survey. Millet weeds develop faster than wheat and inhibit their growth, which in turn affects the yield. In particularly heavily infested areas, the NDVI is around 0.3, and the N-tester (nitrogen content in plants) is low. The NDVI map does not show bare areas of the field, while the wheat has not yet closed in rows, which is a sign of severe weediness.

Scientific research for the period 2018-2020, carried out at the precision agriculture testing area of «AES «Zarechnoye» LLC on an area of 4000 hectares, showed the effectiveness of Earth remote sensing (ERS) means in terms of accurately determining the stages of crop maturation. In parallel with the use of an unmanned aerial vehicle (UAV), monitoring was carried out using satellite images (Figure 10).

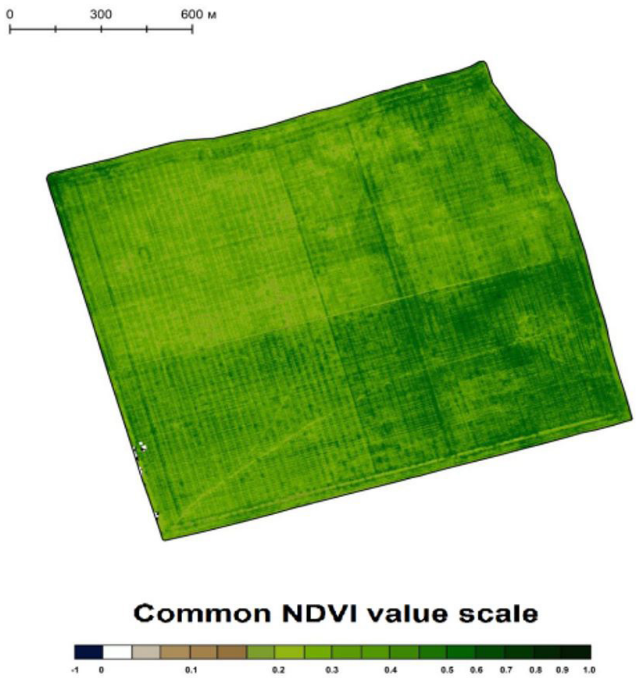

Figure 9. Generally accepted scale of NDVI values.

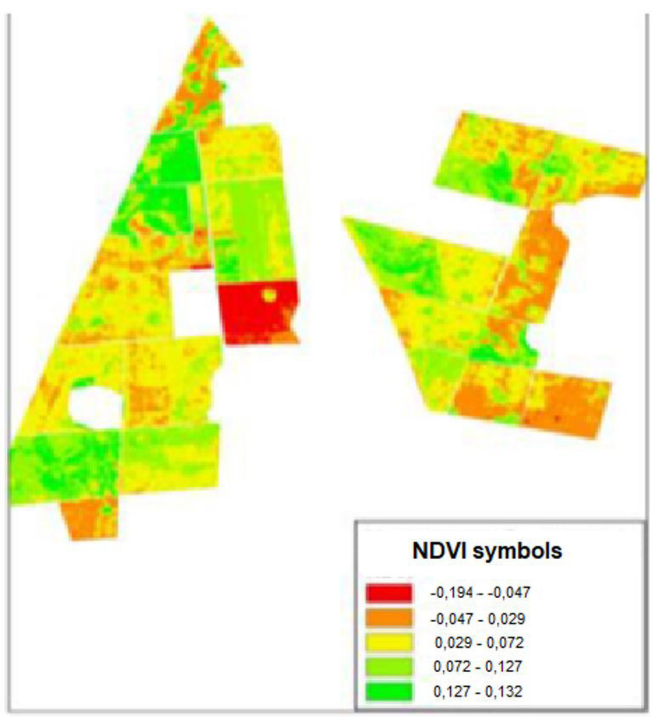

Figure 10. Monitoring of NDVI images by fields during the growing season 2019, «AES «Zarechnoye» LLC.

So, monitoring the vegetation index as a whole for the fields of the testing area made it possible to reveal the following in the conditions of 2019. In early August, a natural decrease in the index was observed, which was associated with a shortening of the growing season by more than 14 days due to an unusually severe drought and lack of productive precipitation, which manifested itself in a greater extent stubble predecessors at the testing area. The higher index from 0.127 to 0.302 belonged to the crop's fields, according to the fallow predecessor. The index in the range from -0.194 to -0.047 had fallow lands after treatment.

In Northern Kazakhstan, one of the main limiting factors of the yield of grain crops, including spring wheat, is the reserves of productive moisture. A common way of accumulating moisture in fields is fallow land. The efficiency of fallowing largely depends on how clean it can be from weeds. The use of a normalized vegetation index has proven itself very well during the pre-sowing campaign and while fallow lands treatment.

Thus, on the example of one of the fields of «AES «Zarechnoye» LLC, it can be seen that during the processing of glyphosate-containing products, a flaw was made. In general, after processing over the entire field, this index decreased, and the remaining green stripe, which, by the way, is not very noticeable from the edge of the field, was also processed after studying satellite images (Figure 11).

The algorithm for assessing the state of crops based on satellite data makes it possible to carry out an assessment at the level of a region, district, and an individual farm, where the state of crops is assessed in each individual field. Crop assessment maps are generated for each cloudless survey date.

At the next stage of the research, the yield on the control elementary plots of fields No. 101-103, No. 104-106, and No. 109 was revealed using the yield mapping system of the John Deere combine. The yield maps used for comparison are presented in Figures 12-16.

Figure 12 clearly shows that in the control variant, most of the elementary counting dots are colored orange and red, which corresponds to a yield in the range from 5 to 15 c/ha, while in the variant with fertilization, there are many dots with a green color, which corresponds to a yield of more than 20 c/ha. At the same time, it should be noted that there are distinct boundaries between the variants and the uniformity of coloring within the testing areas. According to the analysis of the obtained data on the plot without the application of fertilizers, the average yield was 14.1 c/ha, and in the variant, with the application of 29 kg/ha in the physical weight of amorphous, it is 22.5 c/ha. Consequently, the increase due to fertilization was 8.4 c/ha.

Figure 13 shows the comparison results on plot 15 of field No. 104-106. In the control variant, an accumulation of orange dots with an area of about 1/3 of the plot is highlighted, at the same level, but in the variant with fertilization, as well as on a larger plot area, dots with white color are displayed, which corresponds to a yield of 10 to 15 c/ha. Two adjacent passes of the combine on the border between the plots over a greater distance indicate a higher yield when fertilizing. The average yield on the plot without fertilization was 13.2 c/ha, and in the variant with the application of 29 kg/ha in the physical weight of amorphous was 14.6 c/ha. The increase was 1.4 c/ha.

Figure 14 shows the yield mapping data for plot 18 of field No. 101-103. On it, you can see orange and white stripes passing through both variants of the experiment, and there is no clear border between the variants. However, the average yield in the control variant is 11.6 c/ha, and in the variant with the introduction of amorphous at a dose of 19 kg/ha in physical weight was 14.0 c/ha. The difference between the variants is 2.4 c/ha.

In Figure 15, which shows the yield mapping data for plot 2, field No. 101-103, you can see 11 passes of the combine through both comparison variants. Most of these lines show a change in color towards an increase in yield when moving towards the variant with fertilization. According to the results of the analysis, the average yield on the plot without fertilization was 15.1 c/ha, and in the variant with the application of 29 kg/ha in the physical weight of amorphous – 16.9 c/ha, which exceeded the control one by 1.8 c/ha.

A similar picture is observed in Figure 16, which shows the results of mapping the yield in the sixth plot of field No. 109. At the border of the control and experimental variants, the yield increases in most of the bands. According to the results of all observations on the control, the average yield was 10.5 c/ha, and

Figure 11. Satellite image with the detection of flaws in the chemical treatment of the fallow land, «AES «Zarechnoye» LLC.

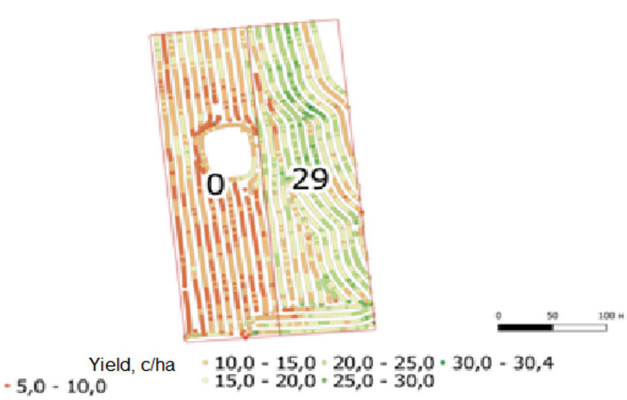

Figure 12. Crop yield on the control elementary plot 14, fields No. 104-106.

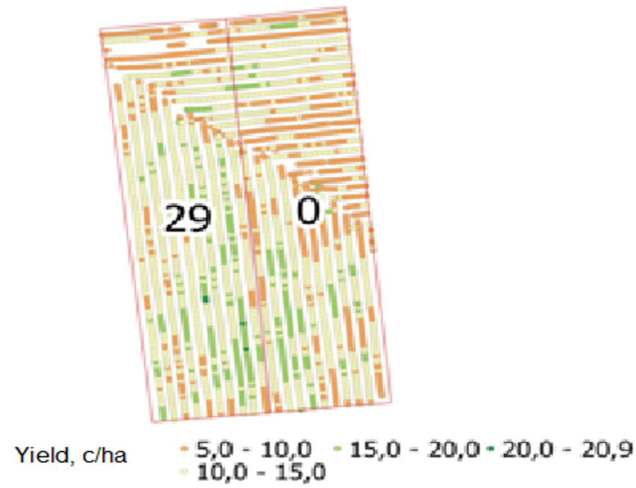

Figure 13. Crop yield on the control elementary plot 15, fields No. 104-106.

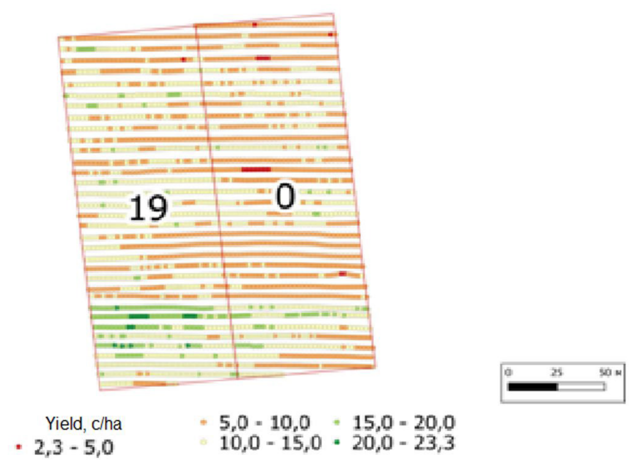

Figure 14. Crop yield on the control elementary plot 18, fields No. 101-103.

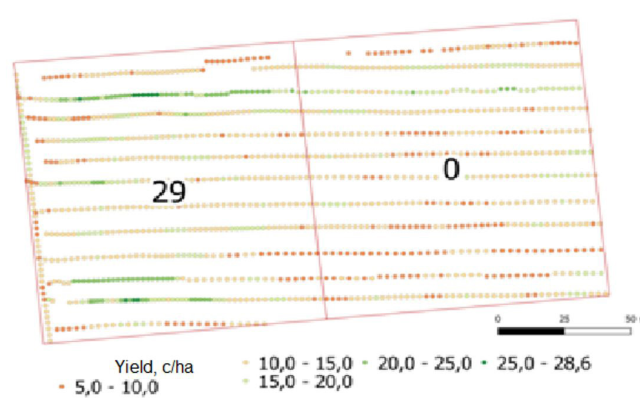

Figure 15. Crop yield on the control elementary plot 2, fields No. 101-103.

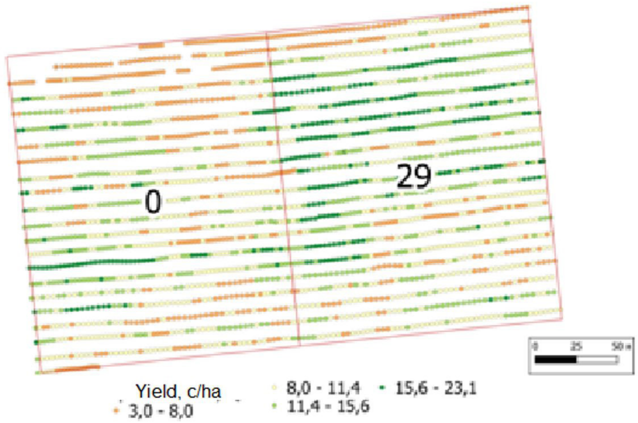

Figure 16. Crop yield on the control elementary plot 6, field No. 109.

in the variant with the introduction of 29 kg/ha in the physical weight of amorphous was 14.2 c/ha. The increase was 3.7 c/ha.

4 Conclusion

Agriculture meets two of humanity's most fundamental needs: food and fiber. Agriculture has been able to keep up with the rising demand for food and other agricultural goods because of the development of innovative farming techniques during the last century. However, increased food consumption, a growing population, and rising income levels are all projected to place further pressure on natural resources. With rising awareness of agriculture's negative environmental consequences, new techniques and approaches should be able to fulfill future food demands while preserving or lowering agriculture's environmental imprint. Thus, according to the results of comparing the yield maps of the John Deere combine in neighboring elementary plots, the following increments were obtained from the introduction of amorphous: at a dose of 29 kg/ha on the plots with a low degree of P_2O_5 supply – 1.4; 1.8; 3.7 and 8.4 c/ha, as well as 2.4 c/ha on the plot with the introduction of 19 kg/ha with an average supply of mobile phosphorus.

Ground route surveys are carried out in the main phases for all test fields; the state of crops according to remote sensing data is built so that each pixel of the satellite raster is assessed on the territory corresponding to the "arable land" object. Nevertheless, the percentage ratio of the gradations of the assessment of the state of crops of ground and satellite data practically coincides. However, in 2018-2020, the assessment of the state of some crops of grain crops based on ground surveys of fields on the farm and using satellite data was slightly different – according to remote sensing data, the percentage of good condition of crops is lower. So, the actual yield of cereals (spring wheat) in 2018 was 25.4 c/ha, in 2019 – 13.2 c/ha, in 2020 – 17.2 c/ha. At the same time, the weather can make significant adjustments to the types of crops in the conditions of Northern Kazakhstan. So, on crops with the earliest sowing dates (the first ten days of May) under the conditions of 2020, grain was poured in extremely hot weather in the absence of precipitation and dry winds. At the same time, in the heading phase on these fields, the vegetation index was noted within 0.5, and the visual assessment of the crops made it possible to draw conclusions about the expected yield at the level of 12-15 c/ha. However, as mentioned above, the actual weather did not allow the grain to fill up normally, which reduced the yield by two times. This is a low yield even for the climatic conditions of Northern Kazakhstan.

However, it is also worth noting that the level of agricultural technology and modern technologies have made it possible to minimize the influence of adverse factors at the landfill, reduce production costs, and obtain a yield level that exceeds the average regional level.

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