Evaluation of the influence of biologically active substances on the physiological processes of soybean plants with the use of multispectral camera and unmanned aerial vehicle

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Abstract. The influence of biologically active substances on the physiological processes of soybean plants with the use of a multispectral camera and unmanned aerial vehicle has been assessed in the article. The researches were carried out on soybean variety MK 100, cultivated on the experimental field of the All-Russian Scientific Research Institute of Soybean in 2018, Sadovoe village of the Amur region. The use of UAV with a multispectral camera made it possible to evaluate the physiological processes of soybean crops in microplot trials and to determine the state of the vegetation using NDVI and NDRE indices. The study of physiological processes was carried out at the biochemical level, where the peroxidase enzyme activity represents an adaptation marker. Under the study site conditions, the treatment with Pulsar herbicide in the phase of the third ternate leaf had a negative influence on soybean plants, as there is a decrease in the specific enzyme activity. The highest indicators of quantum yield of photosynthesis were observed in the stages of flowering and at the beginning of the pod formation that indicates a high activity of the photosynthetic apparatus. The studies aim to assess the influence of biologically active substances on the physiological processes of soybean plants using “DJI Matrice 100” UAV and “Micasense Red Edge” multispectral camera and with laboratory analysis comparison in various growth stages.

1. Introduction

In modern agriculture, the use of UAVs, which are a platform for data collection and an indispensable innovative measuring instrument for solving many tasks in this industry, nowadays is becoming more prevalent [1]. A set of modules, sensors, and software makes it possible to conduct automatic monitoring of the fields. Multispectral sensors help to analyze vegetation, calculate the vegetation index, the chlorophyll content in the leaves, observe conclusions of plant health in general, and predict crop yield. The given method is applied on a large scale in order to determine the zone with the worst vegetation with high accuracy [2].

The use of the NDVI index (normalized difference vegetation index) begins to spread rapidly in the agricultural sector, and the question of introducing these technologies into agriculture is becoming more relevant. Modern hardware, such as drones and multispectral cameras, make the analysis more informative and significantly expand their range of applications in agriculture [3]. NDVI index is a most useful indicator in the early and middle stages of growth: it shows the health of crops (for example,
weak growth or diseases of crops), measured by reflection in the near-infrared spectrum (NIR) and in the red spectrum, which is generally used to indicate greenness of vegetation. Thereby, NDVI is an index by which one can judge the development of a green mass of plants during the growing season [4,5].

An important area of research as expanding the use of chemical plant protection products in agricultural practice is to identify the specific action of herbicides not only on weeds but also on cultivated plants to determine the influence on the physiological processes in agricultural plants, growth, development, and formation of crop yield [6]. The use of endogenous biostimulants, created only on a plant basis, allows to provide low portions of herbicide consumption, creating environmental resistance to pests and diseases, as well as improving plant immunity to various unfavorable environmental factors [7].

The goal of the research is to assess the influence of biologically active substances on the physiological processes of soybean plants using “DJI Matrice 100” UAV and “Micasense Red Edge” multispectral camera and with laboratory analysis comparison in various growth stages.

2. Materials and methods
The researches were carried out on soybean variety MK 100, cultivated on the experimental field of the All-Russian Scientific Research Institute of Soybean, Sadovoe village of the Amur region, Russia, in 2019. Seed treatment was carried out with the preparations produced by ZAO “Ametis” through the processing Dahurian larch (Gmelina) on the day of sowing at the recommended dose. The natural plant growth stimulant BioLarics (active substances: taxifolin, diterpene alcohols, and hydrocarbons) is a water-soluble concentrate of larch resin with high fungicidal activity. The ecologically friendly growth regulator ExtraCor, whose active substances are taxifolin, proanthocyanidins, and paraoxybenzoic acid, contains an extract of larch bark and has antidote properties [8]. The treatment of vegetative plants was carried out with the Pulsar herbicide (active substance: imazamox) in the phase of the third ternate leaf at a dose of 0.8 l/ha.

Based on multispectral images, layersNDVI and NDRE indices were calculated, and a map in the color scheme was drawn up to visualize the state of the physiological processes of soybean plants according to a scale of the given index. The indices were calculated based on reflectance waves of different lengths recorded in the metadata of the images [1]. For obtaining the useful agronomic information, the formula should be applied to the raw data. QGIS software was used to calculate NDVI and NDRE indices. NDVI was defined as a ratio between the difference of infrared and red spectrum to the sum of bands as in equation (1). NDRE - as a ratio, as for NDVI, but instead of the red band, the red-edge band was used as in equation (2) [9].

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$ (1)

$$\text{NDRE} = \frac{\text{NIR} - \text{REDGE}}{\text{NIR} + \text{REDGE}}$$ (2)

For evaluating and analyzing soybean crops of the variety MK 100, we used “DJI Matrice 100” UAV and “Micasense Red Edge” multispectral camera, which provided for taking images in five spectra. Rededge spectral range, provided by the company MicaSense in its RedEdge camera, was used in our studies to measure a ratio of chlorophyll in the leaves, NDRE index. Red-edge wavelength of 717 nm provides a sensitive indicator of the chlorophyll content in leaves density and soil background effects.

For determination of the specific peroxidase activity, soybean plants were selected in the phase of the third ternate leaf in 24 hours after the plants were treated with the Pulsar herbicide and in the flowering phase. Peroxidase activity was determined by the method of A.N. Boyarkin in the modification of A.T. Mokronosov. The amount of protein expressed in units of activity per 1 mg of protein by the method of Lowry [10,11]. With the help of a portable analyzer for the photosynthetic yield with pulse-modulated illumination MINI-PAM fluorimeter, under the field conditions on soybean leaves in the development stages of ternate leaf and flowering, the state of the photosynthetic apparatus
was recorded.

3. Results and discussion

3.1. Vegetation indices analysis

Inspection of fields with the use of “DJI Matrice 100” UAV and “Micasense RedEdge” multispectral camera was carried out in 2018 during the growing season of soybean. Flight altitude was 10 meters from the ground. Photos from the camera were taken out and processed, and an electronic field map was created.

In the process of research, the method of index calculus upon the grid, in each separate block was used, based on plots in the experiment with herbicidal treatment and seed treatment with biologically active substances. NDVI index was calculated by the average value, and the NDRE index was calculated for verification of the clearness of the experiment. We represented both maps in figure 1.

NDRE image, we can see lower readings where less Nitrogen was applied. Chlorophyll has maximum absorption in the red band wave, and so red light cannot penetrate beyond a few layers of the leaf. Leaves are more translucent to red-edge light than red light; the red-edge wavelength penetrates a leaf much more deeply than red or blue wavebands. Therefore, NDRE is more suitable for middle and late growth stages, when crops have accumulated high concentrations of chlorophyll in the leaves, and a red light will penetrate poorly.

![Figure 1. Processed map of greeneries indices of soybean crop test in the Institute of soybean fields, Amur Region, Russia, in 2019. Left: NDVI layer. Right: NDRE layer. The higher the value, the better.](image)

After the preliminary processing of images, we obtained a map with the averaged index values separately for each block-plot (figure 2). It is determinate that the maximum indicator of the NDVI index is one, the closer to this indicator, the better the state of vegetation development in this area [12,13].
Figure 2. Processed RGB map, obtained by UAV from 10 meters altitude, of the field of Institute of Soybean, Amur Regin, Russia, in 2019. NDVI data were calculated by QGIS software for each plot. The greener the color and the higher the value, the better the state of vegetation.

Based on the obtained map, the data were analyzed in the QGIS program, and then their comparative analysis was carried out with the use of “box-and-whisker plot” (figures 3 and 4). According to the reflections of different wavelengths, the numerical values of the indices were calculated, further soybean plant development was assessed. The lowest value was noted in the variety with the use of Pulsar herbicide. The maximum indicator of NDVI was 0.75, in the case of applying the herbicide. In contrast, in the variants with seed treatment by biological preparations, the maximum rate reached 0.86, which is a significant difference. NDRE was pointed to inhibition of vegetation on plots with the use of Pulsar herbicide, and values ranged from 0.39 to 0.41.

Figure 3. NDVI (left figure) and NDRE (right figure) indices value of soybean crop state by the influence of various active substances in Amur Region, Russia in 2019.

The dependence of the obtained crop yield to the NDVI index is shown in figure 5. According to NDVI, the coefficient of determination R2 was 0.72. In the case of NDRE, it was 0.69. For the best correlation, the value of R2 should be more than 0.5. In the event of high determination, a model of prediction of crop yield by NDVI can be constructed. At this stage, we analyzed data on the determination of the suppressed physiological processes of soybean plants.
3.2. Analysis of the physiological state of soybean plants

In the realization of the adaptation potential of soybean plants, a particular part is assigned to peroxidase - a polyfunctional enzymatic system that can respond to a wide range of factors leading to a disorder of homeostasis in plant metabolism [14]. It was established that under field conditions, the treatment with Pulsar herbicide in the phase of the third ternate leaf hurt soybean plants, as evidenced by a decrease in the specific activity of the enzyme (in 2 times) (figure 7). The pre-sowing treatment of soybean seeds of the variety MK 100 by the being studied preparations BioLarics and ExtraCor led to the activation of metabolic processes in plant cells, as indicated by an increase in the level of specific peroxidase activity. We observed the highest activity of the enzyme in the phase of the 3rd ternate leaf – 80.6 u/mg of protein, in the flowering phase – 107.3 u/mg of protein. Compared with the control (54.7 and 45.6 u/mg of protein, respectively) in the treatment of seeds with ExtraCor and Pulsar herbicide in the being studied phases of development.

In order to study the influence of biologically active substances and Pulsar herbicide on the course of production processes, the state of the photosynthetic apparatus in soybean plants was recorded. Data analysis of fluorescence quantum yield showed that the highest value was observed in plants of control variant, regardless of the development phase of soybean plants, as well as with the use of herbicide in
phases of flowering and pod formation (table 1). Thus, this indicates a small part of energy went to the organic matter transformation and was released in the form of fluorescence.

**Table 1.** Influence of biologically active substances and Pulsar herbicide on the quantum yield of chlorophyll fluorescence in soybean leaves of variety MK 100 depending on the phase of growth and development, conditional units (c.u.).

| Test                                      | third ternate leaf | flowering | pod formation | seed filling |
|-------------------------------------------|--------------------|-----------|---------------|--------------|
| Control                                   | 613.7              | 466.0     | 384.5         | 507.8        |
| Pulsar, 0.8 l/ha                          | 531.0              | 394.0     | 383.6         | 434.4        |
| BioLarics, 20 g/t                         | 567.3              | 386.0     | 347.2         | 386.3        |
| BioLarics, 20 g/t + Pulsar, 0.8 l/ha      | 522.0              | 359.0     | 360.6         | 398.7        |
| ExtraCor, 20 g/t                          | 476.0              | 353.0     | 354.8         | 466.0        |
| ExtraCor 20 g/t + Pulsar, 0.8 l/ha        | 522.5              | 290.0     | 365.1         | 435.3        |

The highest rates of quantum yield of photosynthesis were observed in the phases of flowering and the beginning of pod formation: from 0.671 to 0.811 conditional units (c.u.) (figure 8), which indicates a high activity of the photosynthetic apparatus. The maximum values were in the variants with the use of ExtraCor and ExtraCor+Pulsar preparations: 0.804 and 0.811 conditional units (c.u.), respectively.

![Figure 6](image.png)

**Figure 6.** Influence of biologically active substances and Pulsar herbicide on the quantum yield of photosynthesis in soybean leaves of variety MK 100, depending on the phase of growth and development, conditional units (c.u.) 1 - Control, 2 - Pulsar, 3 - BioLarics, 4 - BioLarics+Pulsar, 5 - ExtraCor, 6 - ExtraCor+Pulsar.

4. Conclusion

The use of UAV with a multispectral camera made it possible to assess the physiological processes of soybean crops in microplot trials and showed the possibility of determining the state of vegetation using NDVI and NDRE indices. These indices showed that the use of Pulsar herbicide had a severe effect on the physiological processes of soybean plants, as evidenced by a decrease in the specific activity of the enzyme peroxidase. Natural preparations BioLarics and ExtraCor, influencing the intensity and direction of physiological processes, contributed to the reduction of the toxic load of Pulsar herbicide on soybean plants. Using NDVI and NDRE indices, it will be possible to construct a model for predicting crop yield for new soybean varieties of Amur breeding.

References

[1] Boiarskii B, Hasegawa H, Sinegovskii M and Boiarskaia A 2019 Application of UAV and multispectral camera for field survey in the Amur Region, Russia *CEUR*
Workshop Proceedings 2426 83-9

[2] Boiarskii B, Hasegawa H, Sinegovskii M, Sinegovskaiia V and Chepelev G 2019 Application of NDVI Data to Analyse the Effects of Sowing Methods and Seeding Rates on Soybean Crop Yield J. Eng. Appl. Sci. 14 4290-4

[3] Whelan B M and McBratney A B 2012 Downscaling for site-specific crop management needs? Digital Soil Assessments and Beyond - Proceedings of the Fifth Global Workshop on Digital Soil Mapping 1 353-6

[4] Tucker C J 1979 Red and photographic infrared linear combinations for monitoring vegetation Remote Sens. Environ. 8 127-50

[5] Tucker C J, Holben B N, Elgin J H and McMurtrey J E 1980 Relationship of spectral data to grain yield variation Photogramm. Eng. Remote Sens. 46 657-66

[6] Sinegovskaya V T and Chepelev G P 2018 Productivity of soybean crops, depending on the joint application of herbicides and biologically active substances in Primuranye Far East. Agrar. Bull. 2 44-51

[7] Shapovalov O A, Vakulenko V V and Prusakova L D 2008 Application technology of plant growth regulators Suppl. to J. “Protection Quar. plants” 12 70-88

[8] Mikhailova M P, Kamanina L A, Ostronkov V S and Kuznetsova V A 2017 Role of natural growth regulators in the soybean protection against herbicidal stress Trends agrophysics Dev. from Curr. Probl. farming Agric. Crop Prod. to Futur. Technol. 1 317-9

[9] Berni J A J, Zarco-Tejada P J, Suárez L and Fereres E 2009 Thermal and narrowband multispectral remote sensing for vegetation monitoring from an unmanned aerial vehicle IEEE Trans. Geosci. Remote Sens. 47 722-38

[10] Mokronosov A T 1994 Small practical work upon plant physiology (Moscow: Moscow, Publ.)

[11] Lowry O H, Rosebrough N J, Farr A L and Randall R J 1996 Production of ethyl butyrate using gel-entrapped Candida cylindracea lipase J. Ferment. Bioeng. 82 404-7

[12] Olioso A, Carlson T N and Brisson N 1996 Simulation of diurnal transpiration and photosynthesis of a water stressed soybean crop Agric. For. Meteorol. 81 41-59

[13] Boiarskii B, Hasegawa H, Muratov A and Sudeykin V 2019 Application of UAV-derived digital elevation model in agricultural field to determine waterlogged soil areas in Amur region, Russia Int. J. Eng. Adv. Technol. 8 520-3

[14] Minibaeva F V. and Gordon L K 2003 Superoxide Production and the Activity of Extracellular Peroxidase in Plant Tissues under Stress Conditions Russ. J. Plant Physiol. 50 411-6