Normalized Difference Vegetation Index (NDVI) in Assessment of Grain Crop State

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Abstract. The results of studying the dynamics of the NDVI of winter triticale crops in the conditions of the Northwest of Russia are presented. The NDVI was determined based on remote sensing data obtained by two methods including satellite imagery and aerial photography from an unmanned aerial vehicle (UAV). The analysis of the dynamics of the NDVI of the surveyed area for the period from May 15 to August 8, obtained from the Sentinel-2 L2A satellite, showed the dependence of the index on the increase in biomass of winter triticale by the periods of its growth and development, as well as on the meteorological conditions of the growing seasons. The sharpest increase in the vegetation index was noted in the period from the beginning of June to the beginning of July, which corresponds to the phase of entering the tube — filling of winter triticale grain. In the most favorable weather conditions, the vegetation index reached 1.0, which indicates the formation of dense vegetation by triticale crops. It is confirmed that the strong dependence of the average NDVI on yield occurs against the background of a decrease in the value of the vegetation index. The conducted aerial photography showed the presence of spatial heterogeneity in the studied fields, which caused uneven growth and development of winter triticale plants within the boundaries of one field. The shortage of grain from each hectare will be about 200 kg. In this regard, it is recommended to apply precision farming using NDVI mapping schemes with reference to point-based field surveys.

1 Introduction

Scientific research and work experience of the leading agricultural enterprises of the Novgorod region show that resource-saving technologies are important components of efficient production. During 2019–2022, scientific research works on the topic were carried out at the Rossiya Agricultural Production Cooperative of the Soletsky district of the Novgorod region: Development of a resource-saving feed conveyor to increase the productivity of dairy farming [1]. To optimize the timing of planting and harvesting, conduct operational monitoring of the phytosanitary condition of crops, predict yields and reduce costs due to point and differentiated fertilization in the system of resource-saving technologies, it is necessary to use digital technologies [2, 3]. These measures will contribute to improving the efficiency of agricultural production.

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Digitalization will allow changing traditional technologies to more efficient agricultural production. The data obtained from various sensors and automated control devices make it possible to identify certain patterns for the growth and development of plants, the operation of agricultural machinery, and therefore will affect the main processes in agriculture [4, 5, 6, 7].

The role of digitalization in precision farming is especially great, which makes it possible to level out soil heterogeneity within a single field, which affects the growth and development of crops in certain areas of the field. Such spatial variation of the soil and vegetation cover is due to both natural and anthropogenic factors. The use of high-tech systems in agriculture will allow us to obtain the maximum volume of high-quality and cheapest agricultural products [8, 9, 10].

The use of multispectral aerial photography in agricultural production makes it possible to assess the degree of spatial variation of vegetation cover within a single field. One of the most promising parameters for evaluating crops is the Normalized Difference Vegetation Index (NDVI), which is a simple indicator of the amount of photosynthetically active biomass, for vegetation this index takes positive values ranging from 0.2 to 0.9, and the greater the green phytomass of plants at the time of measurement, the closer the NDVI value is to one. At the same time, due to the relativity of this parameter, it is not possible to estimate the absolute value of the biomass of green leaves, however, it is possible to reliably assess how well or poorly the crop is developing [11, 12, 13]. It is used to optimize the timing of planting and harvesting, to conduct operational monitoring of the phytosanitary condition of crops, forecasting yields and reducing costs due to point and differentiated fertilization in a system of resource-saving technologies. Identification of sites of soaking in agricultural fields will allow timely hydro and agrotechnical measures and, thereby, increase crop productivity. The use of digitalization in agriculture makes it possible to predict the potential yield of crops with high accuracy and apply timely measures to prevent crop losses.

While the world and European experience in agricultural work is already directly related to information technology, this area is still not being used enough in the dairy farming industry.

An analysis of the agricultural activities of leading enterprises in the region within the framework of research work on the introduction of resource-saving technologies using multispectral aerial photography has shown that in order to increase production efficiency, first of all, it is necessary to increase the productivity of forage crops, optimize their mowing time and take measures to reduce crop shortages caused by the heterogeneity of soil and vegetation cover within one field.

The purpose of the study is to evaluate winter triticale crops according to the NDVI, aimed at improving the livestock feed base in the Novgorod region of the North-West of Russia.

To do this, the following tasks were solved:

1) analysis of the phytosanitary condition of vegetation using multispectral aerial photography;

2) calculation of the vegetation index for the periods of growth and development of winter triticale;

3) forecasting the yield of grain crops;

4) conducting a survey of the relief and alignment of fields.

2 Materials and methods

The research was carried out within the framework of the ongoing Plan for Scientific and Technical Development of Agriculture in the Novgorod Region for 2018–2025 based on statistical reports from leading agricultural enterprises in the Novgorod region, data from experimental observations and records, as well as data from feed quality tests. Observations

and yield accounting were carried out according to the methods of the Institute of Feed Research (1971, 1987).

Multispectral aerial photography was carried out in fields with crops of winter triticale of the Nemchinovskaya 56 variety, which is a grain-forage crop characterized by high winter hardiness.

The meteorological conditions of the growing seasons of 2021–2022 were not the same. The distribution of precipitation over the months of the 2021 growing season was uneven. In July, there was an acute lack of moisture, whereas in August, during the harvesting period, the amount of precipitation fell 3.5 times higher than the average annual data. The hydrothermal coefficient was 1,85, which characterizes the year as excessively humid.

In 2022, high air temperatures were combined with insufficient moisture in the soil. The hydrothermal coefficient was at the level of 0.83 characterizing the conditions of growth and development of winter triticale as arid.

The NDVI index was determined on the basis of remote sensing data obtained by two methods: satellite imagery and aerial photography from an unmanned aerial vehicle (UAV).

Satellite imagery from an area of 84.4 hectares was obtained using the EOS Land Viewer service for the period from May 15 to August 10. The Sentinel-2 L2A artificial Earth satellite (ISS) was used as shooting equipment, under 35VPE shooting conditions, the angle of incidence of sunlight <55 °, the cloud cover of the shooting square <15%. The materials of multispectral aerial photography were obtained using a Geoscan Lite aircraft-type UAV with two Sony α6000 (RGB) cameras and a modified Sony α6000 camera for shooting in the near infrared spectrum (NIR) with an accuracy of 0.3 m in plan and 0.5 m in height in the coordinate system WGS-84 EPSG: 4326. The bitmap images obtained from the Sentinel-2 L2A satellite and the Geoscan Lite UAV were converted into an NDVI image using the EOS Land Viewer, as well as Agisoft Metashape software and GIS Sputnik.Agro.

A discrete scale from -1 to 1 with coloring in colors from red to green, respectively, was used as a display of the NDVI value. Each value of the NDVI in EOS Land Viewer was assigned a standard qualitative characteristic of the vegetation state with a certain step and the size of the occupied area by vegetation with a certain index value.

A digital relief model and a 1:5000 scale map of slopes and water runoff of the surveyed area were formed based on remote sensing materials obtained using UAVs. These cartographic materials were prepared by photogrammetric processing of aerial photographs in the AgisoftMetashape software. The spatial resolution of the digital relief model and the slope and water flow diagram map is 30 cm/pix, the accuracy of constructing water flows is 1.0 m with catchment area thresholds of 2142.0 m2. The values of the terrain slope ranges are taken from 0° to 8° in increments of 3°. Slope calculations and modeling of water runoff was performed in the software GIS Sputnik.Agro.

3 Results and Discussion

One of the leading grain-forage crops in the North-West of Russia is winter triticale, which is characterized by high nutritional and feed advantages and has increased resistance to adverse conditions.

An analysis of the dynamics of the NDVI of the surveyed area during 2021–2022 for the period from May 15 to August 8, obtained from the Sentinel-2 L2A satellite, showed the dependence of the index on the increase in biomass of winter triticale by periods of its growth and development, as well as on the meteorological conditions of the growing seasons.

During the tillering phase, grain crops formed moderate vegetation. According to the data obtained, the average value of the NDVI was 0.6.

The sharpest increase in the vegetation index was noted in the period from the beginning of June to the beginning of July, which corresponded to the phase of entering the tube —

filling of winter triticale grain. According to the data obtained, the vegetation index reached 1.0 in some areas, that is, winter triticale formed dense vegetation in these areas. The average value of the NDVI during this period varied from 0.6 to 0.8, which indicates the formation of moderate and dense vegetation of grain crops during this period.

Changes in the NDVI of winter triticale crops over the years of research were less pronounced. Meteorological conditions had the most noticeable effect on the average values of the vegetation index in the period from mid–June to early July during the earing phase — filling of winter triticale grain. During this period, in 2021, the monthly precipitation rate fell in the second and third decades of June, whereas in early July, winter triticale plants were acutely lacking moisture due to the complete absence of rains (Fig. 1).

The NDVI did not exceed 0.6, which indicates the formation of temperate vegetation. In 2022, the most favorable meteorological conditions contributed to the formation of the maximum NDVI value. In the phase of winter triticale entering the tube on June 20, the vegetation index was 0.8. At the same time, grain crops formed dense vegetation.

During the grain filling period in early July, the average NDVI decreased to 0.6, crops formed moderate vegetation. During this period, as the plant developed, such features as the height of sowing, the power of development, the orientation of the leaves, the diameter of the stem began to correlate more with the value of the vegetation index. At the same time, a connection was observed between the formation of triticale grains and a decrease in the value of the vegetation index.

The weather conditions of the post-harvest period in both years of research had a positive effect on the growth of weeds after harvesting winter wheat. Due to the formation of a significant vegetative mass by weeds in the vacated field, the average value of the indicator coefficient was 0.4 indicating the formation of slightly sparse vegetation.

The aerial survey of the fields showed that all the studied fields have spatial heterogeneity. Due to the uneven terrain of the site, the heterogeneity of agrochemical soil indicators, winter triticale crops are characterized by unequal growth and development conditions, which determines the uneven development of plants within the boundaries of one field.

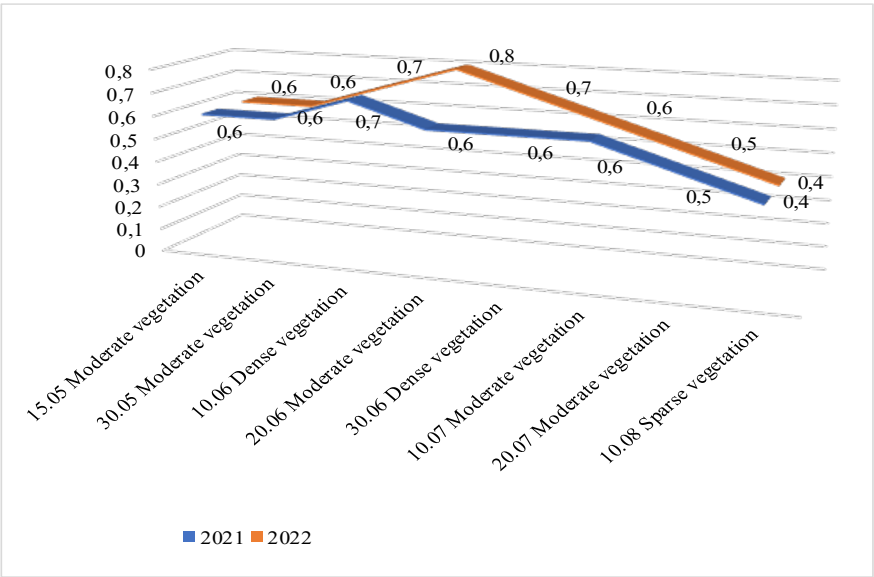

Fig. 1. Dynamics of changes in the vegetation index (NDVI) by dates of multispectral aerial photography, 2021–2022.

According to the average values of the vegetation index during the filling of winter triticale grain, the area with sparse vegetation accounted for 24% of the total field area. The third part of the studied area was occupied under moderate vegetation, 42% of the field area was characterized by dense wheat crops (Fig. 2).

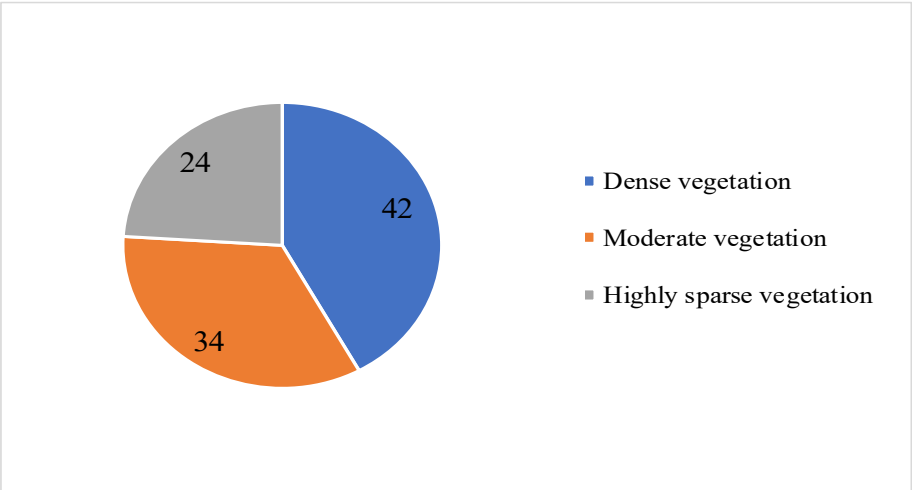

Fig. 2. Phytosanitary status of winter triticale crops, %, on average 2021–2022.

To assess the crops of winter triticale, its biological yield was determined depending on the phytosanitary condition of the vegetation. Forecasting grain yields according to the NDVI index based on images is possible from the middle of the growing season [11]. Therefore, during the grain filling phase, maps, schemes of the NDVI, were built for the purpose of phytosanitary assessment of winter wheat crops.

Crops are characterized by certain elements of biological yield, including the number of productive shoots per unit area and the weight of 1000 seeds (Table 1). The Nemchinovskaya 56 variety winter triticale crops were adopted as the standard, which in the conditions of the Novgorod region forms about 2.2 tons of grain per 1 ha.

Dense vegetation has formed about 780 productive shoots per 1 m^2. At the same time, the biological yield was about 3.9 tons of grain per 1 ha, which was almost 1.8 times higher than the control variant.

Table 1. Productivity of winter triticale crops, on average in 2021–2022

№	Phytosanitary condition of vegetation	The number of productive shoots per 1 m^2, pcs.	Weight of 1000 grains, g	Biological yield, t. of grains per 1 ha	Biological productivity	
					+/- to control, t from 1 ha	+/- to control, %
1	Standard	300	40.2	2.20	-	100
2	Thick	780	39.5	3.85	+1.65	+175.0
3	Moderate	390	40.3	2.66	+ 0.46	+120.9
4	Highly sparse	210	38.7	1.36	- 0.84	- 61.8
	NSR_{05}				0.48	14.6

With moderate vegetation, about 390 shoots were formed per 1 m^2, which led to grain harvest of about 2.7 tons per 1 ha. The increase in yield was not significant in relation to the standard.

In highly sparse areas, the number of productive shoots did not exceed 210. The biological yield of winter triticale in this case was significantly lower than the control variant and amounted to 1.36 tons per 1 ha (Fig. 3).

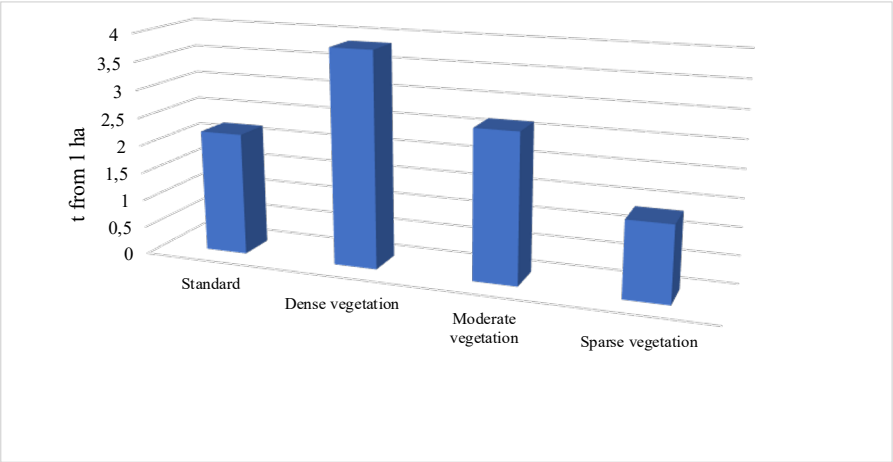

Fig. 3. Biological yield of winter triticale depending on the phytosanitary condition of vegetation, on average in 2021–2022.

Thus, the uneven development of vegetation had an impact on the potential yield losses of winter triticale. The shortage of grain from each hectare in areas with highly sparse vegetation amounted to about 200 kg.

The main reason for the unevenness of grain crops is the topography of the soil. The assessment of the fields for the presence of ditches, the establishment of the relief shape and the direction of water runoff showed that the relief of the surveyed area has a decrease in the direction from south-west to north-east with the highest mark of 72.51 m above sea level and the lowest mark of 48.28 m above sea level (Baltic elevation system). Based on the slope and water runoff maps carried out using unmanned aerial vehicles, the slope of the terrain in the study area reaches 8%.

4 Conclusions

In order to improve the forage base of farms in the Novgorod region and increase the productivity of winter triticale, it is necessary to outline agrotechnical measures for leveling the soil surface, spot fertilization, which will allow leveling the spatial variation of soil and vegetation cover and increase the uniformity of winter triticale development over the entire field area and reduce the loss of unassembled grain.

It is recommended to use NDVI schematic maps linked to point-based field surveys to assess plant biomass and predict grain yields starting from the middle of the growing season.

The use of digital technologies, including methods of remote sensing of the Earth and geoinformation technologies, in agricultural production will help optimize the timing of planting and harvesting, conduct operational monitoring of the phytosanitary condition of crops, predict yields and reduce costs through point and differentiated fertilization. Due to the fairly active development of resource-saving technologies, precision farming systems and the availability of equipment, the materials of the survey of agricultural land by remote methods can be successfully used to generate prescription maps and used in positioning systems, GPS/GLONASS agronavigators and course indicators installed on agricultural machinery to optimize agrotechnical work.

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