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# Monitoring of state of provision with moisture of crops according to remote sensing of Earth

Goal. To determine the connection between the spectral characteristics of agricultural crops and the moisture content of their crops. To develop a system for monitoring the state of moisture content of crops on various administrative levels in different natural-landscape conditions according to space debris data. Methods. A method for determining the provision of moisture crops according to the data of remote sensing of the Earth, based on the complex use of satellite data of various spacious differentiation and catch-based terrestrial data, has been developed. Results Under the vegetation growth indices obtained from the data of space deposition of low spatial resolution of NOAA, an analysis of the vegetation status in accordance with the natural climatic zones was carried out and an area with unsatisfactory moisture supply of crops was identified. It is proposed to determine the moisture content of plants at the local level in terms of spatial distribution of vegetation indices within homogeneous regions and corresponding mathematical-statistical models. Conclusions The system of remote monitoring of the volatility of agricultural crops ensures the efficiency and quality of identification of crisis drought phenomena in agroecosystems and water stresses in crops, as well as the adoption of managerial decisions on adjusting agrotechnologies at different levels of agroecosystem management to prevent the development of arid phenomena and the adaptation of land-use systems to climate change.

*Key words: moisture, crops, satellite data, vegetative indices, remote sensing.*

Ukraine has extremely favorable natural conditions for the development of rural economy: temperate climate, fertile soils, large areas of arable land. At the same time, in separate Ukraine is characterized by drought that has a negative impact on agribusiness.

Over the past 120 years, over 70 droughts have been recorded in Ukraine. During the years of independence Ukraine experienced 11 drought: 1992, 1994, 1996, 1999, 2000, 2002, 2003, 2005, 2007, 2009, 2010. Extremely strong and severe drought was observed in the spring-summer period of 2007. About 2 thirds of the country's territory, more than one third of the crops, caused an area of billions of losses in the zone of its spread [8]. In addition, in the south of Ukraine, in 2007, on an area of up to 5 million hectares, there was a catastrophic dust storm.

In recent decades, the rate of increase in temperature in Ukraine is significantly ahead of the average planetary index, which increases the risk of drought [6]. In order to mitigate the effects of drought, it is necessary to timely detect and monitor the state of moisture content of crops in agricultural crops. In traditional methods for determining the moisture content of crops, data from terrestrial meteorological studies (rainfall, soil temperature and air temperature, soil moisture and air) are used. One of the main problems of traditional methods is the discreteness of the network of agrometeorological stations and stations, which reduces the ability to quickly obtain information in space and time.

To solve this problem at different administrative levels it is expedient to use not only traditional ground methods, but also observations from outer space. The development of modern satellite remote sensing systems, the application of software complexes for processing digital images and geographic information systems (GIS) for the purpose of data analysis and their interpretation contribute to obtaining much more operational and reliable information on the state of crop sowing, in particular the conditions of hydration. There are now enough satellites with equipment that can be used to objectively assess the condition of agricultural lands at the country or oblast level, at the level of individual farms or even individual fields.

Therefore, it is advisable to improve the traditional system of monitoring moisture-deficiency of agro-landscapes and crops for the purpose of operational information provision of management structures and subjects of management of different levels. Consequently, in the context of climate change, the development and implementation of remote sensing technologies from the Earth (RSZ), which due to the high level of visibility, efficiency and objectivity, is the most effective source of geospatial information that substantially complements information from traditional ground sources, for example , concerning the state of moisture content of crops in separate phases of development of plants, which, in turn, makes it possible to timely adjust the technological processes and carry out remote predictive estimates of the productivity of crops and defining critical regions.

By solving the problems of assessing the state of vegetation cover (in particular, their moisture safety) by remote methods, significant influence was made by B.V. Vinogradov, V.Ya. Kondratiev, P.P. Fedchenko, SM Kochubei, T.M. Shadchin, O.A. Wars Among foreign scholars should be noted R. Jackson, B. Gao, F. Kogan. Most studies were conducted within specific territories using specific remote sensing systems.

The purpose of the research is to develop a system for monitoring the state of water supply of agricultural crops at different administrative levels through the integrated use of satellite data of various spatial differentiations in different natural-landscape conditions.

Materials and methods of research. Analysis of moisture content of crops on the basis of satellite information is based on the connection of vegetation with its spectral characteristics. By satellite data of remote sensing in different spectral ranges, various vegetation indices characterizing vegetation state are determined. The most commonly used is the normalized difference vegetation index (NDVI), which is defined as

$$NDVI = (R_{\text{БІЧ}} - R_{\text{Ч}}) / (R_{\text{БІЧ}} + R_{\text{Ч}}),$$

where RBICH and RH are reflected in the near-infrared (780-900 nm) and black (630- 685 nm) bands respectively. For green vegetation, the value of this index usually varies from 0.2 to 0.8 directly proportional to the increase of green phytomass [13], which characterizes the state of moisture content of crops. The moisture content of the green mass of plants is characterized by the water index of NDWI, which should be used as a measure of moisture content. It is the ratio of the difference between the reflection coefficients between the near infrared and the infrared channels to their sum (RBICH - RCICH) / (RBICH + RCICH) [9].

Since the reduction of chlorophyll content in the biomass is due to poor moisture content, for its indirect assessment also The spectral range 690 - 730 nm is used - the "red edge", which is more sensitive to vegetation than the near-infrared, and the vegetation index NDVIRE developed by it, analogue of the NDVI index:

$$NDVIRE=(R_{\text{ЧК}}-R_{\text{Ч}})/(R_{\text{ЧК}}+R_{\text{Ч}}),$$

where RH is the reflection coefficient in the red channel (630 ÷ 685 nm), RCHC is the reflection coefficient in the red edge channel (705 ÷ 745 nm). The use of this index is related to the technical characteristics of the equipment of some modern satellites, in particular RapidEye (5 meters apart).

In addition, in order to reduce the influence of weather conditions, geographic, ecosystem changes, soil, vegetation, topographical conditions on the determination of vegetation, it is expedient to use long series of NDVI index and satellite daytime vegetation temperature data obtained in the thermal range. According to these data, vegetation index (VCI) and temperature (TCI) conditions are calculated, as well as their integral index - vegetation vegetation status index (VHI) [11]. This index characterizes the state of roughness by combining the estimation of humidity conditions and heat resources and is used to estimate the forecast of the crop. The VHI below 40 indicates a different level of vegetation stress and expected yield loss; above 60 - about favorable conditions for pre-harvest harvest. Consequently, the VHI index should be used for spatial determination of vegetation status, in particular forecasting yields and gross collections, depending on climate conditions and agrotechnical factors.

The methodology is based on the use of satellite observations of low spatial resolution - the AVHRR radiometer (NOAA satellite, spatial resolution 4000 m); medium spatial resolution is the MODIS radiometer (Terra i Aqua satellites, spatial resolution 250 m, 500 m), Landsat (30 m) and high spatial resolution (SICH-2 satellites, 8 m and RapidEye 5 m) [2] . The procedure for determining the moisture content of crops involves the following stages (Fig. 1):

1. *Preparation* - obtaining the necessary map and satellite information that undergoes preliminary processing (compilation of logos, normalization and transformation of received data on a digital map basis).

2. *Detection of the territory (region) with insufficient water supply at the level of the country*, which involves obtaining from the space separation data of the low spatial separation of the multi-zonal AVHRR radiometer NOAA satellite vegetation vegetation growth index (VCI) and vegetation status (VHI) vegetation and temperature conditions ( TCI). The result is a map of areas and crop conditions, for example, under the influence of moisture deficit.

3. *Detail at the regional level of the territory, which is under the influence of arid conditions within the boundaries chosen at the first stage of the region.* For this purpose, according to the obtained multispectral images of the mean spatial resolution (MODIS / Terra or Aqua) and the calculated vegetation index NDVI in accordance with [7], the classification of elements of agro-landscapes - water surface, soil, settlements, crops of agricultural crops is carried out. Further classification of agricultural crops for their moisture content is determined by the MODIS water data index (NDWI) calculated according to MODIS (the index value is directly proportional to the moisture content, in particular the negative values of dry vegetation) [9]. The result of these operations is a map of crops classified by the degree of moisture content.

4. *Definition at the local level of the state of moisture content of crops*, which involves the use of data of high spatial differentiation. Depending on the access to these data, the use of space-based materials for LANDSAT, RapidEye, and others can be used. These data specify the placement of plots of agrophytocenoses with insufficient water supply at the level of the state or even the field: in particular for the data of the satellites of the LANDSAT series, the domestic conveyance of SICH-2 - according to the water index of the NDWI; For these satellite data RapidEye - by the narrow NDVIRE. The state of humidity in the selected sites is specified based on the models of moisture content in agricultural crop plants constructed using ground-based experimental data.

According to the results obtained at each level, the research results provide relevant information and recommendations on management of agri-resource potential, as well as forecast assessment of the situation.

Results and discussion. To determine the state of crops at the country level according to the data The MODIS radiometer of the Terra satellite identified the NDVI index; the dynamics charts of the above index were obtained in 2015 and a number of past years. Their analysis showed that the vegetation status in Ukraine as a whole is at a level that is higher than the average annual and almost all previous years (2011-2014) (picture on the cover).

For a more detailed analysis of the state of vegetation in accordance with the natural climatic zones and the identification of areas with unsatisfactory state of crops, the spacious distribution of the above VHI plant vegetation index obtained from data NOAA Satellite Relocation. The analysis of averaged data on oblasts showed that vegetation in the majority of regions on July 15, 2015 was in optimal condition, except for Zhytomyr and Kyiv oblasts, where unsatisfactory vegetation was observed, respectively, in more than 40 and 30% of the territory (figure on the cover, b). In 2014, during this period unsatisfactory vegetation was observed in the Crimea (about 40%) and Kherson region. (30%), ie on the territory of arid Steppe (drawing on the cover, b).

The analysis of the dynamics of the VHI index for the growing season 2011-2015 has shown that this year there is an increase in the area under plants in unsatisfactory conditions, which, in turn, corresponds to the deterioration of the conditions of water availability in the Kyiv and Zhytomyr regions. At the same time, in the Territory of Lviv, Poltava, Odesa and Kherson regions, improvements in the conditions of water supply during the period under review are observed in comparison with 2014, which results in a decrease in the area of crops in unsatisfactory condition to 3-5%. This trend corresponds to the dynamics of the NDVI index, obtained by fields. In particular, the state of crops in the Zhytomyr region is worse than in 2011-2014 - the lowest NDVI value (picture on the cover, g), and in Kherson oblast the state is better: the NDVI value is higher than in previous years (figure on cover, e). Consequently, there is an unconventional situation, when the state of crops in the middle of the growing season in the Steppe zone is much better than in the Kiev and Zhytomyr regions.

At the regional and local stages, monitoring of moisture content of crops in agricultural crops was carried out on the basis of experimental land and satellite data in 2013 on the example of the territory of the Kyiv region. To monitor the dynamics of moisture content of the green mass of plants, the multispectral data of 2 and 6 channels of the MODIS satellite radiometer Terra on May 9, June 2, 2013, obtained from the US Geological Survey (www.mrtweb.cr.usgs.gov), for which identified the water index of NDWI. In the period from May 9 to June 2, 2013, an increase in the water index was observed, indicating an increase in plant moisture due to heavy precipitation during the period from May 13 to June 2, 2013. Within the administrative area, in the presence of a crop mask (digital map view - rhetoric of crops) it is possible to conduct an expert assessment of moisture storage at the local level, extrapolating the operational data of meteorological observations. In particular, almost throughout the territory of Mironovsky district for the period of observations from May 19 to June 4, 2013 p. The intensive growth of NDWI was revealed, which indicated an increase in the moisture in plants due to significant precipitation in late May - early June. Substantial opportunities for analysis of moisture content in plants are provided by materials for removals of systems of high spatial differentiation. So, according to MODIS, for spatial resolution of 500 m, we obtain the distribution of the averaged values of the normalized water index of NDWI within the limits of the raion and the experimental experimental agrarian landfill. According to the SSC Sich-2, Landsat (spatial distinction 8 and 30 m), we obtain the distribution of the values of the normalized water index NDWI.

As noted, the disadvantages of traditional methods for determining the moisture content of agrophytocenoses are the discreteness of measurements in space and time. Therefore, quantitative methods for monitoring the moisture content of vegetation by satellite data are promising, in particular the use of spectral indices that correlate with the water regime of plants, to determine their moisture content in different phonological phases. The studies conducted have justified the use of the vegetation indexes indicated above as an indicator of moisture content in plants, for which they were determined by materials of space removal of different spatial differentiations, in particular MODIS / (Terra, Aqua), Landsat 8, RapidEye and SICH -2 "in accordance with the dates of experimental ground observations, as well as their zonal statistics at the points of observation. These data together showed a high correlation with the data of the content of hygroscopic wool in winter wheat plants obtained from ground surveys.

For the quantitative assessment of moisture content in plants within a single field, a technique for its simulation was developed based on satellite data.

The network of pilot experimental agrarian landfills received ground-based observational reference and calibration information on the state of crops and the content of moisture in plants. The simulation of the content of volatiles in winter wheat plants was carried out using the above indices calculated on the basis of the MODIS / (Terra, Aqua), Landsat 8, RapidEye and SICH-2 satellite imaging data for the corresponding date, and the construction of the equation multiple regression. As a dependent variable, the values of moisture content in plants were used, and as the independent variables the above indices were used, in particular for RapidEye (April 11, 2009) and SICH-2 (May 5, 2012). Accordingly, a logarithmic relationship between the moisture content and the NDVIRE index was obtained:

$V=0,1233 \times \ln(NDVIRE +0,8792$,

as well as polynomial for the NDWI index:

$V=0,6942 – 0,2986 \times NDWI+2,009 \times NDWI2 – 6,7197 \times NDWI3$.

For validation of models from reference data, before the simulation was begun, the points of ground-based experimental research were randomly selected, which were not taken into account for calculating the coefficients of the multiple regression equations. The results of the validation of the models of moisture content multiple regression are shown in Fig. 2. Similar results were obtained for MODIS / (Terra, Aqua), Landsat 8 satellite data.

As a result of these regression models, maps of the spatial distribution of moisture content for winter wheat fields of Mironivsky district were constructed, in which the moisture content changes in within the limits of 60-75%, which testifies to satisfactory moisture content of crops.

Therefore, in the system of monitoring the moisture content of crops it is expedient to use satellite data of various spatial differentiations to determine the spatial distribution of moisture content in plants at the field or farm level, and at the administrative district level, which allows to significantly reduce ground survey of crops for determining their state and forecasting performance.

**Conclusions**

According to satellite information, in 2015 we can expect a significant decline in grain crops in the regions of Zhytomyr and Kyiv oblasts. In other regions, in particular in the Steppe and Livoberezhny Forest-Steppe, in 2015, the grain yield of cereals will be predicted at the level of 2014 or even higher (eg Odessa, Kherson and Poltava region).

In the case of late crops, in particular corn, sunflower and soybeans, in compliance with the technologies of their cultivation in all soil-climatic conditions, crop yields can be expected in 2015, not lower than 2014.

A method for monitoring the volatility of agricultural crops cultures using the remote sensing and GIS technologies provides operational information and management decisions on adjusting agrotechnologies at different levels of management of agro-industrial complex.

At the state level, the central state management bodies are invited to use satellite monitoring of agro-landscapes and crops as an integral part of the state monitoring and forecasting system for emerging crisis phenomena. For this purpose, for continuous monitoring of the whole territory of the country, it is necessary to use satellite-based low-resolution satellite images and vegetation vegetation growth maps based on them. In order to ensure the efficiency and timeliness of the monitoring of arid phenomena, it is expedient to use a combination of low and medium identification cameras located on NOAA and TERRA satellites, as well as high-resolution systems such as RapidEye, in particular to refine and adjust agrotechnologies within certain territories with insufficient water supply on the regional (district) or local (economy, field) levels.

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