DOI: 10.25140/2411-5363-2024-2(36)-266-277
UDC 631.58:528.8

Vitalii Zatserkovnyi[1], Victor Vorokh[2]

[1]Doctor of Technical Sciences, Professor, Head the Department of Geoinformatics
Taras Shevchenko National University of Kyiv (Kyiv, Ukraine)
E-mail: vitalii.zatserkovnyi@gmail.com. **ORCID:** https://orcid.org/0009-0003-5187-6125. **Scopus ID:** 57200165109

[2]Graduate Student of the Department of Geoinformatics
Taras Shevchenko National University of Kyiv (Kyiv, Ukraine)
E-mail: fainkucha@gmail.com. **ORCID:** https://orcid.org/0009-0005-0112-8422

ERS TECHNOLOGIES IN PRECISION FARMING

One of the urgent tasks of modern agricultural production is the problem of further development for ensuring the growing demand for food and other agricultural products on an innovative platform of precision agriculture. Precision farming involves the use of geographic information technologies, earth remote sensing (ERS) technologies, the Internet of Things (IoT), big data technologies and artificial intelligence (AI) aimed at increasing crop production and reducing costs.

The use of ERS technologies for precision farming tasks is due to the unprecedented availability of high spatial diversity images (spatial, spectral and temporal) and, accordingly, the ability to monitor crops, in irrigation management, nutrient input, pest and plant disease control, yield forecasting, etc.

The article provides an overview of the most commonly used ERS systems used in precision farming technologies. This makes it possible to optimize the use of agricultural resources for each section of the field and improve plant productivity based on data on soil structure, pH, nutrients and yield maps, plant protection products (PPP), irrigation in accordance with soil properties, topography, meteorological conditions and a number of other factors.

The use of satellite data requires further research aimed at improving the technology for storing and processing such data, namely cloud computing and machine learning. Given the certain complexity of image processing and the need for certain training of specialists, it is important to test simple but reliable algorithms for the application of remote sensing in real time, which will allow the wider implementation of ERS technologies in precision farming.

***Keywords**: precision farming; geographic information technologies; remote sensing of the Earth; nutrient management, vegetation indices.*

Fig.: 10. References: 14.

Relevance of the research topic. Relevance of the research topic. Due to the increase in the population of the Earth, which today is close to 7 billion and continues to grow rapidly and the decline in land resources due to their depletion, degradation, desertification, etc., the pressure on productive lands is becoming greater. Scientists predict [1] that arable land per capita will decrease from 0.23 hectares in 2000 to 0.15 hectares in 2050. The demand for food and agricultural products is projected to grow by 1.5-2.0 times by 2050 [2].

The problem can be solved by intensifying agriculture, introducing modern technologies, increasing the use of fertilizers, pesticides, irrigation, etc. However, this way of farming does not correspond to the concept of sustainable socio-economic rural development, and the irrational use of plant protection products (PPP) and mineral fertilizers, their imperfection leads to negative pressure on the environment, namely, on deforestation, resistance of pests and weeds to chemicals, soil degradation. Expansion of territories for intensive agriculture leads to the destruction of wildlife, water pollution, etc. [3].

Taking into account the above, an urgent task is the use of such technologies that can increase agricultural production by increasing the efficiency of resource use and reducing environment pollution [4]. Today, such technologies are precision farming technologies, which involve the use of a variety of geospatial information, taking into account the characteristics of each section of the field (making exactly the nutrients that plants need) and reducing the pressure on the environment, parallel driving, saving fertilizers, PPP, seeds, etc. [5].

The use of precision farming technologies will allow agricultural producers to reduce the negative environmental impact of intensive agriculture, optimize production, improving product quality and minimizing costs based on: the use of effective means of production, advanced methods of labor organization and the achievements of scientific and technological progress (STP); monitoring of fields using satellites and UAVs allows farmers to monitor the situation in real time; the use of sensors to obtain information about the state of crops in the field; the

© В. І. Зацерковний, В. В. Ворох, 2024

use of satellite navigation system (GPS) allows you to obtain accurate data on the location of objects, to conduct field zoning for more effective control of crop and soil condition; applications for smartphones and tablets help to control and manage agricultural operations, order deliveries, plan product sales and track the transportation of goods over the Internet. This allows us to more fully take into account the resource potential of agricultural enterprises, the variety of soil, meso- and microclimatic features of each section of the field, to control the implementation of operations in the course of the machine's movement in the field (fertilization or PPP).

Problem statement. An important role in crop production is played by the assessment and consideration of meteorological, agrochemical, agrophysical, agrotechnical soil conditions for crop productivity, crop monitoring and yield forecasting. This indicates the urgent need to create comprehensive information and analytical systems to support precision farming, management of agro-industrial production, based on the use of GIS, ERS, GPS technologies and navigation software and hardware. And this cannot be done without using ERS data, generating a large amount of geospatial, often unique data that can be successfully used in precision farming technologies for managing agricultural enterprises, analyzing the state of fields, identifying crop problems, searching for the causes of these problems and developing effective solutions.

The use of ERS methods and technologies makes it possible to systematically analyze the state of the field, starting from the relief, heterogeneity of soils, their composition, the state of crops to multispectral field diagnostics, crop rotation and retrospective analysis for several years. With the help of retrospective analysis, it is possible to identify outdated problems: soil compaction, the consequences of improper treatment, lack of nitrogen and moisture, the impact of topography, etc. Retrospective analysis is used in the study of the current state of territories to assess the dynamics of its development.

One of the main advantages of applying the ERS data is the ability to compare crop yields over a long period of time, compare farming methods, weather conditions, varieties, etc. with the harvest obtained at the end of the season.

Analysis of recent research and publications. Scientists L. Moldovan, L. Novakovsky, B. Paskhaver, P. Sabluk, A. Tretyak, O. V. Shubravskaya and others made a significant contribution to the analysis of the development of the agro-industrial complex of Ukraine. The problems of introducing precision farming technologies are studied in the works of L. Aniskevich, D. Voityuk, V. Garam, M. Makarenko, O. Tkachenko, M. Tsyganenko. Nevertheless, recognizing the scientific and practical value of the developments of these authors, it should be noted that the problem of using precision farming technologies in the system of modern crop production is far from being solved and requires scientific research. The article is aimed at analyzing, generalizing and evaluating approaches to the introduction of ERS technologies in precision farming technology.

The article is aimed at highlighting the real state of use of ERS technologies in crop monitoring tasks, assessing the state of fields, searching for reasons, providing recommendations for solving possible problems and preventing the occurrence of such problems in the future.

Presentation of the main material.

To improve the efficiency of agricultural business, advanced in economic and technological terms, the countries of the world - the USA, Japan, China, Germany, Great Britain, Denmark, the Netherlands, France, since the 80s of XX century, and since the 90s of 20th century Eastern European countries as well widely use precision farming technologies, the Internet of Things and wireless smart networks, which are becoming increasingly popular every year. This allows these countries to reach a qualitatively new level of production and successfully compete in the world market.

Precision Farming (Precision Agriculture) is a complex of high-tech and efficient technologies for the production and management of crop yields, taking into account within-field variability using information and geographic information technologies (GIT), remote sensing technologies of the Earth (ERS) and global positioning (GPS). This allows not only to automate and optimize production processes, but also to significantly reduce costs, increase the profitability of production and the quality of the final product. Precision farming technologies allow plants to obtain exactly the nutrients that they need.

A significant role in precision farming technologies is occupied by the Internet of Things, which provides agricultural enterprises with real data for making effective decisions. Today, even robots for weeding weeds are already available, which are programmed to move and weed within the specified coordinates. The robot drives between rows and pulls out weeds. Previously, this could not be imagined. Tractors with microprocessors are also common. This allows not only to control and adjust the process parameters, but also to show the actual operating speed, the amount of work performed, engine parameters and fuel consumption. All these smart technologies help to redistribute costs and optimize profits from each part of the field. In general, precision farming systems pay off quite quickly: costs are reduced, yields and land quality are increased [6].

All these listed technologies, as international experience shows, allow achieving a greater economic effect, increasing the reproduction of soil fertility and the level of ecological purity of agricultural production.

Due to the fact that each field is a set of inhomogeneities within one field -different relief (Fig. 1), various agricultural soils, chemical composition of soils (Fig. 2), nutrient content in the soil (Fig. 3), the degree of moisture, etc., in order to obtain maximum yields, various spatial information is needed about each section of the field and even about each square meter of this field (on the similarity of crops, the presence of nutrients, moisture, weeds, pests, plant diseases, etc.).

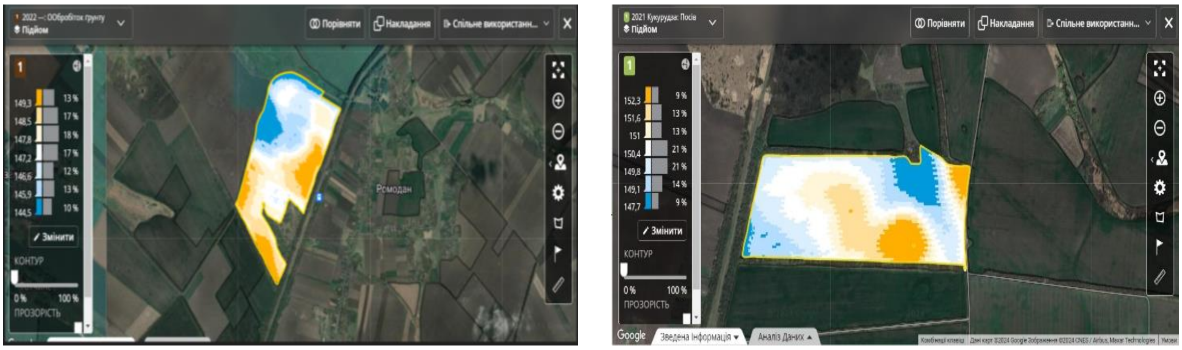


Fig. 1. Example of heterogeneity of field relief

Fig. 2. Example of different agrochemical properties of soils

Fig. 3. Example of alkaline properties of soils

The agrochemical survey technique in precision farming technology involves linking each soil sample taken to a single geolocation system carried out using a navigation system. This makes it possible to more accurately assess the results of surveys, to carry out a detailed account of the variability of the plant environment in space and in time, and to quickly control the productivity of crops on the field.

Monitoring of sown areas is a rather time-consuming process, both for large fields and for small plots scattered throughout the territory of territorial communities. If the crops are young, then monitoring can be carried out by walking or driving through the field, but if the plants have reached a height of 1-2 meters, this is already much more difficult to do. And the lack of information on the entire area of the field is usually a potential loss. Therefore, it is clear that there is an urgent need for the use of ERS technologies to monitor the condition of acreage.

Modern technologies of precision farming for monitoring can and use different methods of obtaining and processing spatial data, namely:

- ground - using various instruments (analysis of soil samples, sheet diagnostics, etc.);
- aerial photography using aircraft, unmanned aerial vehicles (UAV);
- space survey using satellites [7].

Each of these methods has both advantages and disadvantages, and can be quite effective only under certain circumstances.

Agroecological ground monitoring makes it impossible to obtain operational spatial information about the state of agricultural production in space and time in large areas, since the total area of agricultural land in Ukraine reaches more than 42 million hectares, and the area of arable land is 32.5 million hectares.

Taking into account the trends of intensification of agricultural production and global climatic changes, ERS technologies, in front of all satellite ones, become a necessary component of the agro-ecological monitoring system. Using special sensors and programs, global positioning systems (GPS), aerial photographs and satellite images, etc., it is possible to assess the biochemical properties of soils and control their fertility. An important issue is finding the optimal level of use of fertilizers and chemicals. With the help of pictures, you can find out that there are plenty of fertilizers in a certain area, on the other - on the contrary, they are not enough. That is, a differentiated approach is applied to each individual site. This allows you to effectively distribute resources and save fertilizers, plant protection products (PPP), watering, etc. In addition to soil analysis, using special software, you can program a seeder or sprayer for differential application of seeds, fertilizers, water, etc.

The use of remote sensing technologies (ERS) to monitor crops is widely used in many countries around the world and has a constant tendency to increase them.

ERS data of different spatial and temporal distinctions together with terrestrial data provide a lot of valuable and informative data for making reasonable optimal (rational decisions) in the process of management, resource allocation and crop optimization both at the level of countries and at the level of individual farms. The use of GPS devices integrated with smartphones or handheld devices allows you to effectively map fields and individual areas. The use of GIS technologies provides a powerful toolkit for monitoring the stages of harvesting, combating plant diseases, assessing yields, etc.

As a result of the war unleashed by Russia, many agricultural enterprises faced the inability to carry out economic activities on part or all of the lands due to occupation, mining, constant shelling, etc.; staff shortage due to the outflow of the able-bodied population into the ranks of the Armed Forces of Ukraine, or to other units, safer regions; deficit of working capital and inventory; limited opportunities to sell grown products. This forced them to abandon a number of secondary technological operations and the introduction of only extremely necessary plant protection products, that is, the use of a differentiated approach to sowing and the economical introduction of nutrients.

The availability of high-resolution satellite images (spatial, spectral, and temporal) and their extensive archives contribute to the use of ERS in many precision farming programs and technologies, including crop monitoring, irrigation management, nutrient application, disease and pest control, and yield prediction, etc.

Flying over a certain area and performing a space survey of different differences, the satellite captures the necessary areas of the field. Using these images and special software, it becomes possible to map a variety of vegetation indices that can help understand the space-time variability of the conditions of the future harvest. Among the widely used indices are [7]:

- *normalized relative vegetation index (NDVI)*, allows to know the amount of photosynthetic active biomass in plants [8], is a measure of the difference in reflectivity between the red band (RED) and the near infrared band (NIR) images. NDVI ranges from -1 to + 1, where positive values indicate areas covered with vegetation, and negative values indicate areas without vegetation. It is calculated by the formula:

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

where *NIR* – reflection coefficient in the near infrared zone;
RED – reflection coefficient in the red spectral zone.

The main products calculated based on the NDVI index are crop status maps and productivity maps at a particular time or in dynamics. They are necessary for obtaining electronic map tasks and introducing precision farming tools. Today, there are quite a lot of satellites in orbit for shooting the Earth's surface, which differ in the frequency of passing over a specific territory of the Earth and ending with the spectrum of shooting the camera, diversity and cost. Based on data on biomass activity, the index is used in assessing the state of crops. Characterizing the density of vegetation, NDVI indicates those areas of the field that require sowing, application of PPP and fertilizers;

– *leaf area index (LAI)*, shows the ratio of total leaf area to land area. In turn, the area of leaves depends on the amount of intercepted light, accumulated nitrogen, respectively, surface temperature, etc. [7]. This index is a dimensionless coefficient, but its dimension can be reduced (m^2/m^2, ha/ha);

– *soil-adjusted vegetation index (SAVI)*, used to diagnose water stress and soil moisture conditions for many crops. Can be used for irrigation planning. It is calculated by the formula:

$$SAVI=\frac{(NIR-RED)(1+L)}{(NIR+RED+L)}, \qquad (2)$$

where *L* – index of soil improvement;

– *normalized relative water index (NDWI)*, measures the amount of water in vegetation. It is used to assess water stress in plants, as well as to identify areas with a high water content in vegetation. It is calculated by the formula:

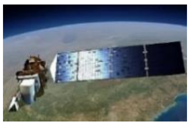
$$NDWI=\frac{GREEN\text{-}NIR}{GREEN+NIR}; \qquad (3)$$

– *normalized red margin difference (NDRE)*, measures the amount of chlorophyll in the leaves of plants. NDRE is often used to estimate nitrogen stress regardless of the amount of nitrogen in the soil. Often used to create variable rate nutrient input maps. It is calculated by the formula:

$$NDRE=\frac{NIR\text{-}REDedge}{NIR+REDedge}. \qquad (4)$$

The main characteristics of satellites used in precision farming are presented in Table 1.

Table 1 – Main characteristics of satellites used in precision farming

Indicator	Sentinel 2	Landsat 8	Landsat 9	MODIS	EOS SAT-1
					
Spatial diversity, m/pixel	10 – 60	30	30	250-1000	1,4/2,8
Number of spectral channels	13	11	11	36	11
Shooting frequency, per day	5	8	8	4 times per day	daily up to 1 mln km^2
Retrospective	From August 2015	From August 2013	September, 27 2021	From 1999	From January 2023
Quantity of photos per season	From March to October 54 photos	From March to October 34 photos	From March to October 34 photos	365	365
Products possible to get	Images in natural colors Vegetation index *NDVI*	Image in natural colors Vegetation index *NDVI* Soil temperature Snowiness	Image in natural colors Vegetation index *NDVI* Soil temperature Snowiness The smallest changes in lakes, rivers, forests and seas around the world	Image in natural colors NDVI vegetation index (change in dynamics by field for comparison with other fields	Irrigation management, identifying problems that threaten crops, analyzing fertilizer and seed use, monitoring climate change, identifying plant stress from heat, cold and water, and monitoring crop growth

One of the priorities in the implementation of the concept of precision farming is the definition of the main stages of the project and their sequence. Thus, a logical model was built that demonstrates the basic steps necessary to introduce this technology and obtain data for further work with them Fig. 4.

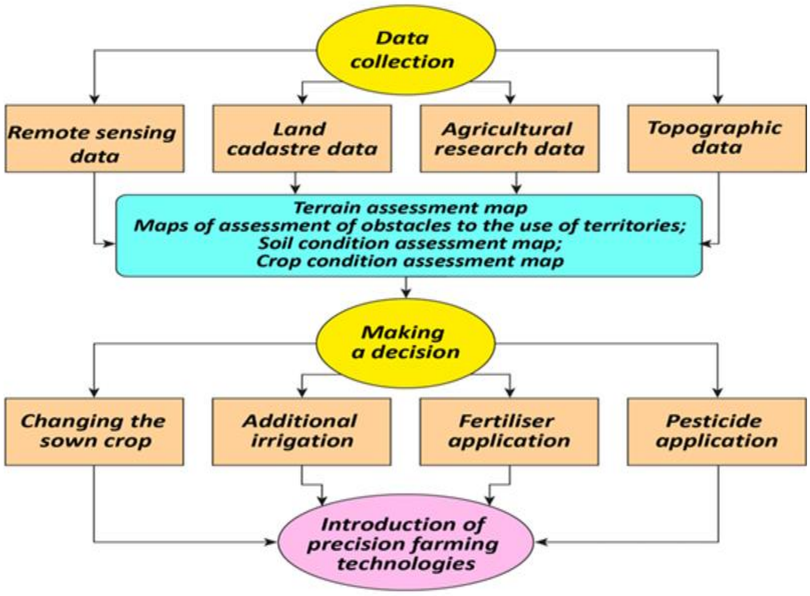


Fig. 4. Logical model of the sequence of stages for the introduction of precision farming technologies

After analyzing the current products and capabilities of ERS, the main vegetation indices that make it possible to conduct precision farming, the analysis was carried out using the methods considered. The objects of the study were agricultural fields of the Dnipropetrovsk region - the leader in sown areas in 2023 in Ukraine (1560.1 thousand hectares) [9].

Fig. 5, as an example, shows a snapshot of the territory of the Sinelnikovsky district of the Dnipropetrovsk region.

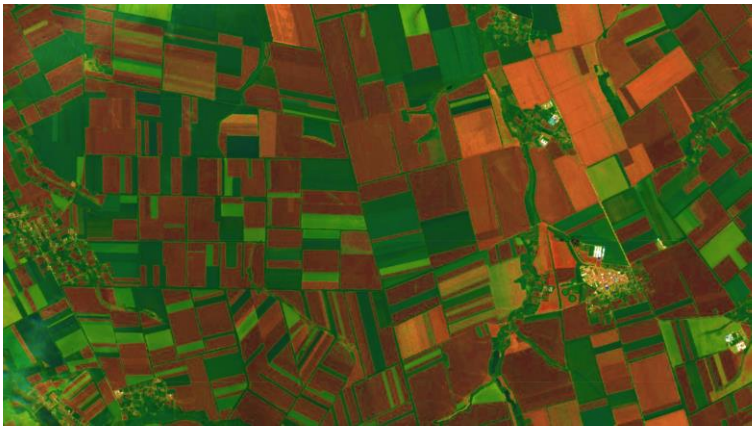


Fig. 5. A snapshot of the territory of Sinelnikovsky district, Dnipropetrovsk region 21.05.2023, data of the Sentinel-2 MSI satellite, Level 2-A

The first step was to analyze the state of the crop using the NDVI calculation. As it is known, the values of the normalized differential vegetation index can be from -1 to + 1, where the values are (-1 - 0) infrastructure and water, and the values are (0 - + 1) plants [11].

So, plants that have NDVI values from 0 to 0.3 are probably not healthy and are usually negatively affected by the environment (lack of moisture, sun, fertilizers, etc.) [12]. In turn, plants with a value of 0.3 and above are healthy and feel great.

Maps of the distribution of NDVI values, made according to the Sentinel-2 MSI satellite, Level 2-A are shown in Fig. 6.

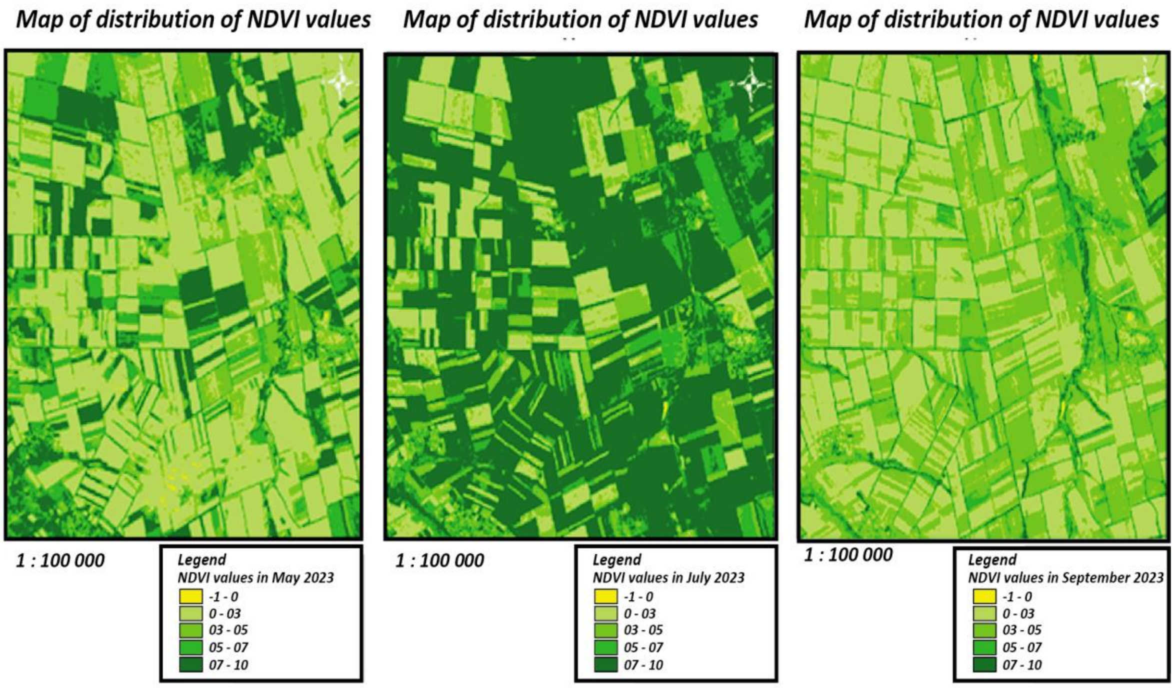


Fig. 6. NDVI maps, based on Sentinel-2 MSI, Level 2-A

At the beginning of the season, NDVI can demonstrate how the plant feels after wintering, also, as already mentioned, you can monitor the development and condition of plants during the season, as well as find out which fields are ready for harvesting at the end of the season - the lower the NDVI value, the closer to ripening is the culture [8].

Thus, according to the most uneven distribution of vegetation index values, the boundaries of one field were chosen, on the example of which further analysis of Fig. 7 was carried out.

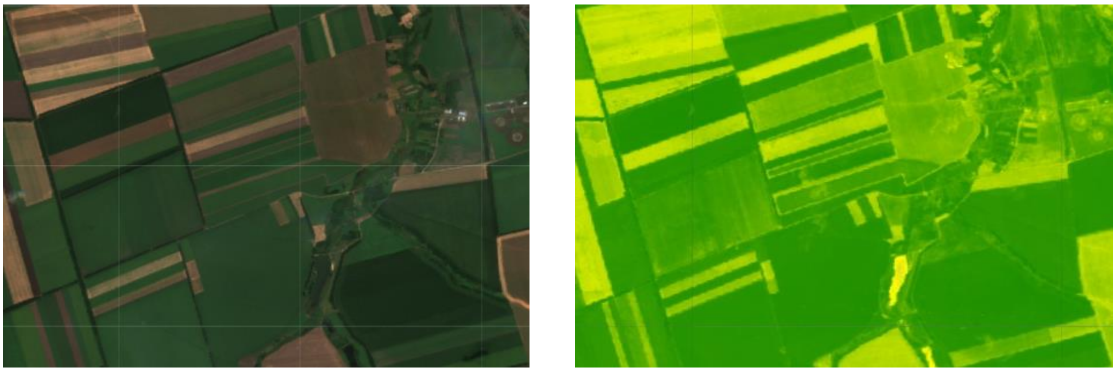


Fig. 7. Distribution of NDVI values in one of the fields in the Sinelnikovsky district in June 2023, data from the Sentinel-2 MSI satellite, Level 2-A

Analyzing maps of the distribution of active photosynthetic biomass, spots of lower values in the fields were found, signaling the heterogeneity of crop development.

The first step in this situation is to analyze the humidity of vegetation to eliminate the problem of insufficient irrigation. Since early detection of water shortages can prevent many negative impacts on crops.

So, using formula (3), distribution maps were calculated and constructed and the value of the normalized relative water index was estimated (Fig. 8).

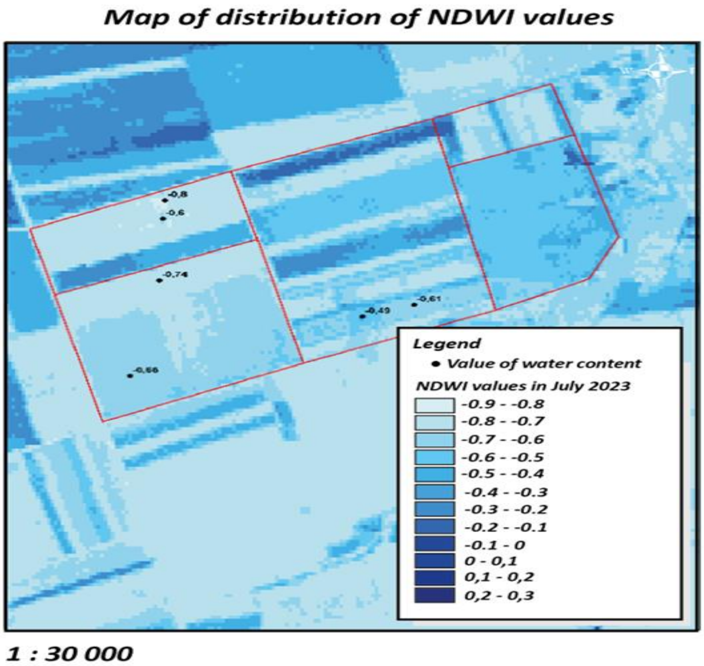


Fig. 8. Map of the distribution of NDWI values, made according to the Sentinel-2 MSI satellite, Level 2-A, own development

From the resulting map, clearly visible value difference within the individual fields. The largest was a difference of 0.2 units for the same crop, which may indicate both waterlogging and insufficient irrigation of certain areas of the field. In any case, this can be useful information for farmers who will make further decisions.

A similar situation was observed when calculating the soil-adjusted vegetation index (SAVI), which can also be used to diagnose water stress and soil moisture conditions for many crops and to plan irrigation. To assess nitrogen stress regardless of the amount of nitrogen in the soil and create nutrient input maps, it is also advisable to calculate the normalized red edge difference (NDRE). Being similar to NDVI, NDRE is a good option for monitoring crops at a late stage of their development, since closer to maturation the chlorophyll content increases, at which NDVI reaches a maximum value of 1.0 and, therefore, is saturated, which in turn avoids the use of NDRE [13; 14].

That is why the data for August 2023 in the field area of the previously considered Fig. 9 and Fig. 10 were further analyzed.

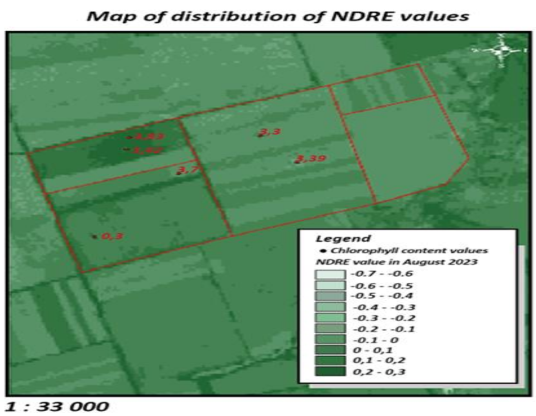


Fig. 9. NDRE map, based on Sentinel-2 MSI, Level 2-A

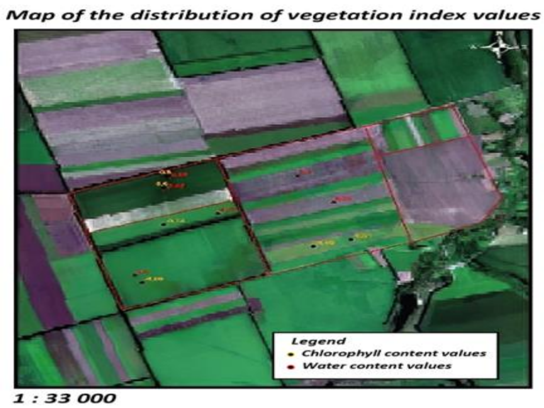


Fig. 10. Map of the distribution of values of vegetation indices, made according to the Sentinel-2 MSI satellite, Level 2-A, own development

Conclusions. Based on the collected and analyzed information, a logical model was developed that demonstrates the stages of introducing precision farming technologies. The primary stage is the collection of ERS data, since they enable both a quick preliminary review of territories and a detailed in-depth analysis with subsequent decision-making to support the development of crops.

Using statistical data on the amount of acreage in Ukraine, the territory was selected for the study, during which the values of the main indices of vegetation in this region were analyzed and fields were found that demonstrate a heterogeneous distribution of these values, respectively, may indicate the negative impact of certain factors on plant development.

This algorithm can be applied to other agricultural fields, it is also possible to modify it with the addition of more vegetation indices for the introduction of precision farming.

These results demonstrate the effectiveness of ERS technologies and GIS tools in precision farming.

References

1. Lal, R. (1991). Tillage and Agricultural Sustainability. *Soil and Tillage Research*, *20*, 133–146. https://doi.org/10.1016/0167-1987(91)90036-W.
2. Wik, M., Pingali, P., & Brocai, S. (2008). Global Agricultural Performance: Past Trends and Future Prospects. *World Bank Group*. https://openknowledge.worldbank.org/handle/10986/9122.
3. Hendricks, G. S., Shukla, S., Roka, F. M., Sishodia, R. P., Obreza, T. A., Hochmuth, G. J., & Colee, J. (2019). Economic and environmental consequences of overfertilization under extreme weather conditions. *Journal of Soil and Water Conservation*, 74(2), 160–171. https://doi.org/10.2489/jswc.74.2.160.
4. Delgado, J. A., Short, N. M., Roberts, D. P., & Vandenberg, B. C. (2019). Big data analysis for sustainable agriculture. *Frontiers in Sustainable Food Systems*, 3, 54. https://doi.org/10.3389/fsufs.2019.00054.
5. Aubert, B. A., Schroeder, A., & Grimaudo, J. (2012). IT as enabler of sustainable farming: An empirical analysis of farmers’ adoption decision of precision agriculture technology. *Decision Support Systems*, *54*(1), 510–520. http://dx.doi.org/10.1016/j.dss.2012.07.002.
6. Pavlenko, O. (2016, November 21). Zemlerobstvo maibutnoho ta ukrainski realii [Agriculture of the future and Ukrainian realities]. *LB.ua*. https://lb.ua/blog/opavlenko/351352_zemlerobstvo_maybutnogo.html.
7. Zatserkovnyi, V. (2018). *Dystantsiine zonduvannia Zemli. Fizychni osnovy* [Remote sensing of the Earth. Physical basis]. Nizhyn Mykola Gogol State University.
8. OneSoil Company. (2018). *What the NDVI index is and how it makes a farmer’s life easier*. https://blog.onesoil.ai/en/what-is-ndvi.
9. Latifundist Media. (2024). *Posivna onlain 2022/23* [Sowing campaign online 2022/23]. https://latifundist.com/posevnaya-online-2023.
10. Tsyliuryk, O. (2023, July 19). Dotsilnist i efektyvnist zastosuvannia tekhnolohii tochnoho zemlerobstva [Feasibility and efficiency of applying precision agriculture technologies]. *Ahronomiia Sohodni*. https://agronomy.com.ua/statti/1785-dotsilnist-i-efektyvnist-zastosuvannia-tekhnolohii-tochnoho-zemlerobstva.html.
11. Farmonaut Technologies Private Limited. (n.d.). *NDVI vs NDRE and Their Applications in Agriculture*. https://farmonaut.com/blogs/ndvi-vs-ndre-and-their-applications-in-agriculture.
12. Tsyliuryk, O. (2023, July 19). Dotsilnist i efektyvnist zastosuvannia tekhnolohii tochnoho zemlerobstva [Feasibility and efficiency of applying precision agriculture technologies]. *Ahronomiia Sohodni*. https://agronomy.com.ua/statti/1785-dotsilnist-i-efektyvnist-zastosuvannia-tekhnolohii-tochnoho-zemlerobstva.html.
13. Lapchynskyi, V., & Boiko, O. (2011). Mozhlyvosti vykorystannia HIS/DZZ tekhnolohii u tochnomu zemlerobstvi [Potential use of GIS / remote sensing technologies in precision agriculture]. *Journal of the Dnipro State Agrarian and Economic University*, *1*, 81-84. https://www.researchgate.net/ publication/317121895_Mozlivosti_vikoristanna_GISDZZ_tehnologij_u_tocnomu_zemlerobstvi.
14. Farmonaut Technologies Private Limited. (n.d.). *NDVI vs NDRE and Their Applications in Agriculture*. https://farmonaut.com/blogs/ndvi-vs-ndre-and-their-applications-in-agriculture.

Список використаних джерел

1. Lal, R. Tillage and Agricultural Sustainability / R. Lal // Soil and Tillage Research. – 1991. – № 20. – Pp. 133-146. https://doi.org/10.1016/0167-1987(91)90036-W.

2. World Bank Group [Electronic resource]. – Access mode: https://openknowledge.worldbank.org/handle/10986/9122

3. Economic and environmental consequences of overfertilization under extreme weather conditions / G. S. Hendricks, S. Shukla, F. M. Roka, R. P. Sishodia, T. A. Obreza, G. J. Hochmuth, J. Colee // J. Soil Water Conserv. – 2019. – № 74. – Pp. 160-171.

4. Big data analysis for sustainable agriculture / J. Delgado, N. M. Short, D. P. Roberts, B. Vandenberg // FSUFS. – 2019. – № 3. – Pp. 54.

5. Aubert, B. A. IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology / B. A. Aubert, A. Schroeder, J. Grimaudo // Decis. Support Syst. – 2012. – № 54. – Pp. 510-520.

6. Землеробство майбутнього та українські реалії [Електронний ресурс]. – Режим доступу: https://lb.ua/blog/opavlenko/351352_zemlerobstvo_maybutnogo.html.

7. Зацерковний, В. І. Дистанційне зондування Землі. Фізичні основи : навч. посіб. / В. І. Зацерковний. – Ніжин : НДУ ім. М. Гоголя, 2018. – 380 с.

8. Компанія OneSoil. What the NDVI index is and how it makes a farmer's life easier [Електронний ресурс]. – 2018. – Режим доступу: https://blog.onesoil.ai/en/what-is-ndvi.

9. Latifundist Media, 2013 -2024. Посівна онлайн 2022/23 [Електронний ресурс]. – Режим доступу: https://latifundist.com/posevnaya-online-2023.

10. Компанія «Агрономія сьогодні», 2023. Доцільність і ефективність застосування технологій точного землеробства [Електронний ресурс]. – Режим доступу: https://agronomy.com.ua/statti/1785-dotsilnist-i-efektyvnist-zastosuvannia-tekhnolohii-tochnoho-zemlerobstva.html.

11. Farmonaut Technologies Private Limited, 2023. NDVI vs NDRE And Their Applications in Agriculture [Electronic resource]. – Access mode: https://farmonaut.com/blogs/ndvi-vs-ndre-and-their-applications-in-agriculture.

12. Компанія «Агрономія сьогодні», 2023. Доцільність і ефективність застосування технологій точного землеробства [Електронний ресурс]. – Режим доступу: https://agronomy.com.ua/statti/1785-dotsilnist-i-efektyvnist-zastosuvannia-tekhnolohii-tochnoho-zemlerobstva.html.

13. Лапчинський, В. Можливості використання ГІС/ДЗЗ технологій у точному землеробстві. [Електронний ресурс] / В. Лапчинський, О. Бойко. – Режим доступу: https://www.researchgate.net/publication/317121895_Mozlivosti_vikoristanna_GISDZZ_tehnologij_u_tocnomu_zemlerobstvi.

14. Farmonaut Technologies Private Limited, 2023. NDVI vs NDRE And Their Applications in Agriculture. [Electronic resource]. – Access mode: https://farmonaut.com/blogs/ndvi-vs-ndre-and-their-applications-in-agriculture.

Отримано 21.05.2024

УДК 631.58:528.8

Віталій Іванович Зацерковний[1], Віктор Васильович Ворох[2]

[1]доктор технічних наук, професор, зав. кафедра геоінформатики
Київський національний університет імені Тараса Шевченка (Київ, Україна)

[2]аспірант кафедри геоінформатики
Київський національний університет імені Тараса Шевченка (Київ, Україна)

ТЕХНОЛОГІЇ ДЗЗ У ПРЕЦИЗІЙНОМУ ЗЕМЛЕРОБСТВІ

Одним з актуальних завдань сучасного аграрного виробництва є проблема подальшого розвитку спрямованого на забезпечення зростаючого попиту на продукти харчування та інші сільськогосподарські продукти на інноваційній платформі прецизійного землеробства. Прецизійне землеробство передбачає застосування геоінформаційних технологій, технологій дистанційного зондування Землі (ДЗЗ), Інтернет речей (IoT), технологій великих масивів даних та штучного інтелекту (ШІ), спрямованих на збільшення виробництва продукції рослинництва та зменшення витрат.

Застосування технологій ДЗЗ для задач прецизійного землеробства обумовлене безпрецедентною доступністю знімків високої просторової розрізненості (просторової, спектральної та часової) і відповідно можливістю здійснювати моніторинг посівів, в управлінні зрошенням, внесенням поживних речовин, боротьбі зі шкідниками та хворобами рослин, прогнозуванні урожайності тощо.

У статті наданий огляд найбільш уживаних систем ДЗЗ, що використовуються в технологіях прецизійного землеробства. Це дозволяє оптимізувати використання ресурсів сільськогосподарських підприємств для кожної ділянки поля і покращити продуктивність рослин на підставі даних про структуру ґрунту, pH, поживних елементів та карт врожайності, засобів захисту рослин (ЗЗВ), зрошення відповідно до властивостей ґрунту, рельєфу, метеорологічних умов та ряду інших факторів.

Використання супутникових даних потребує подальших досліджень спрямованих на вдосконалення технологій збереження та обробки таких даних, а саме хмарних обчислень та машинного навчання. Враховуючи певну складність обробки зображень і необхідність певної підготовки фахівців, важливо апробувати прості, але надійні алгоритми для застосування дистанційного зондування в режимі реального часу, що дозволить більш широке впровадження технологій ДЗЗ у прецизійне землеробство.

Ключові слова: *прецизійне землеробство; геоінформаційні технології; дистанційне зондування Землі; управління поживними речовинами, вегетаційні індекси.*

Рис.: 10. Бібл.: 14.