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# COMPARISON OF NDVI, NDRE, MSAVI AND NDSI INDICES FOR EARLY DIAGNOSIS OF CROP PROBLEMS

Andrii Voitik[a], Vasyl Kravchenko[b], Olexandr Pushka[c] ,Tetyana Kutkovetska[d], Taras Shchur[e*], Sławomir Kocira[f]

[a] Department of Agroengineering, Faculty of Engineering and Technology, Uman National University of Horticulture, Ukraine, e-mail: av.afex81@gmail.com, ORCID: 0000-0002-8196-3102,
[b] Department of Agroengineering, Faculty of Engineering and Technology, Uman National University of Horticulture, Ukraine, e-mail: kr.vasyl.v@gmail.com, ORCID:0000-0003-2334-0705
[c] Department of Agroengineering, Faculty of Engineering and Technology, Uman National University of Horticulture, Ukraine, e-mail: pushka79@ukr.net, ORCID: 0000-0002-6481-8536,
[d] Department of Agroengineering, Faculty of Engineering and Technology, Uman National University of Horticulture, Ukraine, e-mail: tanya_kut@ukr.net, ORCID0000-0002-4879-2954
[e] GVA Lighting, Inc, Oakville, Ontario, Canada, e-mail: shchurtg@gmail.com, ORCID 0000-0003-0205-032X
[f] Department of Machinery Exploitation and Management of Production Processes, University of Life Sciences in Lublin, Lublin, Poland; e-mail: slawomir.kocira@up.lublin.pl, ORCID 0000-0002-2888-3023

** Corresponding author: e-mail: shchurtg@gmail.com*

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ABSTRACT

In precision agriculture, it is possible to use satellite monitoring of fields. Satellite monitoring systems allow you to get free images with a resolution of up to 10 m per pixel, which is sufficient to determine the state of vegetation of plants on such indicators as the normalized vegetation index NDVI. However, the NDVI indicator already indicates the existing problems of correction which will not help to restore the lost yield of crops, but only helps to prevent further losses. Using the NDSI soil salinity index, it is possible to determine the difference in its properties from spectral images. Also, you can study the vegetation of plants in the early stages of their development, in fact immediately after germination. Soil-adjusted vegetation index, such as MSAVI, is used for this purpose. Studies indicate the possibility of using NDSI and MSAVI indicators for early diagnosis of confirmed crops NDVI and NDRE (indicating chlorophyll activity in plants) at later stages of their development. Studies conducted on soybean, spring barley and maize crops sown in the spring of 2021 indicate a correspondence between raster field maps show-ing the above indices made from March to July. Statistical analysis of raster images of field maps using specialized software showed a correlation between NDSI and MSAVI in March and May, respectively, with NDVI and NDRE indexes in June and July. Therefore, it is possible to judge the expediency of using NDSI and MSAVI indicators for early diagnosis of possible problems with plant vegetation, as well as for the creation of maps of differential fertilization.

## Introduction

Forecasting the future yield of crops is an important component of sustainable and profitable agricultural production. One way to predict is to identify possible plant problems early. To identify these problems, you need to conduct a timely inspection of crops. This work is possible with the involvement of employees of the agronomic service, who will inspect the fields with the use of drones, or by means of satellite monitoring systems (Sagan et al., 2020).

The latter method, however, is the least accurate but has many advantages over others. First, this method requires minimal labour and time. Also, you do not need to spend on expensive equipment, logistics, and related costs.

Modern satellite monitoring systems such as Sentinel-2 allow you to take images of the surface with an accuracy of 10 m per pixel. This is enough to have differential and accurate information about the state of the fields (Kayad et al., 2019; Phung et al., 2020). Of course, it is not possible to directly identify the type of pests or diseases but possible to estimate the general condition of plants or soil surface, and already based on the analysis of these data to draw conclusions (Karaiev et al., 2021).

There are many methods to analyse data from satellite images in different frequency bands. Among them NDSI (normalized differential index of soil salinity) - allows you to assess the salt content in the soil surface, MSAVI (modified vegetation index adjusted for soil) - allows you to assess the condition of young vegetation when the soil surface is not completely covered with vegetation, NDVI (normalized differential vegetation) - allows you to assess the condition of adult plants and NDRE (normalized differential index of the difference of red spectra) - allows you to assess the activity of chlorophyll in plants, their health and nutrient requirements, is the best analogue of the vegetation index.

NDSI and MSAVI indices are determined before sowing and after germination, respectively. These indices in the early stages allow to identify possible problem areas and draw the attention of experts to them. It is necessary to determine the correlation between these indices and the condition of plants in the late stages of their growth using NDVI and NDRE indices.

The NDVI index became the most widespread and popular due to the availability of software tools for its determination. However, there are significant risks of its incorrect use (Huang et al., 2021) and understanding of the obtained results. When evaluating this index, it is necessary to have relevant knowledge and take into account a different number of variable factors, such as atmospheric effects, saturation of the atmosphere with aerosol particles, etc.

Methods of correction of the NDVI index (Hassan et al., 2019) using the NDRE index allow a better understanding of the obtained data. Although these methods provide a more accurate representation of the state of the crops, it is still the current state of the plants that allows you to identify existing problems, and not to predict their possible appearance. The research was conducted on wheat crops and needs clarification for other crops.

The relationship between the NDVI and NDRE indices was also investigated (Boiarskii and Hasegawa, 2019) and it was found that the NDRE index makes it possible to understand the chlorophyll content and nitrogen demand in plant leaves. This non-contact diagnosis of the state of crops is more reliable in comparison with the classic definition of the NDVI index. The research results indicate the need to consider more parameters for a better assessment of the state of plants and forecasting their yield.

There are opportunities to improve the obtained results when using the normalized vegetation index (Shammi and Meng, 2021) - a combination of the 0 influence the values of vegetation indices obtained with the help of UAV or satellite monitoring. This indicates that the use of vegetation indices for yield forecasting should be applied throughout the entire period of plant growth with a certain frequency, at least once a month, taking into account both the type of plant and the stage of its development. But at different stages of plant growth, especially early ones, the NDVI and NDRE indices are not able to provide adequate data on the condition of crops.

The MSAVI index (Daldegan et al., 2020), which is a reliable indicator of vegetation for areas with low vegetation, corresponding to crops in the initial stages of development, is better suited for early diagnosis of the condition of crops. However, the comparison of vegetation indices was carried out mostly for meadows, and not for industrial crops. In the early stages of plant development, when the amount of biomass is still small and on satellite images of fields, open soil occupies a larger area, the adjusted MSAVI index provides more reliable data.

The influence of the amount of green biomass on the readings of NDVI indices is quite significant (Fabijańczyk and Zawadzki, 2022; Qawaqzeh et al.,2021). It was established that in areas with a large number of plants, the indicators of both indices are equivalent, while in the study of areas with low vegetation, objective data can be obtained only by the MSAVI index.

It was also established (Almeida-Ñauñay et al., 2020) that the MSAVI index is correlated with temperature indicators during plant vegetation and, especially, precipitation. Accordingly, MSAVI is an important indicator for determination of the condition of plants and must be taken into account when predicting their development.

One of the possible options for early diagnosis of crops at the stage before their emergence is the evaluation of soil colour to determine heterogeneities. The possibility of using the NDSI salinity index to determine differences in the chemical composition of the soil surface has been proven (Aceves et al., 2019). It was found that this index allows to distinguish soil areas with different content of ions of metal salts and correlates with the electrical conductivity of the soil. The effect of the salinity index on vegetation was compared only with the NDVI vegetation index. Research conducted in arid climatic conditions established the presence of a certain relationship between these two indices, which allows us to conclude the feasibility of using the salinity index for early diagnosis of crops.

Also, there is an influence of the NDSI index on the yield of agricultural crops and soil fertility (Solangi et al., 2019). Soil remote sensing data using the salinity index has been found to correlate with fertility and is less expensive than traditional soil analysis methods.

The relationship between salinity and vegetation indices, taking into account both normalized and adjusted vegetation indices (Nguyen et al., 2020), provides ample opportunities for the application of the salinity index in agricultural production in predicting plant yields.

Taking into account the results of previous studies, there is a real possibility of early diagnosis of possible problems on crops with the use of satellite monitoring systems. For this, the MSAVI adjusted vegetation index and the NDSI soil salinity index can be used, as determined during the early stages of plant growth. These data need to be compared with vegetation indices on NDVI and NDRE to establish a correlation, which is what this research is aimed at.

## Materials and methods

Research was carried out on three fields: the first - soybeans on the area of 23 hectares, the second - spring barley on the area of 17 hectares, the third - corn on the area of 24 hectares. All crops were sown in April 2021. All fields were located in the central part of Ukraine in the Uman district. Distances between fields were within 5 km, which indicates the same soil and climatic conditions. According to the FAO classification, the type of soil – normal black soil.

The climate is temperate continental. Summers are usually hot and dry, winters with little rainfall and short frosts. Spring is cool and humid; autumn is warm and mild. The average annual rainfall in 2021 was 484 mm, the average daily temperature was 10.1°C.

The relief of the fields, though uniform, but with differences in altitude from 220 to 235 m above sea level. The slopes are gentle. A topographic map of the fields (Fig. 1) was built using satellite data DEM (digital altitude map).

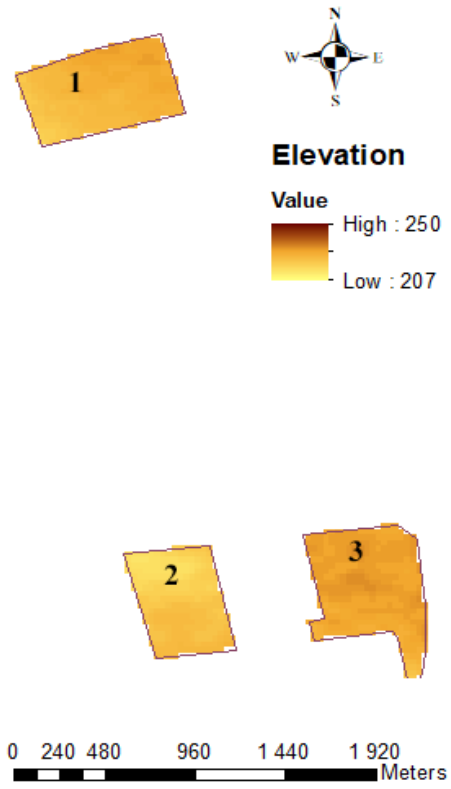


*Figure 1. Map of the relief of the fields (the distance between the fields corresponds to the scale): 1 – soybean, area 23 ha; 2 – spring barley, area 17 ha; 3 – corn, area 14 hectares*

Sentinel-2 satellite imagery was used to calculate the indices. The condition was a cloudiness of less than 10% to obtain clear images. The resolution of the images is 10 m per pixel and only when calculating the NDRE index the resolution is 30 m per pixel.

Images taken from March to July 2021 were used. Images from March 28 were used to determine the NDSI salinity index, from May 22 to determine the adjusted vegetation index MSAVI, and from June 21 and July 12 to determine the normalized NDVI vegetation index and the NDRE red difference index.

All indices were calculated according to the formulas presented in Table 1 (Meivel and Maheswari, 2022).

Table 1.
*Formulas for determining the NDSI, MSAVI, NDVI and NDRE indices*

| Index name | Formula for determination |
|---|---|
| Normalized differential index of soil salinity NDSI | RED – REDEDGE / RED + REDEGE |
| Modified vegetation index adjusted for MSAVI soil | $\frac{2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - RED)}}{2}$ |
| Normalized vegetation differential index NDVI | MIR−NIR / MIR+NIR |
| Normalized differential difference index of red NDRE spectra | NIR−REDEDGE / NIR+REDEDGE |

According to the above formulas, the indices were calculated using the tool "Raster Calculator" software ArcGIS 10.8 (ESRI, 2019).

All obtained bitmaps were superimposed on the borders of the corresponding fields obtained with the help of Google Earth Pro software and transferred in the form of KML-files to the program ArcGIS 10.8.

The "Band Collection Statistic" tool was used to carry out statistical calculations, which made it possible to perform a multivariate analysis of a set of raster bands. The value of the variance of the values depending on the mean and the correlation coefficient, which indicated the relationship between the data sets, were determined.

## Results and discussion

Figure 2 presents data from the NDSI indexes (based on satellite images from March 2021), MSAVI (data from May 2021), NDVI (data from June and July 2021) and NDRE (data from June and July 2021) for the three subject fields.

The obtained data show that for the field №1 (soybean) the NDSI salinity index is uniform except for the area in the east (on the right). Here, the NDSI index is slightly higher, and the MSAVI adjusted vegetation index shows that this is where the first seedlings (light spots) appear in May. In June, a significantly better condition of the plants was observed in this part of the field, which is confirmed by the data of the NDVI vegetation indices and the difference of the red spectra of the NDRE.

In July, the vegetation on the field levelled off, but the area on the steps, as evidenced by the data of the NDRE index, has a lower chlorophyll activity. This can be explained by the fact that the plants in this area developed faster and, accordingly, quickly used up the reserves of nutrients in the soil and need additional feeding. Observations demonstrate the effectiveness of using NDRE as a sensitive index for monitoring chlorophyll content (Boiarskii and Hasegawa, 2019). Different indices may be most useful for different crops, plant densities, seeding rates and growth stages.

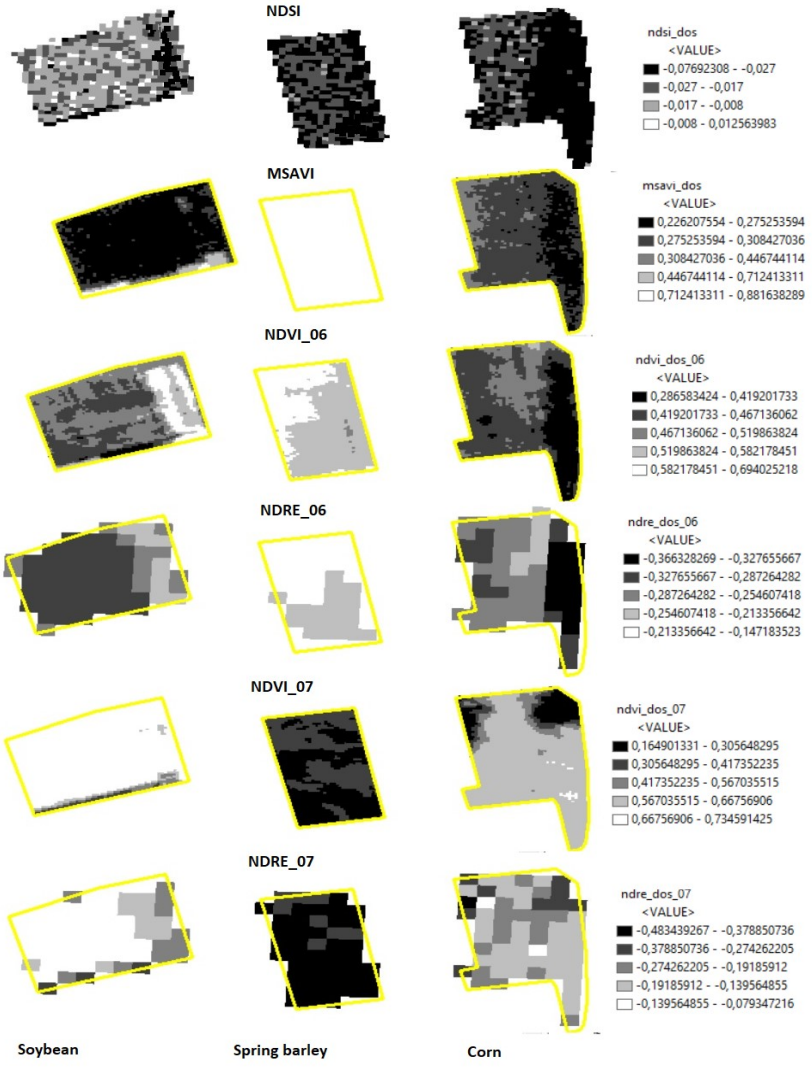


*Figure 2. NDSI soil salinity index maps (March 2021), MSAVI adjusted vegetation index (May 2021), NDVI normalized vegetation index (June and July 2021) and NDRE red spectrum difference index (June and July 2021) for January and corn*

The conducted studies (Naguib and Daliman, 2022) indicate that the lower layers of the vegetation cover have less influence on the NDVI estimation. This effect is intensified in plants with several layers of leaves. NDRE can offer better insight into no-change or late-season crops, such as soybeans and corn, because it can take into account not only the upper layers of plants, but also the middle and lower layers. As a result, NDRE can sometimes offer a more accurate estimate in areas where NDVI would simply be constant.

In the field No2 (spring barley) we observe a slightly higher NDSI salinity index in the south-eastern part (a lower right corner). Data from the MSAVI adjusted vegetation index show the presence of homogeneous friendly seedlings in May. Unlike soybeans and corn, spring barley was bred 15 days earlier, as shown by the MSAVI index. Although uniform seedlings were obtained in May, in June we see less plant development in the south-eastern part of the field (NDVI index) and lower chlorophyll activity in them (NDRE index). These indicators correlate with the salinity index. In July, the plants reached full maturity, as shown by both the NDVI and NDRE indices, and were ready for harvest.

Map results for field No3 (maize) show that there is also an irregularity in the NDSI salinity index, which is clearly visible in the eastern (right) part of the field. Here the indicators of the index are somewhat higher. Researchers (Allbed and Kumar, 2013; Havrylenko et al.,2021) indicate that the salinity index data can be used to identify different areas in fields that will be adjusted with future crop yields.

As can be seen from the data of the adjusted MSAVI vegetation index, plant sprouts appeared later in this part. Problems on this part of the field continue in June. According to the data of the normalized vegetation index NDVI and the NDRE index, plants here develop worse, and the activity of chlorophyll is the lowest. In July, the situation changes and the vegetation on the field is evened out, yet in the north-eastern part of the field (top right) the plants are lagging behind in development. The same situation appears in the north-western part of the field. This problem has apparently not been observed in the early stages (NDSI and MSAVI index data). Although, research data (Almeida-Ñauñay et al., 2023) indicate that NDVI, MSAVI and NDRE indices were able to predict signs of yield problems in wheat crops. Studies conducted on corn for silage (Herbei et al., 2022) also confirmed the possibility of using the MSAVI index for yield prediction.

Table 2 shows the statistics of each layer (index), namely, the minimum and maximum value, the mean, and the standard deviation. The matrices of mutual covariance and correlation between the indices studied are also indicated.

Analysis of the spectral data (Fig. 2) for the field №1 shows that an early diagnosis of the field using NDSI and MSAVI indices in this case indicates problems during the growing season, which appeared in later images in the form of NDVI and NDRE indices. In this example, for soybeans at the initial stages it would be possible to identify problem areas of the field and develop a map of differential plant nutrition, taking into account the difference between the salinity index and seedling rate.

In the field No2, the NDSI salinity index correlates with the vegetation index and red spectrum indices. Using this data, it would also be possible to identify problem areas at the stage before sowing spring barley and adjust the fertilizer application plan and, as an additional option, the seeding rates.

Table 2.
*Statistical data of raster layers of field maps (indexes) and their covariance and correlation matrices*

| STATISTICS of INDIVIDUAL LAYERS | | | | | | |
|---|---|---|---|---|---|---|
| Layer | MIN | MAX | MEAN | STD | | |
| NDSI | -0.0769 | 0.0126 | -0.0249 | 0.0107 | | |
| MSAVI | 0.2262 | 0.8816 | 0.4385 | 0.2550 | | |
| NDVI_06 | 0.2866 | 0.6940 | 0.4969 | 0.0681 | | |
| NDRE_06 | -0.3663 | -0.1472 | -0.2660 | 0.0485 | | |
| NDVI_07 | 0.1649 | 0.7346 | 0.5397 | 0.1763 | | |
| NDRE_07 | -0.4834 | -0.0793 | -0.2361 | 0.1195 | | |
| COVARIANCE MATRIX | | | | | | |
| Layer | NDSI | MSAVI | NDVI_06 | NDRE_06 | NDVI_07 | NDRE_07 |
| NDSI | -0.00041 | 0.00733 | 0.00833 | -0.00446 | 0.00907 | -0.00394 |
| MSAVI | 0.00733 | -0.12704 | -0.14608 | 0.07872 | -0.16037 | 0.06873 |
| NDVI_06 | 0.00833 | -0.14608 | -0.16582 | 0.08893 | -0.18046 | 0.07870 |
| NDRE_06 | -0.00446 | 0.07872 | 0.08893 | -0.04748 | 0.09631 | -0.04234 |
| NDVI_07 | 0.00907 | -0.16037 | -0.18046 | 0.09631 | -0.19469 | 0.08624 |
| NDRE_07 | -0.00394 | 0.06873 | 0.07870 | -0.04234 | 0.08624 | -0.03697 |
| CORRELATION MATRIX | | | | | | |
| Layer | NDSI | MSAVI | NDVI_06 | NDRE_06 | NDVI_07 | NDRE_07 |
| NDSI | 1 | 1.01144 | 1.00599 | -1.00630 | 1.01035 | -1.00810 |
| MSAVI | 1.01144 | 1 | -1.00649 | 1.01364 | -1.01975 | 1.00293 |
| NDVI_06 | 1.00599 | -1.00649 | 1 | 1.00225 | -1.00436 | 1.00524 |
| NDRE_06 | -1.00630 | 1.01364 | 1.00225 | 1 | 1.00175 | -1.01055 |
| NDVI_07 | 1.01035 | -1.01975 | -1.00436 | 1.00175 | 1 | 1.01651 |
| NDRE_07 | -1.00810 | 1.00293 | 1.00524 | -1.01055 | 1.01651 | 1 |

The field No3 indicates a significant correlation between all studied indices. The difference begins to appear only in July, when corn enters the later stages of the growing season, as evidenced by the NDVI and NDRE indices. That is, in this case it is possible to diagnose problems with plants in the early stages of growth.

It should be noted that the effect of the NDSI salinity index is ambiguous. Thus, in the field №1, where soybeans grew, lower values of the index corresponded to the area with the best plant development. Fields No2 and No3, where spring barley and corn grew, have the opposite result. Here, the best plant development is observed in the areas of fields where the values of the NDSI index were higher. This may be due to the difference in the crops themselves, as soybeans are legumes and barley, and corn are cereals. Additional research is needed to determine these patterns.

Analysis of the data of statistical studies shows that the most uneven are the values of the adjusted vegetation index MSAVI. Here, the standard deviation is the largest and is 0.255. This indicates that different crops have different sowing dates and, consequently, the germination of seedlings. Therefore, to obtain the most reliable data for each crop, you need to use different date satellite data, according to the date of sowing and the expected period of germination.

The data of the correlation matrix between the raster layers (graphical display of indices), that this indicator is in the range from -1.02 to 1.017. If we consider the possibility of using

NDSI salinity indices and the MSAVI adjusted vegetation index for early diagnosis of possible problems with agricultural plants, we see that the correlation between these indices and NDVI and NDRE indices is about 1.006. This indicates a correspondence between the graphical data.

Also, the covariance matrix shows the relationship between NDSI index data and NDRE red spectrum index, which records chlorophyll activity. The value of the covariance index here is on average at -0.0042.

## Conclusions

The indicators of soil salinity indices NDSI and modified vegetation index MSAVI at early stages of growth of plants such as soybean, corn and spring barley were studied. The readings of these indices were controlled by the more classic vegetation index NDVI and red edge index NDRE, which were determined already at the later stages of plant development. The conducted studies indicate the possibility of using the NDSI and MSAVI indices for early diagnosis of problems with plant development in different areas of fields.

Also, the use of these indices allows developing maps for differential fertilizer application in advance. However, it is necessary to study in more detail the influence of the soil salinity index on the development of various types of plants and its relationship with the physical, mechanical and agrochemical properties of the soil.

Statistical studies of the correlation between raster images of soil salinity indices (NDSI, March 2021), adjusted and normalized vegetation indices (MSAVI, May 2021, and NDVI, June and July 2021) and the red spectrum index (NDRE, June 20, June 20) calculated at different stages of development of soybean, corn and spring barley plants show that the correlation is in the range from -1.02 to 1.017, and in some cases is 1.006 (correlation between rasters of NDSI and MSAVI indices with normalized vegetation index NDVI_06 obtained in June ).

For a full understanding of the feasibility of using the NDSI soil salinity indices and the modified MSAVI vegetation index for early diagnosis of problems with agricultural crops, additional studies that will take into account yield maps and data from agronomic surveys of plants will be needed.

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# PORÓWNANIE WSKAŹNIKÓW NDVI, NDRE, MSAVI I NDSI DO WCZESNEJ DIAGNOZY PROBLEMÓW Z PLONEM

**Streszczenie.** W rolnictwie precyzyjnym możliwe jest wykorzystanie satelitarnego monitoringu pól. Systemy monitorowania satelitarnego pozwalają na uzyskanie darmowych zdjęć o rozdzielczości do 10 m na pixel, co jest wystarczającą wartością do określenia stanu wegetacji roślin na podstawie takich wskaźników jak znormalizowany wskaźnik wegetacji NDVI. Jednakże, wskaźnik NDVI już wskazuje na istniejące problemy w kwestii korekty, która nie jest w stanie odzyskać stracony plon, a tylko pomaga uchronić przed dalszymi stratami. Istotne jest badanie możliwości identyfikacji problemów na wczesnych etapach wegetacji roślin, na przykład na etapie kiełkowania i pierwszym etapie rozwoju rośliny lub wpływu właściwości gleby na przyszły rozwój roślin. Stosując wskaźnik zasolenia gleby NDSI, możliwe jest określenie różnicy w jej właściwościach poprzez obrazowanie spektralne. Można także badać wegetację roślin na wczesnych etapach ich rozwoju, w zasadzie po etapie kiełkowania. W tym celu stosuje się wskaźnik roślinności dostosowany względem gleby, taki jak MSAVI. Badania wskazują na możliwość zastosowania wskaźników NDSI i MSAVI do wczesnej diagnozy potwierdzonych plonów NDVI i NDRE (wskazujące na aktywność chlorofilu w roślinach) na późniejszych etapach ich rozwoju. Badania przeprowadzone na soi, jęczmieniu wiosennym i kukurydzy zasianych wiosną 2021 roku wskazują na odwołanie do map rastrowych pól, wykonanych od marca do lipca, które wskazują na powyższe wskaźniki. Analiza statystyczna obrazów rastrowych map polowych przy użyciu specjalistycznego oprogramowania wykazała korelację pomiędzy NDSI i MSAVI w marcu i maju, odpowiednio ze wskaźnikami NDVI i NDRE w czerwcu i lipcu. Zatem, możliwa jest ocena stosowności użycia wskaźników NDSI i MSAVI do wczesnej diagnozy możliwych problemów z wegetacją roślin, jak również do stworzenia map o różnych stopniach nawożenia.

**Słowa kluczowe:** mapy polowe, diagnostyka rozwoju roślin, wskaźnik wegetacji, wskaźnik zasolenia gleby, zróżnicowany nawóz