BULLETIN OF THE POLISH ACADEMY OF SCIENCES
TECHNICAL SCIENCES, Vol. 71(1), 2023, Article number: e144582
DOI: 10.24425/bpasts.2023.144582

CONTROL AND INFORMATICS

Assessment of benefits resulting from the use of computer control systems in precision agriculture

Mariusz R. RZĄSA*

Opole University of Technology, Faculty of Electrical Engineering Automatic Control and Informatics, ul. Prószkowska 76, 45-758 Opole, Poland

Abstract. Rising food prices mean that solutions are sought that will reduce the costs of agricultural production. One area of research is precision agriculture. This solution requires a computerized plant growth monitoring system. The paper presents a computer system for monitoring plant growth, developed for the needs of precision agriculture for small agricultural areas. The work contains a description of the monitoring system divided into the key elements of the process. An exemplary method of preparing orthophotomaps of the area was presented. The method of making maps that can be implemented on a personal computer has been described. The paper describes the most frequently used Geologic Indicators and Vegetation Index. A test of determining the coefficients was carried out on exemplary acreage with an area of 5.28 ha. Typical positioning systems for agricultural machines are discussed. The DGPS (Differential Global Positioning System) navigation method was used in the tests, which confirmed that it can be used in precision agriculture for small agricultural areas while maintaining sufficient positioning accuracy. The presented system was tested during one cycle of vegetation of winter barley sown with the no-plowing method. On this basis, an analysis of savings resulting from the reduction of the amount of fertilizers and plant care products used was carried out. The proposed system does not require complicated computer systems. It was designed in such a way that it can be implemented on standard PC equipment cooperating with a short-range drone equipped with a standard RGB (Red Green Blue) camera.

Key words: precision agriculture; field mapping; vegetation indicator; geological indicator; precision GPS.

1. INTRODUCTION

The increasing number of people and changes in eating habits increase the demand for agricultural production. At the same time, there is no significant increase in the new land for agricultural production in the European Union. In order to increase the yield from the owned agricultural area while minimizing the increase in agricultural production costs, it is necessary to search for modern methods of growing plants.

Farmers who cultivate the land must meet the new requirements. In the European Union, there are a number of organizations that support farmers and help to ensure food quality, traceability, trade, and promotion of agricultural products in the EU. In addition, the EU provides financial support to farmers, encourages the use of sustainable and environmentally friendly practices and at the same time invests in rural development.

An example of such an institution can be the Common Agricultural Policy CAP. This institution supports farmers in improving productivity [1], among other things. The efforts of such programmers and other institutions have no chance of success without support in the form of developing and implementing new plant cultivation technologies.

The agricultural structure of the European Union Member States differs significantly (Fig. 1). Based on statistical data from the European Commission Eurostat. Romania is the country with the highest ratio of farms to agricultural acreage in Europe. Poland is also one of the countries with a large number of farms in relation to the surface area. This proves that small farms predominate in a given country. Therefore, in these countries, modern technologies used in agriculture should be targeted at small farms. This paper discusses the possibility of using a computerized plant growth control system for small agricultural areas, typical for small farms.

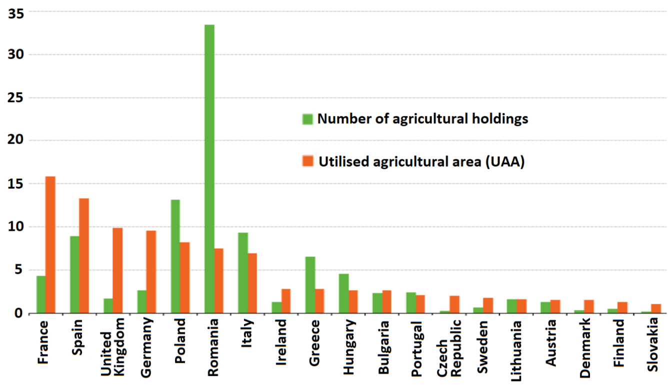


Fig. 1. Agricultural structure of European Union Member (Source: Eurosat (online data code: ef_kvaareg) [2])

2. TYPE OF AGRICULTURAL PRODUCTION

Currently, two types of farming are dominant: extensive and intensive [3]. In the Middle East, Central America, the United States, and Africa, where there is no need for high performance, high yields are obtained by cultivating large areas of land. Ex-

*e-mail: m.rzasa@po.edu.pl

Manuscript submitted 2022-07-16, revised 2022-11-29, initially accepted for publication 2022-12-28, published in February 2023.

tensive farming, based on the extremely limited use of artificial fertilizers, is dominant in these regions in which mainly mineral fertilizers and pesticides are used. This requires a lot of work with relatively low material costs.

In Europe, due to the limited agricultural area, extensive agriculture is not popular. It is used only for organic food production and is primarily based on the stimulation of agricultural production through natural and technologically unprocessed resources. This does not guarantee the achievement of high productivity. However, in this instance, the high biological quality of agricultural products and the protection of the natural environment are of higher importance.

Intensive agriculture with a different scale of concentration dominates in Europe. Advanced monitoring systems for large-scale cultivation, which allow for high yields through intensive fertilization, high mechanization, and production automation, are immensely popular in Western European countries. It facilitates high yields through intensive fertilization, high mechanization and production automation. On the other hand, the use of modern technologies intended for large-area crops for small acreage is often economically unjustified. The way out of this situation is the use of precision farming, which can be easily adapted to the needs of compact plots of land.

Precision agriculture uses information technology to adjust the doses of fertilizers and plant protection products to the potential requirements of cultivated plants and is being implemented in many countries on an increasing scale. Agriculture is often combined with other activities for the protection of the environment. As an example, biological waste treatment can be used to aid soil fertilization. Currently, composting is becoming increasingly popular as a method of biological waste treatment [4]. The composting process is completed with hygienization, which makes the final product non-toxic and facilitates spreading it on less fertile agricultural land for enrichment before sowing crops.

Precise fertilization lowers production costs and reduces the environmental impact of pesticides. However, it is linked to the analysis of soil conditions that affect plant growth and the tracking of crop growth. This approach requires the use of appropriate measurement techniques to monitor crop growth. Such monitoring provides the ability to isolate areas to which the appropriate amount of fertilizers should be selectively delivered. It is presented in this work as a solution for computer monitoring of agricultural acreage and an example of its implementation on a sample agricultural area.

3. TYPE OF AGRICULTURAL PRODUCTION

Precision farming is based on monitoring plant growth and reacting selectively to any anomaly. GPS navigation is used to precisely and selectively respond to anomalies in plant growth. On the other hand, information on the state of the growth of plants is collected in the form of detailed orthophotomaps [5]. Figure 2 shows the steps of monitoring and controlling the process. The process starts with mapping the area before sowing with precise GPS positioning. The appropriate precision is achieved thanks to reference markers placed in the field. To analyze soil fertility, a photo of the area is made with the use of drones or airplanes. Then the image is subjected to computer analysis in order to identify the areas requiring the application of fertilization agents. On this basis, selective soil fertilization treatments are carried out in order to homogenize the area. Then, after the crops have been sown, the growth of the plants is periodically monitored. Vegetation maps provide a basis for computer analysis, on which decisions on selective fertilization, application of appropriate plant protection measures and irrigation are based. The analysis algorithm will take into account the weather conditions and their forecast. The monitoring process is carried out throughout the growing season of the crop. Following the end of the vegetation period, the harvesting process is carried out with monitoring of productivity. Harvest data provides valuable information about the effectiveness of the process, and based on this information, it is possible to make adjustments to the computer algorithms that will be used in future plant growth control processes.

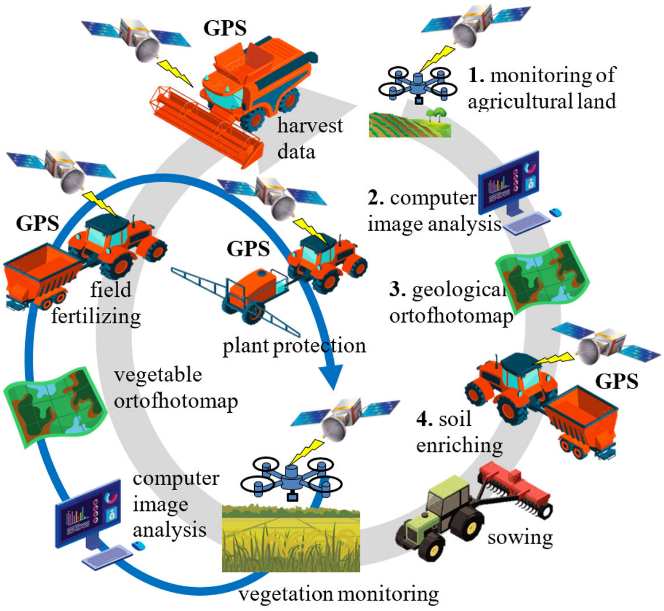


Fig. 2. Precision Farming System Duty Cycle (Graphics from vecteezy.com were used for the drawing)

Precision farming systems combine knowledge about soil fertility (soil productivity) with the process of fertilization, the use of plant protection products and agrotechnical practices. This process must be supported by modern IT and telecommunication technology and appropriate adaptation of agricultural machinery. The paper describes low-cost solutions that enable their application to typical solutions used in small farms.

The analysis of information about the growth of plants is used to predict and prevent the effects of occurring anomalies. Computer algorithms used in precision agriculture process information about the spatial and temporal variability of plant characteristics in combination with weather conditions. Often these types of algorithms use neural networks. Repeatedly, these data are supplemented by information on the occurrence of plant macrophages that occur in a particular area, which allows for a much more precise selection of plant protection products. The information is usually collected in the form of spatial-temporal maps.

The key element of the management system in precision agriculture is the monitoring process for the preparation of precise orthophotomaps of the terrain, associated with a process of image analysis that permits the identification of zones requiring intervention. A precision guidance system for agricultural machinery in areas requiring interventions is of secondary importance. The following sections of this article will discuss the key elements of this system.

4. TECHNOLOGY OF ORTHOPHOTOMAPS PRODUCTION

With the current state of technology, it is not overly difficult to map terrain from high altitudes with good resolution. It is possible to take satellite or aerial photos with resolutions up to several centimeters. However, the cost of acquiring such photos for the purposes of precision farming for small agricultural areas is often economically unjustified. For this reason, a terrain mapping solution was proposed based on taking a series of photos with a drone from a relatively low height using low-cost cameras.

To begin, an analysis of the available orthophotomap techniques applied to small agricultural acreage was carried out. Currently, taking photos with an area of several hundred or even several thousand hectares using satellite techniques is not inordinately complex. Such photos can be obtained after meeting the full formal and legal conditions. The key characteristic of these photos is their remarkably high resolution, which means they can certainly be used to monitor plant growth. However, it may prove difficult or nearly impossible for the average small-scale farmer to meet the requirements to access these photos as that access is closely monitored by military organizations and some state institutions. Farm owners may only use low-resolution images. These types of photos can be used to assess lichens on exceptionally large areas, up to thousands of hectares, but for several hectares, they are often insufficient.

Regarding the typical size of agricultural areas in Europe, the usage of this technique is marginal. An alternative to satellite imagery for the preparation of orthophotomaps for large areas of tens to hundreds of hectares is taking pictures from a plane. A popular system for this purpose is ATLAS (Advanced Thermal and Land Application Sensor). A 15-channel multispectral scanner which captures thermal radiation, infrared radiation and visible light spectrum is installed on a light airplane. During the flight, a series of images with a resolution of about 2 m per pixel are taken at one-second intervals. In order to create an orthophotomap of an area it is necessary to compile a series of photographs [6]. The position of the flying airplane is measured at least once every second. Therefore, during the flight, continuous correction of the flight path is required based on the average of the measured values. However, this facilitates the repeatability of flights with the required accuracy for the needs of precision agriculture.

The ATLAS system is equipped with a multispectral camera that enables the recognition of 15 spectral channels in the range of radiation channels across the thermal, near-infrared visible spectrums. Installed sensors are equipped with calibration systems; however, they need a suitable active reference light source for all bands. Atlas is capable of approximately 2.0-meter resolution per pixel when flown in NASA's Lear jet and sees about a 30-degree swath width to each side of the aircraft. However, the use of this type of system to monitor an area ranging from a few to several hectares is economically unjustified.

When applied to areas from a few hectares to several dozen hectares, a much more economical solution is to use a drone with a wide-spectrum camera. Drones can remember and program the flight route, which guarantees the repeatability of the created maps. Low-cost cameras mounted on the drone guarantee a resolution of several to several dozen cm/pixel from a height of several dozen meters.

Currently, all matters related to piloting unmanned aircraft are regulated by the Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft. Pursuant to this regulation, an unmanned aerial vehicle pilot may be a person who has reached the age of 16, passed the exam and become an operator of the unmanned aircraft system, provided that the flight involves a drone weighing up to 25 kg; the flight will not take place over bystanders within the visual range of the VLOS pilot; the flight altitude will not exceed 120 m above ground level; the flight path will not pass over controlled areas. In precision farming applications, these requirements are met in most cases. Sometimes the only requirement is to move the pilot of the aircraft in order to maintain eye contact with the drone.

In the case of agricultural acreage with an area of several hectares, the flight at a height of 120 m is not sufficient for taking a photo of the entire area. In this case, the terrain map should be created based on the sequence of photos from the drone flight. Such photos can be assembled using available software or using our own software based on image correlation algorithms.

After correcting the scale of the image, one of the methods that allow a user to combine images that partially overlap is the method of the best-correlated pixels [7]. It consists of searching for the best correlation both with the pixel in the Y_k image with the same coordinates as the pixel in the X_k image and with the pixels in its immediate vicinity (Fig. 3). The final result is the shift value for which the highest correlation coefficient is obtained.

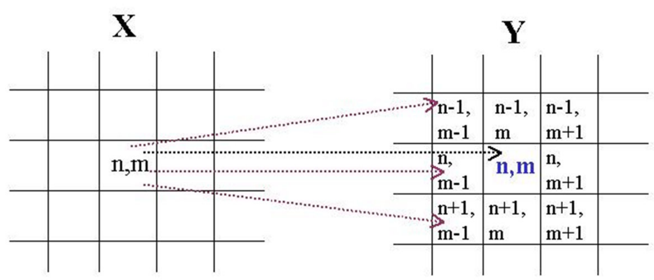


Fig. 3. The best-correlated pixels method algorithms

The mathematical notation of this method with the restriction of the distance of neighboring pixels to those from the set B is expressed by the equation and the calculation of the largest correlation value R_x:

$$R_{X_{k[m,p]},Y_{k[m+l,p+j]}}[n] = \sum_{l\in B}\sum_{j\in B}\sum_{n=0}^{N_k-1} x_k[m,p]\cdot y_{(k+n)}[m+l,p+j], \qquad (1)$$

where: N – number of pixels in the overlap area, x_k, y_k – pixel values for the offset k of coordinates $[n,m]$.

The second step in the process of composing time-lapse photos is color saturation matching. As the drone changes its position, there are differences in the lighting of the area and, consequently, subsequent photos differ in terms of color saturation. After the process of adjusting the position of individual photos, there are areas in which two adjacent photos partially overlap. These areas are called overlaps (Fig. 4). Based on the registered differences in color saturation for individual pixels in the overlap area, the color saturation is corrected.

Fig. 4. The overlap area

The color correction process consists of the appropriate adjustment of the color saturation for each of the basic colors of the RGB image components (R – read, G – green, B – blue). The correction algorithm consists of calculating the averaged correction factors for each of these components and calculating the correction factor. Then, for each pixel of the image added Y, the RGB component values are multiplied by this factor. The correction coefficients are calculated from the relationship:

$$k_{\mathrm{B}} = \frac{1}{N}\sum_{i=1}^{N}\frac{\mathrm{B}_{Xi}}{\mathrm{B}_{Yi}}\,, \qquad (2)$$

where: B_{Xi}, B_{Yi} – values of the B component in i-th pixel.

For taking pictures, Hyperspectral Imaging Cameras are used [8]. These cameras record images at different wavelengths of light from visible light to deep infrared (Table 1).

Spectral analysis of the spectrum of light reflected from the plant surface allows us/the user to determine their condition [9]. The parameter that proves the condition of plants is the proportion of the light reflectance in the range of visible light to the infrared band (Fig. 5). For properly developing plants, these differences amount to more than 50%. As the condition

Table 1
Wavelengths recorded in images from Hyperspectral Imaging Cameras

Color	Wavelength of the light [nm]
B – Blue	0.4826
G – Green	0.5613
R – Red	0.6546
NIR – Near infrared	0.8646
SWIR 1 – Short-wave infrared	1.6090
SWIR 2 – Short-wave infrared	2.2010

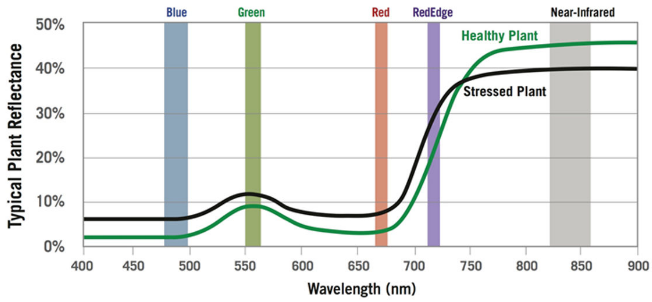


Fig. 5. Typical reflectance curve of healthy vs stressed plant [10]

of the plants deteriorates, this difference becomes increasingly smaller. Thus, successful monitoring of these differences provides valuable information on the quality of plant growth.

A multispectral camera mounted on a drone can be used to collect data on the level of light reflectance from an agricultural area covered with plants. Today, these types of low-cost multispectral sensors with HD resolutions and WiFi data transmission are available at an economically reasonable price. Such solutions can be successfully used in precision agriculture for small agricultural areas. These sensors are most often equipped with several independent optical converters recording the image for different ranges of the light wave spectrum (Fig. 6).

After synchronizing the images from different optical sensors, it is possible to analyze the growth of plants on their basis. Multispectral sensors are much more expensive than RGB cameras.

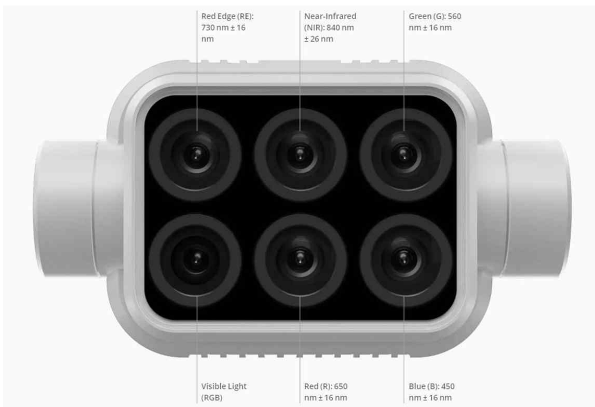


Fig. 6. Multispectral sensor [11]

For this reason, only RGB cameras can be justified for exceedingly small agricultural areas. For these kinds of solutions camera images are usually presented in two color compositions (Fig. 7). An RGB composition is created when the three basic RGB channels are assigned the actual spectral colors according to Table 1. A characteristic feature of this type of painting is that the color of the water (e.g., a river) (Fig. 7a) takes on a dark green tone and is in low contrast against the vegetation. To improve the contrast of elements in the image, color conversion is performed in the unreal CIR composition. It involves replacing values of RGB channels with values from other wavelengths. Color B is assigned to values corresponding with Green (0.5613), color G is assigned to values corresponding with Red (0.6546) and color R is assigned to NIR values (0.8646). In the example map in Fig. 7b, the river is colored black or dark blue, while the intense vegetation is colored red, which is quite a high contrast.

(a)

(b)

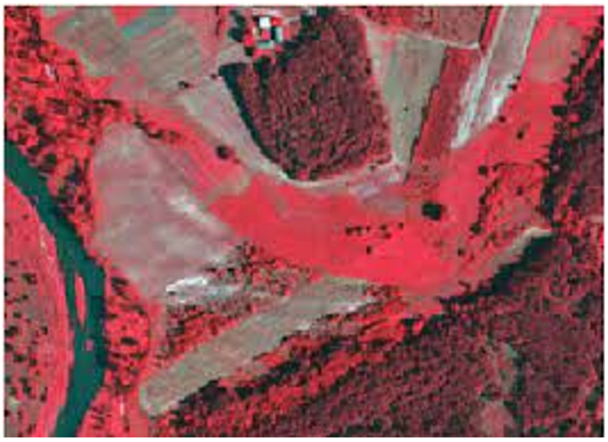


Fig. 7. Sample picture from color composition (a) RGB, (b) CIR [12]

5. PRECISE GUIDANCE SYSTEM FOR AGRICULTURAL MACHINERY

The second system necessary in precision farming is the one navigating the operation of agricultural machinery which must be equipped with a system that will guide the machine while driving along a given technological path in the field. In addition, this system should control a fertilizer dispenser. Systems based on GPS navigation are most often used to navigate the movement of an agricultural machine. A simple microprocessor controller connected to the navigation system of the agricultural machine is enough to control the fertilizer dispenser.

Agricultural machine motion control systems require appropriate positioning accuracy. Since 2000, the signal from 24 NAVSTAR satellites has been widely shared. However, the U.S. Department of Defense disabled the SA (Selective Availability) module, whose task was intentional interference of signals causing a decrease in tracking accuracy from 3 to 12 m. Guidance is based on receiving signals from several NAVSTAR satellites with known coordinates and on their basis calculating the position of the agricultural machine (Fig. 8).

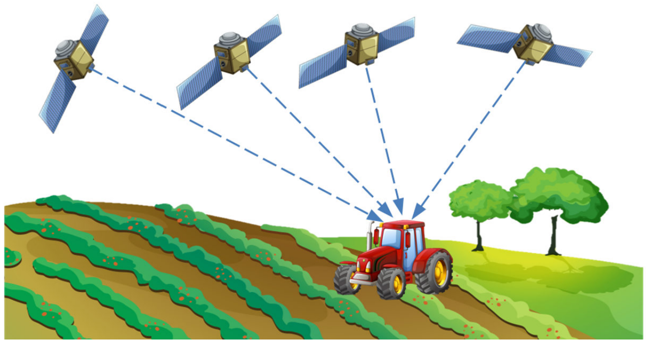


Fig. 8. GPS navigation (Graphics from vecteezy.com were used for the drawing)

This solution is unsuitable for precision agriculture where an accuracy of less than 1 m is required. To obtain an accuracy of less than 1 m, correction of the GPS signal by external assistance systems called Differential GPS (DGPS) is required (Fig. 9). DGPS systems send their own signals to the receiver, which contain differential corrections to correct the position calculation error [13]. In DGPS systems differential corrections are sent by land base (reference) stations with a precisely known position (Fig. 9a) or by geostationary satellites (Fig. 9b). In the solution presented in Fig. 8), the range of correction signals is limited to a few or several kilometers, depending on the power of the base station transmitter. Because of global network coverage, much larger communication with the ground station via geostationary satellites is possible. Currently, 5 differential satellite systems which correct GPS signals are operating in the world: WAAS – covering the territory of North America; EGNOS – covering Europe, which can be supported additionally by the Russian system GLONASS and MSAS – involving Japan. In addition, there are paid global OmniSTAR and StarFire (from JohnDeere) systems available. Standard DGPS systems send differential corrections with some delay due to the need for data post-processing. Therefore, the positioning accuracy for one-channel DGPS systems (EGNOS, WAAS, OmniSTAR-VBS, StarFire-1) is 0.5–1.0 m. For two-channel systems (Omni-STAR-HP, StarFire-2), where the signal is emitted in two frequency bands with simultaneous use of ground reference stations, the positioning accuracy is 10–15 cm.

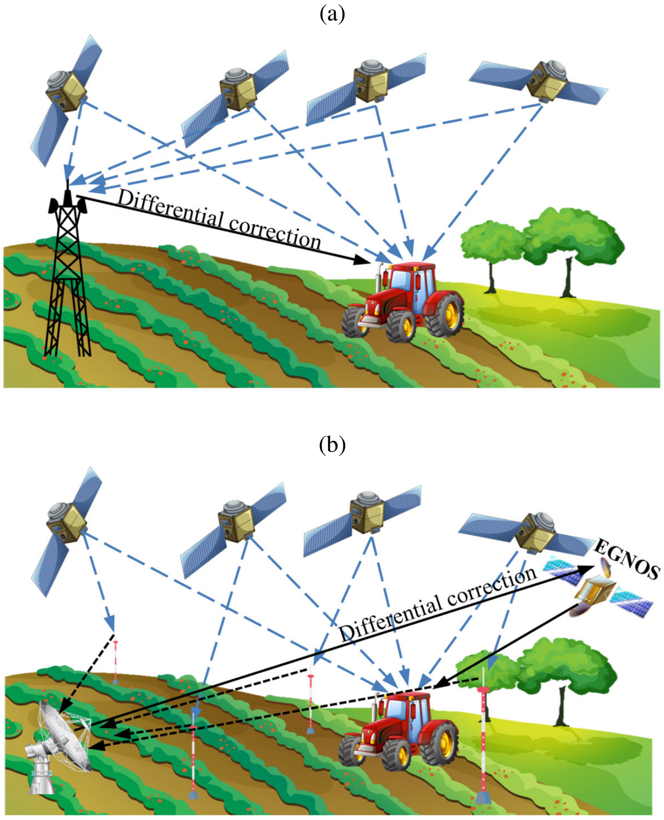


Fig. 9. DGPS navigation (Graphics from vecteezy.com were used for the drawing)

The most advanced tracking system is RTK-DGPS (Real Time Kinematic DGPS) where correction signals are received from a reference station in real time (Fig. 10). They allow for positioning accuracy of 1–3 cm. However, it requires setting up additional transmitting antennas near agricultural machinery.

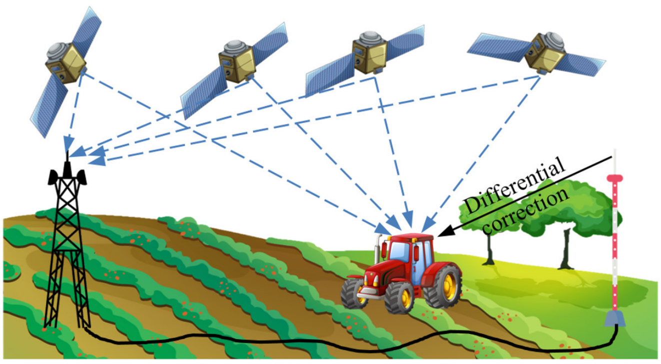


Fig. 10. Navigation RTK-DGPS (Graphics from vecteezy.com used for the drawing)

6. METHOD OF DETERMINATION OF GEOLOGICAL CONDITIONS

Harvest abundance is greatly affected by geologic conditions. Based on orthophotomaps, it is possible to delineate areas with different geological conditions. On this basis, it is possible to precisely enrich these areas with the necessary components and minerals needed for proper vegetation.

Analysis of geological conditions can be done on the basis of an orthophotomap of the area before sowing. In this work, it was used a test area belonging to the Schools Complex of the Agricultural Training Center named after Fr. Jan Dzierżoń in Bodgańczowice.

The test area, in which wheat was planned to be sown by the no-till method, was 5.28 ha. The DJI Phantom 3 Advanced drone was used to take pictures based on which the orthophotomap was prepared. This drone can reach an elevation of up to 100 m above the ground and has a working height of about 50 meters. It has a range of up to 3.5 km. The drone was equipped with a dual-channel DGPS guidance system with GLONASS differential satellite corrections system, allowing it to determine location with an accuracy of several centimeters. The drone was programmed for a defined flight path over the test area, which guarantees the repeatability of orthophotomaps in different seasons. The pictures were taken with a camera with an f/2.8 lens and an aperture angle of 94 degrees, mounted on a drone. The resolution of the images was 2.7 K, with a size of 12 megapixels. Image stabilization during the drone solder was provided by a 3-axis gimbal. The drone was moving at an altitude of about 50 m during the shooting. An image of an orthophotomap taken in autumn is shown in Fig. 11.

Geologic evaluation is done based on geologic indicators and water content indicators. Geologic indicators identify different types of rocks and minerals. The most common geologic indicators are as follows [14]:

The **CMR** (Clay Minerals Ratio) indicator facilitates the demonstration of clay and aluminite content. Hydrated minerals

Fig. 11. Orthophotomap of test area before barley feed

such as clays and aluminite absorb radiation in the 2.0–2.3 nm range of the spectrum. The value of this ratio is determined by the intensity of two selected light lengths in the shortwave infrared band:

$$\mathrm{CMR} = \frac{\mathrm{SWIR1}}{\mathrm{SWIR2}}. \tag{3}$$

The **FMR** (Ferrous Minerals Ratio) is used to identify iron-rich minerals. As the indicator above, it also represents the ratio of the absorption of two infrared light wavelengths, but with different long wavelengths:

$$\mathrm{FMR} = \frac{\mathrm{SWIR1}}{\mathrm{NIR}}. \tag{4}$$

Hydrothermally altered rocks that have undergone oxidation of iron-containing sulfides are well identified by the **IOR** (Iron Oxide Ratio). The presence of silicates containing limonite and limonite iron oxide causes absorption in the blue band and reflection in the red band. This causes areas with strong iron changes to be bright:

$$\mathrm{IOR} = \frac{\mathrm{RED}}{\mathrm{BLUE}}. \tag{5}$$

The iron content of the soil has a positive effect on plant growth, but the degree of iron oxidation by sulphites (acid rain) causes soil acidification, which has a negative effect on plant growth. In the evaluation of sites to be enriched with minerals, the IOR is a key factor.

The IOR coefficient calculated for the orthophotomap in Fig. 8 was used (Fig. 12). In order to present graphically the distribution of the IOR coefficient on the studied area, its values were calibrated to the range of 0–255. This operation simplifies the analysis of the results, as it is possible to present it as a gray-scale image.

Fig. 12. Distribution of IOR values on the investigated agricultural land

Maps of the distribution of IOR values are subjected to image analysis on the basis of which areas requiring deacidification are determined. For this purpose, the image is binarized and then open spaces are closed, smaller areas are grouped and then areas lying outside the agricultural area and exceedingly small, ungrouped fragments are removed. This method gives a binary area in which deacidification needs to be carried out (Fig. 13). This kind of map can be introduced into a guidance system for agricultural machinery that will selectively de-acidify the acreage.

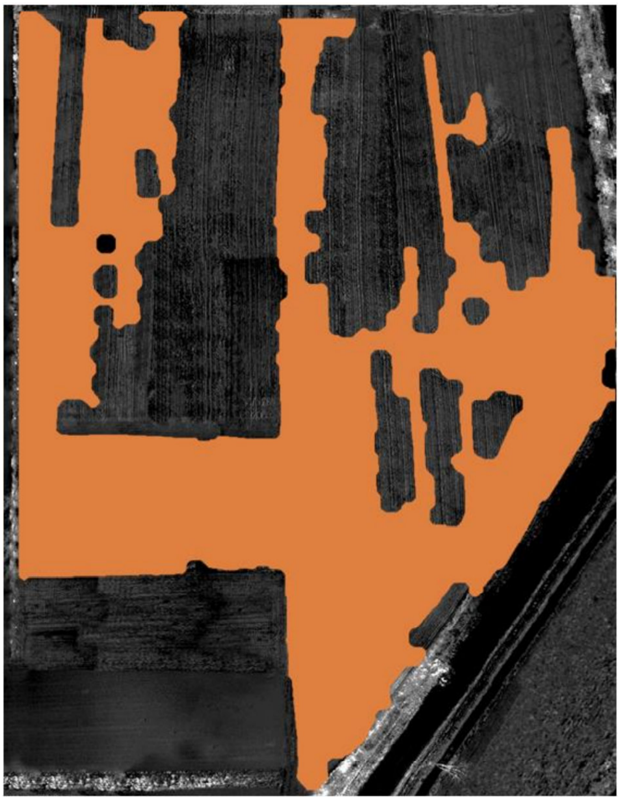


Fig. 13. Orthophotomap with marked areas where deacidification will take place

7. PLANT GROWTH MONITORING

The vegetation index is a parameter that determines the quality of the growth of plants. Based on this index, a decision concerning the use of fertilizers or plant protection products can be made. It should be determined periodically during the vegetation process. If significant differences in the growth of plants are observed in a given area, it is necessary to go to selected places to take samples for laboratory tests. Based on the samples taken from the selected sites, the cause of the reduced growth is determined and a follow-up strategy is developed.

Defining the vegetation index involves measuring the difference between light absorbed and reflected by plant leaves. The ratio of light absorbed to light reflected from the plant surface is influenced by the presence of chlorophyll, water and cellular structures. Chlorophyll absorbs red light at about 0.67 nm and blue light at about 0.45 nm. The contained water in the leaves absorbs infrared light, with a wavelength of about 1.4 to 1.9 nm, and the cellular structures strongly reflect wavelengths in the range of 700 to 1100 nm. This provides the basis for developing a range of vegetation indices.

One of the most popular vegetation indices is the Normalized Difference Vegetation Index (NDVI), which measures the ratio of the difference and sum of the amount of reflected near-infrared and red light. The basis of this formula is the absorption of red light by chlorophyll and the low absorption of the near-infrared range by green leaves [15]:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}. \tag{6}$$

To detect areas where plant germination does not occur, a good indicator is the SR (Simple Ratio). It is determined from the ratio between the amount of reflected near-infrared and red radiation. For green plant leaves this ratio can take on values of several tens, while for unplanted soil it is about zero [16]:

$$\mathrm{SR} = \frac{\mathrm{NIR}}{\mathrm{RED}}. \tag{7}$$

Soil background makes it difficult to observe vegetation based on indicators. This is especially difficult when plant vegetation that partially covers the soil is observed. In this case, it is reasonable to use the Modified Soil Adjusted Vegetation Index (MSAVI). The disadvantage of this index is its sensitivity to changes in the atmosphere [17]:

$$\begin{aligned}\mathrm{MSAVI} &= \frac{2 \cdot NIR + 1}{2} \\ &= -\frac{\sqrt{(2 \cdot NIR + 1)^2 - 8\,(NIR - RED)}}{2}.\end{aligned} \tag{8}$$

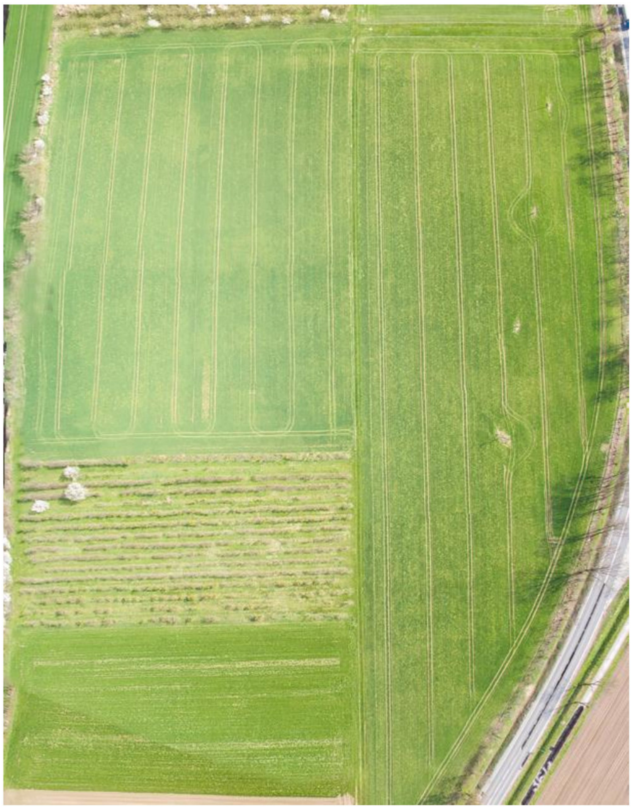
To reduce the impact of atmospheric conditions, the Visible Atmospherically Resistant Index (VARI) has been developed. The advantage of this solution is analysis in the range of visible light, which enables the use of RGB cameras to monitor the area [18]:

$$\mathrm{VARI} = \frac{\mathrm{GREEN} - \mathrm{RED}}{\mathrm{GREEN} + \mathrm{RED} - \mathrm{BLUE}}. \tag{9}$$

An exemplary analysis of barley vegetation in the tested area was made for an orthophoto taken in spring (Fig. 14a). From that, the VARI index was calculated and its values are presented in Fig. 14b.

As it was done for the IOR indicator after image processing, the areas which require detailed analysis and the application of appropriate measures to improve the growth in these areas are determined (Fig. 15).

(a)



(b)

Fig. 14. An orthophotomap of the study aerial taken in the spring after barley germination (a) RGB image, (b) distribution of VARI index values

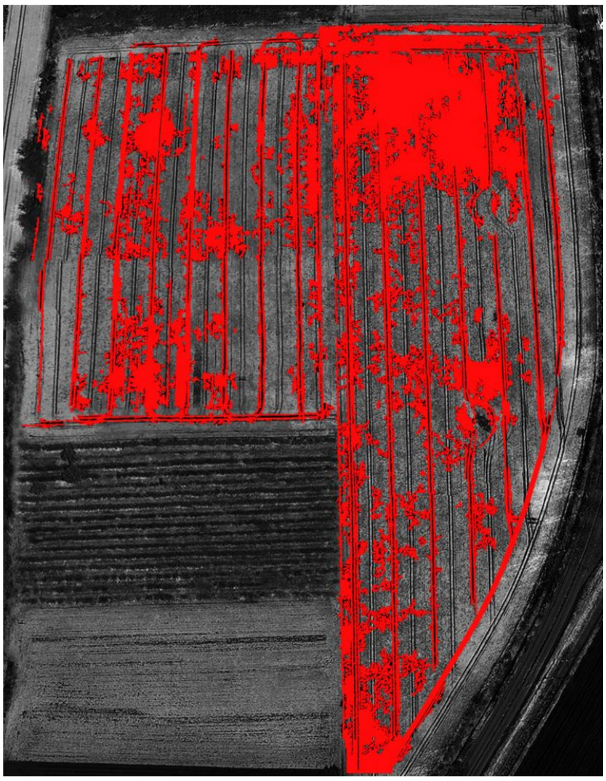


Fig. 15. Orthophotomap with marked areas where detailed analysis and treatment should be done

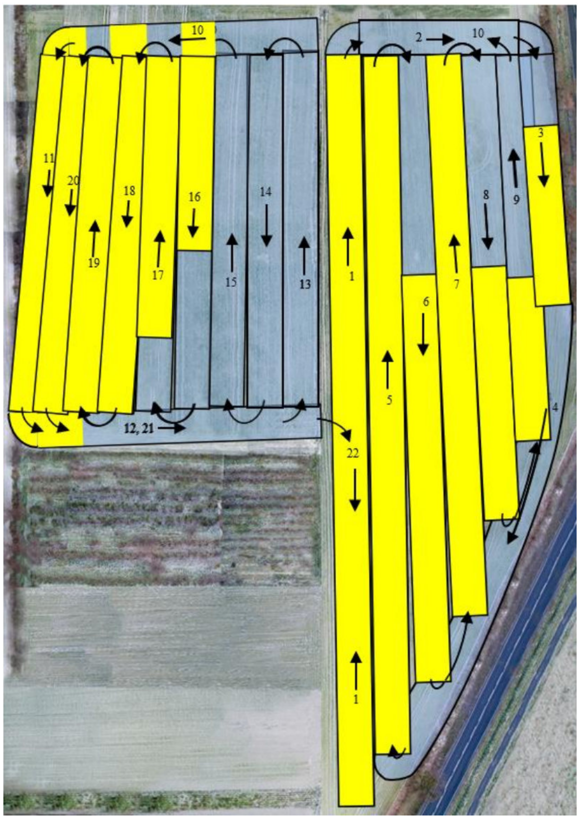


Fig. 16. Orthophotos with marked tracks for agricultural aeral requiring fertilization

8. BENEFIT ANALYSIS

The analysis of the benefits resulting from the use of a computerized plant growth monitoring system was carried out on the basis of the results of experimental studies conducted on the investigated agricultural area. Based on the results from Figs. 13 and 15, taking into account the parameters of agricultural machines used to perform specific works, orthophotos are prepared considering the direction of the agricultural tractor movement together with the signals controlling the operation of the spreader or sprayer.

The image of the investigated agricultural area with marked traction is shown in Fig. 16. The traction marked in the figure is recorded in the GPS, thanks to which the agricultural machines will move along the designated technological paths throughout the entire vegetation cycle. In the exemplary solution, 15 m wide technological paths were used. The area requiring fertilization before sowing winter barley is marked in yellow. Due to the width of the technological path, a spreader mounted on an agricultural tractor with a sowing width of 15 m was used for fertilization, with the possibility of controlling the emission of fertilizer. The programmed GPS precisely guides the agricultural tractor along the programmed tramlines. When the spreader enters the areas marked with yellow, the control system automatically starts the spreader. The control system can be implemented on a tablet with appropriate software for precise location and an interface controlling the operation of the spreader. Another much better solution is the proprietary GPS system used in more expensive agricultural machinery.

Based on orthophotomaps for monitoring plant growth, traction maps for spraying are prepared (Fig. 17). It is assumed that a typical sprayer with a capacity of 300 l and a spraying width of 15 m with a 5-section control system will be used for spraying. The solution enables work to be performed with an accuracy of up to 3 m of the spray width. It is a typical sprayer used for the cultivation of small agricultural areas. As in the case of the spreader, a computerized control system in cooperation with the GPS is used to control the operation of the sprayer. Due to the possibility of controlling five sections of the sprayer, the traction of the agricultural tractor movement was marked on the orthophotomap with the division into five control sections marked with different colors.

In order to evaluate the benefits of using a system for precise monitoring of plant vegetation, a comparison of the surface area that should be sprayed with plant products or fertilized was performed. The surface areas were compared in relation to the entire agricultural area. In the case of using traditional methods of plant cultivation, plant protection products and fertilizers are sprayed over the entirety of the agricultural area. Such a comparison is a measure of the profits from the economical use of fertilizers and plant protection products. Minimizing fertilizers and plant protection products also protects the environment.

The total area of agricultural land was 5.28 ha. On the basis of the orthophotomap from Fig. 13, the area to be fertilized was calculated. The total area fertilized was 3.2 ha, which is 60% of the total area. Similarly, for the sprayings performed, the total

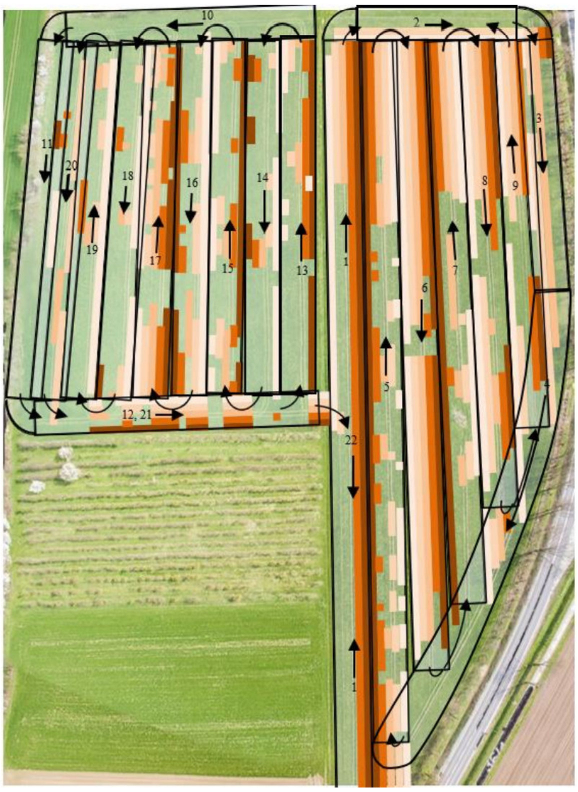


Fig. 17. Orthophotos with marked tracks for agricultural aeral requiring spraying

area sprayed was 2.87 ha, which is 54% of the total area. These results confirm the percentage gains resulting from the use of a computer system for monitoring crop vegetation and justify its application.

9. CONCLUSIONS

The system presented in this publication can be used to monitor small agricultural areas. This solution is especially important due to the fact that nowadays precision farming for small agricultural areas is relatively unpopular among farmers. One of the reasons is the relatively high cost of commercial systems that are designed for large areas. For smaller acreages, simplified systems using drones for acreage monitoring and PCs for image analysis are a good solution. This kind of improvement is a valuable tool for precision farming on small acreage. The results shown in this report should be used to build low-cost systems for precision agriculture.

REFERENCES

[1] European Commission, "EU legislation on organic farming," [Online]. Available: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy_en [Accessed: 13. July 2022].

[2] Eurosat, "Farm_structure_statistics," [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=farm_structure_statistics/pl&oldid=370127 [Accessed: 13. July 2022].

[3] P. Sharifi, "Sustainable Agriculture: And Introduction to Extensive and Intensive Agriculture," *J. Eng. Appl. Sci.*, vol. 12, no. 10, pp. 2747–2751, 2017, doi: 10.36478/jeasci.2017.2747.2751 .

[4] D. Anders and M.R. Rząsa, "The possibility of composting animal waste products," *Environ. Prot. Eng.*, vol. 33. no. 2, pp. 7–15, 2007.

[5] H.Ü. Evcim, A. Değirmencioğlu, G. Özgünaltay Ertuğrul, and İ. Aygün, "Advancements and transitions in technologies for sustainable agricultural production," *Econ. Environ. Stud.*, vol. 12, no. 4, pp. 459–466, 2012.

[6] J. Barwicki, K. Mazur, W.J. Wardal, M. Majchrzak, and K. Borek, "Monitoring of typical field work in different soil conditions using remote sensing – a literature review and some concepts for the future," *Agricult. Eng.*, vol. 19, no. 3, pp. 5–13, 2015.

[7] V. Mosorov, D. Sankowski, Ł. Mazurkiewicz, and T. Dyakowski, "The 'best-correlated pixels' method for solid mass flow measurement using electrical capacitance tomography," *Meas. Sci. Technol.*, vol. 13, no. 12, pp. 1810–1814, 2002.

[8] I. Tahmasbian, N.K. Morgan, S.H. Bai, M.W. Dunlop, and A.F. Moss, "Comparison of hyperspectral imaging and near-infrared spectroscopy to determine nitrogen and carbon concentrations in wheat," *Remote Sens.*, vol. 13, p. 1128, 2021, doi: 10.3390/rs13061128.

[9] J. Zhu, Q. Xu, J. Yao, X. Zhang, and Ch. Xu, "The changes of leaf reflectance spectrum and leaf functional traits of osmanthus fragrans are related to the parasitism of cuscuta japonica," *Appl. Sci.*, vol. 11, p. 1937, 2021, doi: 10.3390/app11041937.

[10] "Uncovering spectral signatures in a pecan orchard," *MicaSense*. [Online]. Available: https://micasense.com/uncovering-spectral-signatures-in-a-pecan-orchard/ [Accessed: 14. July 2022].

[11] "dji-p4-multispectral-agriculture-drone," *Ghostysky*. [Online]. Available: https://www.ghostysky.com/product/dji-p4-multispectral-agriculture-drone/ [Accessed: 14. July 2022].

[12] E. Wiśnieska, "Teledetekcja i fotogrametria obszarów leśnych" [Online]. Available: https://www.geomatyka.lasy.gov.pl/aktualnosci/-/asset/_publisher/PD11goFHmwok/content/teledetekcja-i-fotogrametria-obszarow-lesnych [Accessed: 13 Dec. 2020].

[13] R.M. Chauhan, "Advantages and challeging in E Agriculture," *Orient. J. Comput. Sci. Technol.*, vol. 8, no. 3, pp. 228–233, 2015.

[14] M.A. Mahboob, B. Genc, T. Celik, S. Ali, and I. Atif, "Mapping hydrothermal minerals using remotely sensed reflectance spectroscopy data from Landsat," *J. S. Afr. Inst. Min. Metall.*, vol. 19, pp. 279–289, 2019, doi: 10.17159/2411-9717/2019/v119n3a7.

[15] L. Cabrera-Bosquet, G. Molero, A.M. Stellacci, J. Bort, S. Nogués, and J.L. Araus, "NDVI as a potential tool for predicting biomass, plant nitrogen content and growth in wheat genotypes subjected to different water and nitrogen conditions," *Cereal Res. Commun.*, vol. 39, no. 1, pp.147–159, 2011, doi: 10.1556/CRC.39.2011.1.15.

[16] G. Melillos and D.G. Hadjimitsis, "Using simple ratio (SR) vegetation index to detect deep manmade infrastructures in Cyprus," in *Proc. SPIE 11418, Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXV*, 2020, p. 114180E, doi: 10.1117/12.2557893.

[17] J. Qi, A. Chehbouni, A.R. Huete, Y.H. Kerr, and S. Sorooshian, "Modified soil adjusted vegetation index," *Remote Sens. Environ.*, vol. 48, no. 2, pp. 119–126, 1994, doi: 10.1016/0034-4257(94)90134-1.

[18] L.S. Eng, R. Ismail, W. Hashim, and A. Baharum, "The use of VARI, GIL, and vigreen formulas in detecting vegetation in aerial images," *Int. J. Technol.*, vol. 10, no. 7, 2019, pp. 1385–1394, doi: 10.14716/ijtech.v10i7.3275.