AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 17, No 1, pp 81-86, 2025
Published by Faculty of Agriculture, Trakia University, Bulgaria
ISSN 1313-8820 (print)
ISSN 1314-412X (online)
http://www.agriscitech.eu
DOI: 10.15547/ast.2025.01.010

Assessing the applicability of drone-mounted multispectral camera measurements to characterize wheat status during the vegetation

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(Manuscript received 24 May 2024; accepted for publication 16 December 2024)

Abstract. *With the development of technologies, the possibilities for qualitative assessment of the condition of plants are increasing significantly.* ***The research aims*** *to compare real measurements that are taken simultaneously with portable devices for measuring vegetative indices and with multispectral cameras that perform remote measurements from the air by attaching them to an FPV drone. During the measurements, a part of the vegetative period of wheat was traced.* ***Research methods*** *include ongoing simultaneous measurement with portable devices of Normalized Difference Vegetation Index with PlantPen and Normalized Difference Greenness Index with N-Pen (Photon Systems Instruments, Czech Republic) and with multispectral cameras MAPIR Survey3N NGB (NIR+Green+Blue) and RGN (Red+Green+NIR), which are placed on a DJI drone. The obtained spectral images were processed with specialized software for processing multispectral images.* ***The results*** *show that remote sensing with autonomous aerial vehicles provides a reliable estimate of vegetative indices, which could increase economic efficiency in crop production.*

Keywords: Winter wheat, Vegetative indices, Multispectral camera, Unmanned aerial vehicle

Introduction

With the development of technologies, the possibilities for qualitative assessment of the plants' condition using spectral technologies are increasing significantly. In the last decade, new technologies based on multiscale remote sensing have been widely tested to improve agricultural productivity and the sustainability of farming. Modern methods of remote vegetation monitoring are effective and save time and money compared to manual measurements. Phenotyping plays an important role in crop science research. The accurate and rapid acquisition of phenotypic information of plants in different environments helps explore the inheritance and expression patterns of the genome to determine the association of genomic and phenotypic information to increase crop yield (Yang et al., 2017). Mapping crops such as winter wheat and associated weed canopy cover is generally important for crop and weed management (Akumu and Dennis, 2023). Various vegetative indices have been developed according to the desired results.

Unmanned aerial vehicle (UAV) imaging technology has been widely used to rapidly estimate the physiological condition, nutritional status, disease detection, and yield estimation in crop plants, but the accuracy will still be affected by the variety, the growth stage, and other factors (Shu et al., 2024). The measurement of vegetative

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indices based on images from UAV is influenced by various determinants. According to some authors, the reliability of the measured vegetative indices is affected by the type of camera and its consistency under different lighting conditions (Orlando et al., 2022; Shafiee et al., 2023). Optical calibration is essential to the accuracy of measuring instruments (Sampaio et al., 2020). According to some authors, several types of studies can be combined in addition to vegetative indices. Some results demonstrate that combining vegetation indices and texture from multispectral drone imagery can improve the accuracy of leaf area index estimation during the vegetative growth stage of winter wheat (Weilong et al., 2023). The reliability of the results gives hope that remote sensing will largely replace ground-based sampling.

The research aims to investigate changes in winter wheat during vegetation using vegetative indices derived from remote measurements from the air by multispectral cameras attached to an FPV drone and measurements taken simultaneously with portable devices on the field.

Material and methods

Study Area Field experiments were conducted during the 2023–2024 growing season of winter wheat (*Triticum aestivum* L.) in the Stara Zagora region, Bulgaria (42.396729 N, 25.578660 E). The climate is transitional continental. The average annual temperature is 12.9 with an average annual rainfall of 598 mm. The field was examined from April to the end of May in 2024. During these periods, the average monthly temperature and precipitation were: for March – 4.5ºC and 36.3 l/m^2; for April – 15.7ºC and 55.8 l/m^2; for May - 16.6ºC and 61.8 l/m^2, respectively.

Multispectral and Field Data Acquisition

Two portable instruments PlantPen and N-Pen (Photon Systems Instruments, Czech Republic) were used for field measurement of the vegetative indices. N-Pen measured Normalized Difference Greenness Index NDGI:

$$NDGI = \frac{R_{780} - R_{560}}{R_{780} + R_{560}}$$

The instrument was set to average 10 separate measurements to calculate one NDGI value.

PlantPen measured Normalized Difference Vegetation Index:

$$NDVI = \frac{R_{740} - R_{660}}{R_{740} + R_{660}}$$

At least the leaves of 30 plants were measured at different places in the field.

The images were acquired using Survey3 RGN and NGR cameras (MAPIR, Inc, San Diego, CA 92126 USA). The cameras work in three spectral bands. The Survey3 RGN camera works in the near-infrared region at 850 nm, Red at 660nm, and Green at 550 nm. The Survey3 NGR camera works in near-infrared, green, and blue at 475nm. All images are automatically geo-tagged using the included GPS. The cameras were mounted at DJI Mavic 3 UAV as shown in Figure 1. The UAV multispectral data collection was conducted between 11:00 and 13:00 h, and the day was cloudless. Calibration of cameras was made using the Diffuse Reflectance Standard Calibration Target Package, which contains 4 calibration targets of known reflectance.

Figure 1. Used multispectral cameras mounted at DJI Mavic 3 UAV

The obtained spectral images were processed with specialized software MAPIR Camera Control (MCC) for multispectral images. After calibration, 2 vegetative indices were calculated – NDVI (Normalized Difference Vegetation Index) and GNDVI (Green Normalized Difference Vegetation Index).

$$NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}} \quad GNDVI = \frac{R_{NIR} - R_{green}}{R_{NIR} + R_{green}}$$

The NDVI is one of the first vegetative indices introduced in the 1970s. It detects and quantifies the presence of living green vegetation using reflected light in the visible and near-infrared bands. NDVI is useful in understanding vegetation density and assessing changes in plant health. The NDVI value mathematically ranges from -1 to 1. Values close to 0 correspond to areas with very little vegetation or early stages of cultivation. NDVI increases in proportion to vegetation growth. An area with dense, healthy vegetation will have an NDVI close to one.

The second calculated index (GNDVI) is an indicator of the photosynthetic activity of the vegetation. It is one of the most widely used vegetation indices to determine water and nitrogen uptake in the crop canopy. GNDVI is more sensitive to chlorophyll content variation than NDVI (Gitelson et al., 1996).

Results and discussion

The wheat vegetation phase at the time of the measurements was flowering and soft dough. In order to demonstrate the capabilities of the drone-mounted multispectral cameras for assessing the condition of wheat crops, it is necessary to answer some methodological questions. One of them is: does the distance between the camera and the ground somehow influence the value of the vegetation indices? This is important when the ground surface is not horizontal and the drone flies at a constant altitude.

The impact of the height of the flight is checked by taking photos during one flight over the same area at two different heights. The photos were taken on May 7, 2024 at clear sky. On Figure 2 one can compare the NDVI indices of the same area (enclosed by a rectangle) photographed at approx. 22 m (a) and at approx. 38 m. The values of the indices are encoded in colour and the colour scale is located at the right side of Figure 2.

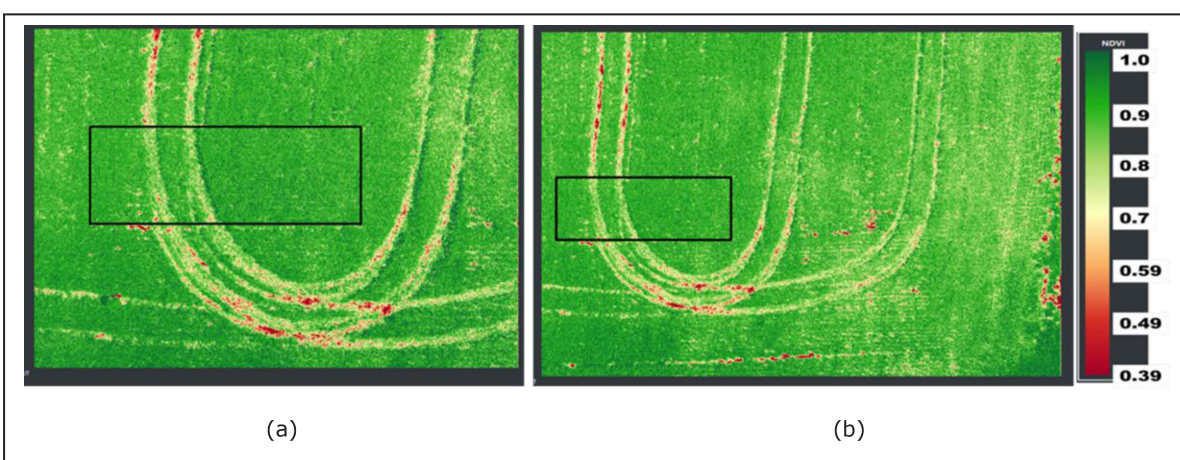

Figure 2. Comparison of the NDVI index of the same area (enclosed by a rectangle) at two different heights. (a) – colour map of the NDVI index at approx. 22 *m* and (b) – at approx. 38 *m*. The images were taken on May 7, 2024.

It is clearly seen that the colours in the area of interest are the same in both photos and, therefore, the values of the correspondent index are the same. Looking at Figure 2, one can conclude that the height of the flight has no impact on the results of measurements.

The NDVI index is the most frequently used index but we decided to use the GNDVI index in the presented study because, as mentioned above, it is more appropriate to track the changes in the photosynthetic activity and the nitrogen uptake in the crop canopy. Figure 3 illustrates the bigger informativeness of the GNDVI index in this specific case.

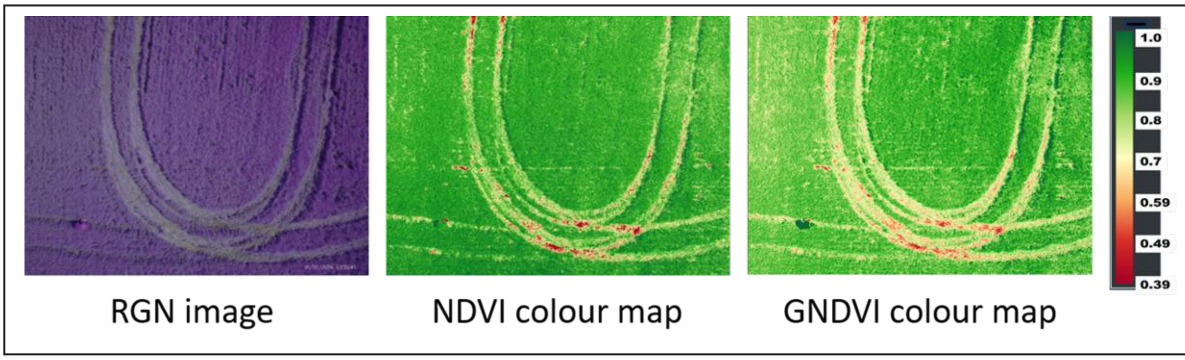

Figure 3. RGN image of certain area of the wheat plantation and NDVI and GNDVI colour maps obtained after processing the same RGN image. The images were taken on May 7, 2024.

Looking at the colour maps of NDVI and GNDVI indices on Figure 3 and excluding the traces from tractors one can see that the variations of the NDVI index across the studied area are smaller than those of the GNDVI index (small variations in the greenness). The GNDVI picture reveals more shades of the colours and, therefore, a wider range of the values of the correspondent index.

Figure 4 shows the change in the vegetation of the spatial distribution and the values of the GNDVI index in approximately the same area. Four colour maps of this index are presented. The dates of the measurements are typed below the pictures and the colour scale is located at the right side of the figure. Looking at the color maps it is easy to see that first – the distribution changes, and second – the values of the index if comparing the same area change to lower numbers. The same tendency is seen for the entire picture as average.

The NDVI values in wheat vary at different growth stages (Aranguren et al., 2020). The maximum values are observed at flowering stage. At grain filling stage, NDVI values start to decline, because of reduced chlorophyll content. This decline continues through the maturity stage, where NDVI values are at their lowest.

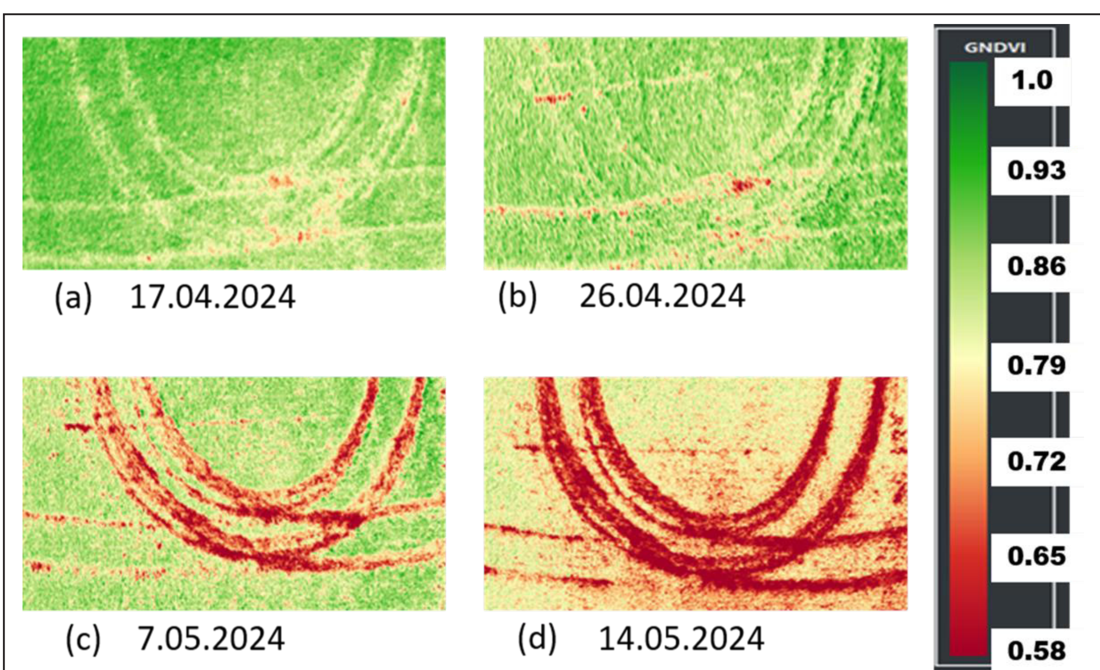

Figure 4. Colour maps of the GNDVI index within approximately the same area with the time running. The dates of the pictures are typed below them

One of the aims of this study was to compare real measurements that are taken simultaneously with portable devices for measuring vegetative indices and with multispectral cameras that perform remote measurements from the air. In Table 1 one can see the numerical values of the NDGI index obtained by measurements with the portable device N-Pen. The measured values varied from 0.677 and 0.739.

Table 1. Measurements of the NDGI index with N-Pen

Date	Average	Min	Max	SD
11.04.2024	0.6944	0.662	0.718	0.013
17.04.2024	0.6774	0.661	0.700	0.026
26.04.2024	0.7002	0.633	0.724	0.013
7.05.2024	0.7390	0.698	0.756	0.021
14.05.2024	0.7316	0.693	0.747	0.016

Looking at the average values one can conclude that the differences between them are small. Taking into account the standard deviation values it can be stated that this index is almost constant during the studied period which contradicts to the observed tendency in the pictures (Figure 4). Moreover, the average numerical values (between 0.68 and 0.74) correspond to light reddish to orange colours on the colour scale of the same figure. There are several reasons for this discrepancy between the two types of measurements. One of them is differences in spectral information, used for calculation of NDGI index in N-Pen and GNDVI index using Mapir camera. Another reason is that the experimenters who did the measurements with portable devices, were entering the field through the traces from the tractors and, therefore, the measurement area was in the traces or very close to them. As is seen from the colour maps on Figure 4, the colours in many places of the traces correspond to numerical values within the range mentioned above (between 0.68 and 0.74). Another factor which leads to this significant discrepancy is that the measurements with the portable devices are very local and only the leaves of the plants were measured, while at remote measurements not only the leaves but the ears and stems of the plants were measured as well. In addition, the back side of the leaves and the plants lying down give different reflectance than the face side of the leaves and the plants standing up. The averaging of the signal within the pixel should not play a significant role because in our case the size of the pixel at a flight height of 22 m is approximately 4 x 5.5 mm and at 38 m – 7 x 9.5 mm.

Similar results were observed for the measurement of the NDVI index with PlantPen. The variation in the measured values varied between 0.722 and 0.756.

Similar results were observed for the measurement of the NDVI index with PlantPen, presented in Table 2. The variation in the measured values varied between 0.722 and 0.756.

Table 2. Measurements of the NDVI index with PlantPen

Date	Average	Min	Max	SD
11.04.2024	0.7441	0.70	0.77	0.017
17.04.2024	0.7407	0.68	0.77	0.023
26.04.2024	0.7227	0.67	0.76	0.030
7.05.2024	0.7528	0.66	0.78	0.021
14.05.2024	0.7566	0.73	0.78	0.016

The presented results show that there is no direct relation between the local measurements of the NDVI and GNDVI indices with the portable devices and the remote measurements with the drone-mounted multispectral cameras. The measurements with the drone-mounted multispectral cameras can be used for assessing the condition of wheat crops, but for extracting more and valuable information from the raw data one should use more powerful processing software which would give an access to the numerical data of every pixel of the original file and, therefore, allow the application of different ways of data processing.

Conclusion

PlantPen and N-pen instruments measured the leaves of wheat. Therefore, at these stages of winter wheat development, the differences in measured values of NDVI and NDGI vegetative indices are small.

The vegetative indices derived from multispectral images mounted on UAV demonstrate easily observable differences in the winter wheat field during vegetation. The maps of vegetative indices give an idea of the distribution of the indices over the field. They contain a huge amount of information that could potentially be extracted and analyzed. The results show that remote sensing with autonomous aerial vehicles provides a reliable estimate of vegetative indices, which could increase economic efficiency in crop production.

Processing and analyzing images from multispectral cameras is not routine work. Further research should be done to clarify the ways of extracting reliable information from the source images.

Acknowledgements

This work was supported by the Bulgarian Ministry of Education and Science under the National Research Programme "SMART CROP PRODUCTION" approved by Decision of the Ministry Council №866/26.11.2020 and by HORIZON EUROPE program HORIZON-CL6-2021-CLIMATE-01 (Land, ocean and water for climate action) Topic: HORIZON-CL6-2021-CLIMATE-01-08 Type of Action: HORIZON-RIA

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