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Application of an Unmanned Aerial System (UAS) for Precise Fertilization

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Abstract: The unmanned aerial system (UAS) eBee Plus, the eMotion guidance software and the Pix4dfields data processing software were investigated on two plots of wheat in PPK Valpovo. By using normalized difference vegetation index (NDVI), application maps for nitrogen fertilizer were obtained, which resulted in the saving of nitrogen fertilizer applied in the feeding of this crop. This guidance and data processing software has proven to be easy to use and suitable for agricultural crop producers who own larger areas to grow. The average grain yield of the Gabrio variety (7.92 t/ha) by eight individual plots, with an emphasis on plot 9A-4, had the average grain yield of this variety of 8.48 t/ha, which is 6.61% higher yield than the average of this variety on these plots. Multi-year research and direct comparison of multi-year parameters obtained from the plots results in an increasingly expedient and optimal use of resources for work and an increase in the quantity and quality of products.

Keywords: nitrogen fertilization; normalized difference vegetation index; precision agriculture; unmanned aerial vehicle; vegetation index

1 INTRODUCTION

Agricultural production is demanding in itself, and rationalization of production is very important from an ecological and economic point of view. The use of unmanned aerial system (UAS) opens new opportunities for rationalization [1]. As the demand for more food increases, so do the costs of agricultural production and greater extraction of nutrients from the soil. The lack of nutrients from the soil is compensated by fertilization, and the use of digital agriculture tools enables the monitoring of nitrates in the soil, soil temperature, electrical conductivity of the soil, soil moisture and other parameters and obtaining data in real time, which facilitates timely decision-making [2]. A geographic information system (GIS) is an integrated system of computer tools and user program support for the purpose of collecting, organizing, analysing, and modelling spatial data with the aim of solving complex problems of analysis and planning. Data processing is incomparably faster, data is more accessible and updated in real time. Small UAS equipped with Global Navigation Satellite System (GNSS) and photo equipment are used in agriculture. Today, the leading and most expensive system for geo-locating or determining the position of an UAS is the GNSS [3]. UAS use GNSS to quickly and efficiently map the production plot. It is also possible to create a map of the vegetation index and introduce it into the tractor system and treat only certain parts of the plot based on it, which reduces the consumption of plant protection products and mineral fertilizers. The vegetation index can be obtained by combining images from several spectral areas, mainly using the red and near-infrared part of the electromagnetic spectrum [4]. The measure of electromagnetic radiation of vegetation, the amount of green cover, the amount of biomass, the absorption of photosynthetic activity of radiation and the radiation of the index are defined as factors influencing the creation of the index. There are several vegetation indices, and one of the most commonly used is normalized difference vegetation index (NDVI) [5]. Inadequate fertilization often means excessive use of fertilizers. Precision fertilization emphasizes that growers should use different fertilization methods, different fertilizers and application rates according to different soil types, weather conditions and other [6]. Precision fertilization methods can be very useful in solving the problem of low fertilization efficiency.

The goal of this research is to provide a method for a precision fertilization map creation using remote sensing by UAS, show the mode of operation of the UAS eBee Plus that fly with the eMotion application, and process the obtained images in the Pix4dfields application.

2 MATERIALS AND METHODS

2.1 eBee Plus UAS

The flight time per battery of eBee Plus UAS is up to 59 minutes, which gives maximum efficiency when image large areas [7]. This aircraft can be operated at any altitude and at different wind speeds, as it is resistant to external conditions. Technical data about the UAS, the necessary software and management are presented in Tab. 1.

Table 1 Technical data on the UAS [7]

UAS	
Wingspan	110 cm
Weight	1.1 kg
Motor	Silent motor, brushless, electric
The range of the radio connection	3 km, usually up to 8 km
Demountable wings	Yes
Camera	senseFly S.O.D.A., Parrot Sequoia, TermoMAP
Software	
Flight planning and monitoring	eMotion
Management	
Automatic 3D flight planning	Yes
Flight speed	40 – 110 km/h (11 – 30 m/s)
Wind resistance	Up to 45 km/h (12 m/s)
Maximum flight time	59 minutes
Automatic landing	Linear landing with 5 meters accuracy
Handheld launch	Yes

The steps of the operation of the UAS are: data collection, processing of the collected data, creation of application maps, generation of indexes with interpretation and analysis. The UAS is equipped with a S.O.D.A camera. for capturing high-resolution aerial photogrammetric aerial images and precise digital models of surfaces. The crop is seen in a realistic state, and it is possible to see all the defects on the plants at the recorded moment. The image can be used for the purpose of protecting plants and destroying weeds on the recorded plot due to its accuracy. The Parrot Sequoia+ camera collects multispectral images of the surface. The camera contains four lenses for marking the plot during image. It contains green, red, red edge and near infrared spectrum lenses that provide absolute reflectance measurements. Technical data for both cameras are shown in Tab. 2. The eBee Plus UAS is controlled using the eMotion software.

Table 2 Technical data about S.O.D.A. and Parrot Sequoia+ cameras [7]

S.O.D.A. specifications	
Resolution	20 MP
Resolution at a height of 100 m	2,3 cm/px
Sensor size	12.75 × 8.5 mm
Pixel density	2.33 qm
Image format	JPEG or DNG
Parrot Sequioa+ specifications	
Pixel size	3.75 qm
Focal length	3.98 mm
Resolution	1280 × 960
Greed band	530 – 570 nm
Red band	640 – 680 nm
Red edge band	730 – 740 nm
Near infrared band	770 – 810 nm

With eMotion, flights are accomplished using mission blocks. The desired block (aerial mapping, corridor, etc.) is selected, the region to be mapped is marked, key settings are defined and eMotion automatically generates the UAS flight plan. By opening the Working Area Parameters, the destination from which the aircraft takes off is located. The selected location/point is near the planned flight mission for reasons of reducing battery consumption. Then the flight radius is given, which depends on the size of the mission itself. Under Working Area Parameters, the third icon was selected and Add mission block was added. By choosing Horizontal Mapping from the drop-down menu, the flight surface was determined, which resulted in a square feature of the surface (Fig. 1). The same image shows the selected points (in black in the image) that mark the image area and flight direction (in white in the image). The next step is determining the spatial resolution. When selecting a spatial resolution (pixel size) of 2.8 cm, the flight height is automatically adjusted to 119 m above sea level. By adjusting this parameter, the flight mission was adjusted and ready for implementation. After connecting the necessary equipment, the eMotion software was started, in which the flight mission was saved. After selecting the prepared mission at the bottom of the page on the left side, select Connect and then Connect to UAS. This enables connection with an UAS and then the realization of a flight mission is possible. By selecting the airplane icon on the left side of the eMotion window, the desired mission is added. Depending on the sequence of missions in the specified window of the software, the flight itself will be performed. On the right side of the mentioned software window are visible all key parameters of the aircraft, and their monitoring during the flight is extremely important (Fig. 2). At the opening of the mission, the Landing position was added, as the place where the aircraft will land after completing the mission. This is done by physically placing the aircraft at the landing site and clicking the mouse to mark the exact spot where the aircraft is shown on the screen. The plane descends downwind, and takes off (throws) upwind. Fig. 3 shows an overview of the flight parameters. The moment the aircraft reached a height of 75 m by pressing the icon on the Start mission screen, the collection of images began.

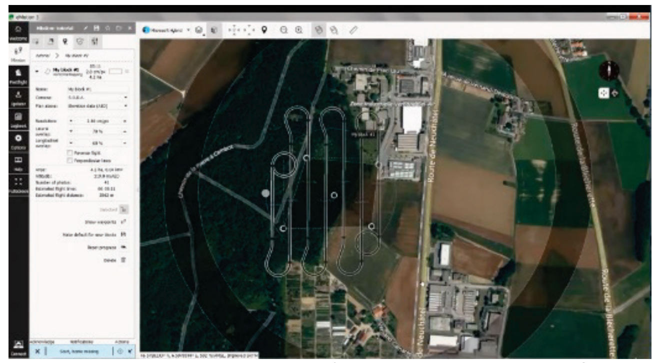

Figure 1 Rectangluar area limits for imaging using eBee Plus UAS

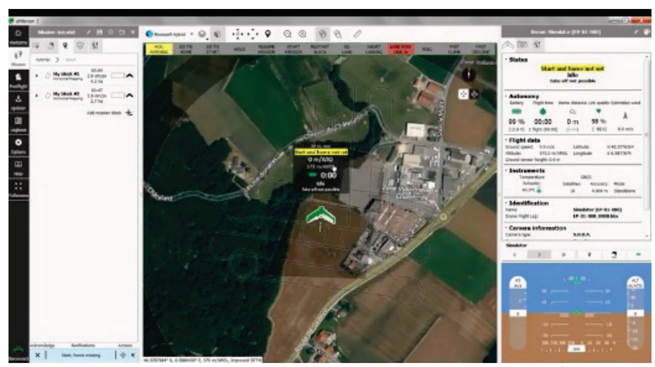

Figure 2 Flight parameters for imaging using eBee Plus UAS

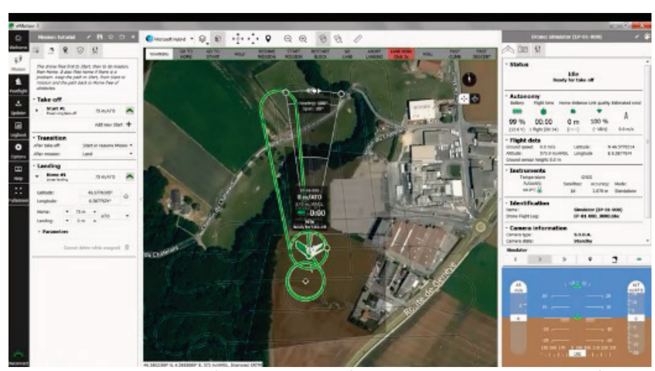

Figure 3 Additional flight parameters for imaging using eBee Plus UAS

The footage collection ended the moment the mission was completed. The data is saved on a USB card in the aircraft camera. After the flights on all prepared missions, the images were transferred to a computer (GIS workstation) and then data processing followed.

Pix4Dfields is software that converts images collected by aircraft into a map that can be immediately transferred to an agricultural machine as such or used later for analysis. The moment the data was loaded, the software automatically recognized the camera model, the image coordinates were automatically read, and the satellite image was opened. At the end of the processing itself, a reflection map was created on which the image area was outlined. At the end of the delineation, the desired vegetation index (NDVI) was selected. On the home page of the software, the New project icon (Plot 9A-4 and Plot 17P-1) is selected. By clicking on import files and double-clicking on images, a computer window is opened where all the captured images are marked and the processing of the images is started (by clicking on Apply).

2.2 Vegetation Index

The NDVI is the most used vegetation index for assessing the state of the vegetation, representing a good indicator of photosynthetic activity, in the simplest terms the ratio between the near-infrared (NIR) and the visible red part of the spectrum that plants reflect [5]. Its result ranges from -1 to +1, and the higher the value, the healthier the plants, with stronger vigor and lushness. It is also an indicator of the bio-physical properties of vegetation, the fractional cover of vegetation and the state of vegetation and biomass [8]. The NDVI index on surfaces with dense vegetation reacts to red reflectance, and is relatively insensitive to changes in infrared reflected rays. Also, this index is based on the properties of chlorophyll. The advantages of NDVI are independence from topography or radiation reflection, ease of use, good distinction between land surfaces and vegetation, easy readability due to high image resolution [9]. The disadvantage of this index lies in its great sensitivity to background noises, as ground reflections or atmospheric radiation and water content in plants. NDVI also primarily measures chlorophyll content and does not directly correlate with crop nitrogen status or nutrient requirements, which can lead to misinterpretations when assessing fertilization needs. Additionally, factors such as soil moisture, leaf area index, and atmospheric conditions can influence NDVI readings, potentially confounding the relationship between vegetation indices and nutrient stress. The temporal resolution of NDVI data might not align with critical growth stages, further limiting its effectiveness in dynamic agricultural systems. The factors that influence the measured value of the index include the resolution of the digital image of the observed area, atmospheric conditions, soil moisture, soil salinity, soil cover and differences in soil type. NDVI indices are visualized by color: brown, dark red, red, yellow, green and dark green. Each mark of the vegetation index has its own meaning, so the brown color indicates the surface of the soil, the dark red color indicates a crop with very poor emergence or diseases, the red color indicates a crop with weak emergence, the yellow color indicates a plant with uneven emergence, the green color indicates a plant in good condition, and dark green indicates excellent crop condition. Images acquired by UAS provide information on crop fertilizer needs [10]. Multispectral images are obtained so that the optical sensors function according to the principle of receiving light rays of a certain wavelength, and based on this, the image is determined. They are used to monitor the condition of crops in all stages of development, which facilitates making timely and informed decisions about crop treatment and fertilization, thus reducing costs and maximizing yield [11]. The state of the crop can be seen on the basis of the reflected light, as the wavelengths of the reflected light.

2.3 Case Study at PPK Valpovo

PPK Valpovo cultivates areas in the wider area of Valpovo totalling 5440 ha, of which 4850 ha are in conventional agricultural production, and 590 ha are cultivated according to the principles of ecological plant production. In agricultural production, the winter crops are wheat, barley and rapeseed, and the spring crops are corn, sunflower, soybeans and sugar beets. In the last two years, this company has intensified the use of new technologies and UAS, especially in the production of wheat. At the moment, they grow wheat on about 600 ha and several varieties, two of which were investigated in this paper. The variety is Kraljica winter wheat, of very good quality and fertility. It is the leading variety of the Osijek Agricultural Institute in the Republic of Croatia. This variety has a high yield potential, good crop stability, adaptability to different production conditions, tolerance to low temperatures and the most common wheat diseases. In addition to the Republic of Croatia, this variety is now successfully produced in a dozen countries in the surrounding area and beyond. The Gabrio variety is also a winter wheat with good lodging tolerance, high yield potential and grain quality, having medium resistance to frost, tolerant to drought and stress, and stable in different environments, even on poorer soil types.

3 RESULTS AND DISCUSSION

Predicting the amount of nitrogen required for wheat to reach its potential peak in a given year is difficult due to temporal and spatial variability, and within-field variability is a major source of uncertainty in wheat breeding decisions [12]. The goal of precise fertilization is to add as much fertilizer as is really necessary, and with it we improve the application of fertilizer according to actual needs [13]. GNSS determines the location of the tractor, collects and processes data and applies it to the agricultural plot [14]. At the end of processing, the created application maps were later used in precision agriculture. Research has confirmed that NDVI determined early in the growing season is a good predictor of the final grain yield of winter wheat across several locations and years [11]. The data used for precise fertilization are selected directly in the software. The software has the Color Maps and Prescription option, where it is possible to determine the amount of applied fertilizer in a certain area by color. At the beginning of March 2022 at PPK Valpovo an agricultural plot called 9A-4 with an area of 85.58 ha was recorded. In the previous season, sunflowers were the pre-crop on the plot, while wheat was recorded for the purposes of determining the amount of fertilizer needed for the second feeding. A sunny day was chosen for the image, with a wind speed of up to 3 m/s. The preparation of images in the eMotion software took only 20 minutes. A Sequoia camera was used for obtaining multispectral images for precise fertilization. A large amount of data was obtained (4648 images). Data processing was done in Pix4dfield software. The processing and creation of the multispectral map began with the entry of all images. The video was processed for about 20 minutes, which did not require the Internet. The first feeding was done in the classic way with 180 kg/ha KAN, and the second feeding using the application map (Fig. 4). On plot 9A-4, an average value of fertilizer of 150 kg/ha was applied. The range ranged from a minimum of 120 kg/ha to a maximum of 190 kg/ha, depending on the vegetation index of crop development obtained by UAS images. In the third plot (Fig. 5), the range ranged from a minimum of 100 kg/ha to a maximum of 150 kg/ha (average 120 kg/ha), which is 20 kg/ha less than in the second plot, where the range is from the minimum up to a maximum amount per hectare of 70 kg. It is important to note that as much as 78% of the plot was in the range of 20 kg, which means that after the second feeding there was an equalization of the crops within the plot itself.

Figure 4 Application map for the second supplementary fertilization on plot 9A-4

Figure 5 Application map for the third supplementary fertilization on plot 9A-4

On plot 17P-1, with an area of 51.53 ha, the pre-culture was sunflower, and in the first feeding, 180 kg/ha of KAN was applied, while the second feeding was carried out using the application map, and the third in the classic way. The fertilizer distribution in the second crop had the average value of 147 kg/ha, with a range of 130–160 kg/ha. The crop was quite uniform, so there were no big variations in fertilizer application. At the time of the third fertilization, the crop was almost uniform over the entire surface. As the map of the vegetation index was extremely uniform, the third supplement was done using the conventional approach.

Tab. 3 shows the average grain yield of the Gabrio variety (7.92 t/ha) by individual plots, eight of them, with an emphasis on plot 9A-4 and the average grain yield of this variety of 8.48 t/ha, which is 6.61% higher yield than the average of this variety on these plots. Also shown is the average grain yield of the Kraljica variety on five plots, an average grain yield of 8.31 t/ha. It can be seen that this variety on plot 17P-1 achieved the highest grain yield of 8.80 t/ha, which is 5.89% higher than the average yield of this variety. The average grain yield of the Gabrio variety, without plot 9A-4, was 7.75 t/ha, while the Kraljica variety achieved an average grain yield of 8.10 t/ha (without plot 17P-1). The total grain yield of the Gabrio variety on the area of 222.74 ha was 1771.31 t, of which the grain yield from plot 9A-4 (85.58 ha) was 725.71 t. The Kraljica variety achieved a total grain yield of 1330.79 t (on an area of 160.16 ha), of which 453.46 t were obtained on plot 17P-1 (an area of 51.53 ha). In one study, an average grain yield of 7.08 t/ha was recorded using variable doses of nitrogen fertilizer compared to control (5.92 t/ha) and uniform application before and during the growing season (6.22 t/ha). Research results show that the precision system can reduce overall nitrogen application levels from conventional pre-sowing levels by 59-82% depending on location. It has already been shown experimentally that reducing the amount of nitrogen fertilizer does not compromise the yield [15]. Fertilizer application leads to increased levels of nitrogen and phosphorus in the atmosphere and in most ecosystems on Earth [16]. It has been confirmed that the application of high nitrogen intake is, on the one hand, an incentive to achieve high quality standards, but on the other hand, it is the cause of a high positive nitrogen balance in the soil and the potential risk of air and water pollution. Site-specific management and application of nutrients required by the crop to reach its maximum potential yield can reduce nutrient pollution of groundwater and downstream water sources [17].

Table 3 Analysis of the yield of wheat varieties Gabrio and Kraljica

Gabrio variety			
Plot	ARKOD ID	Area, ha	Yield, t/ha
7A-1	2265712	9,09	6,79
7A-5	2265488	25,45	6,76
8A-3	2259785	9,70	8,31
8A-4	2263621	15,88	8,32
8A-5	1518677	19,94	8,34
8A-6	1512402	13,93	8,00
9A-4	1518178	85,58	8,48
13A-2	1518050	43,17	7,70
Average:			7,92
Kraljica variety			
Plot	ARKOD ID	Area, ha	Yield, t/ha
17P-1	1517257	51,53	8,80
18P-1	1516262	33,24	7,91
22P-2	1519208	48,10	8,13
16P-1	1517350	8,00	8,17
22P-1	1518511	19,29	8,19
Average:			8,31

Multi-year research and direct comparison of multi-year parameters obtained from the plots results in an increasingly expedient and optimal use of resources for work and an increase in the quantity and quality of products. In addition, the adoption of precision agriculture guarantees sustainable agriculture from the point of environmental protection.

4 CONCLUSIONS

The integration of advanced technology into agricultural practices has led to significant improvements in crop management and resource efficiency. In this case, the application of the eBee Plus UAS, paired with the eMotion guidance software and Pix4Dfields data processing software, was utilized to assess two distinct plots of wheat located in PPK Valpovo. Through the collection of high-resolution aerial imagery and precise data analysis, application maps for nitrogen fertilizer were generated utilizing NDVI. The creation of these application maps enabled more targeted and efficient application of nitrogen fertilizer, ultimately leading to a notable reduction in the quantity of fertilizer used during the wheat cultivation process. This approach not only enhances the sustainability of agricultural practices by minimizing excess nitrogen applications—which can lead to environmental concerns such as runoff and soil degradation—but also supports farmers in lowering input costs.

Moreover, the eMotion guidance software and Pix4Dfields provide intuitive user interfaces, making them accessible and practical tools for agricultural producers, especially those managing large tracts of land. The ease of use associated with this technology allows farmers to effectively implement precision agriculture techniques without requiring extensive training or expertise in remote sensing. Consequently, the combination of UAS technology, data processing software, and innovative agronomic practices holds great promise for optimizing crop production while promoting environmental stewardship in agriculture.

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