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MULTISPECTRAL ASSESSMENT OF UAV AND FIELD SPRAYER CHEMICAL CROP PROTECTION IN WHEAT

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Abstract: Modern agriculture increasingly relies on advanced technologies such as remote sensing and unmanned aerial vehicle (UAV) systems to monitor crop conditions and optimize pesticide application. This study aimed to compare the effects of pesticide application using UAV system DJI Agras T30 with those of a conventional field sprayer Kubota XTS326 and Kubota M135GX tractor in wheat production.

The research was conducted in Grmovci-Zemun (44°50′47″N, 20°11′07″E), Republic of Serbia, where the impact of pesticides on plant health was assessed using three vegetation indices: NDVI, SAVI, and EVI. Data were collected at three time points: before application, and 15 and 30 days after pesticide application (DAPA), using the DJI Phantom 4 Multispectral UAV.

The results showed that before pesticide application, all treatments exhibited high NDVI values (0.90–0.92). At 15 DAPA, the differences among treatments were minimal, whereas at 30 DAPA, the UAV system recorded the highest values for all indices (NDVI = 0.709; SAVI = 0.228; EVI = 0.209), compared with the field sprayer (NDVI = 0.686; SAVI = 0.217; EVI = 0.205) and the control (NDVI = 0.625; SAVI = 0.209; EVI = 0.188). These findings confirm that the UAV system ensured longer preservation of green biomass and a more favorable vegetative response compared with both the field sprayer and the control. The results indicate that UAV systems represent a valuable alternative in precision agriculture, providing more efficient pesticide application while reducing resource consumption.

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INTRODUCTION

Wheat is cultivated under a wide range of climatic conditions and is one of the most important field crops worldwide. To achieve stable yields and high-quality grain, it is essential to maintain favorable agroecological conditions and provide effective protection against diseases and pests throughout the growing season. Chemical crop protection plays a crucial role, but its effectiveness depends on the application technology, dosage, droplet distribution, and prevailing weather conditions [1].

Remote sensing has emerged as a modern tool for monitoring crop conditions, enabling the timely detection of biotic and abiotic stresses before they become visually apparent. This approach is based on recording reflected electromagnetic radiation with sensors, while multispectral cameras make it possible to collect data across different parts of the spectrum [2,3,4]. Vegetation indices such as NDVI, EVI, and SAVI are widely used to quantify vegetation status, assess biomass, and detect plant stress, as they capture differences in the reflectance of visible and near-infrared radiation [5,6].

Unmanned aerial vehicle (UAV) systems have been increasingly applied in precision agriculture in recent years. Compared with satellites, UAV systems offer higher temporal and spatial resolution, allowing more frequent imaging and more detailed crop condition analysis. They can be equipped with multispectral, thermal, or RGB cameras and are also employed for chemical crop protection. Their advantages in pesticide application include reduced water and labor requirements, as well as the potential for improved pesticide coverage due to the downward airflow generated by propellers [1,2].

This study aimed to compare the effectiveness of pesticide application with a UAV system and a conventional field sprayer in wheat production by monitoring vegetation indices (NDVI, EVI, and SAVI). Special emphasis was placed on the dynamics of index values before and after treatment, as well as on vegetation uniformity within each treatment.

MATERIALS AND METHODS

The study was conducted on experimental plots in Grmovci (44°50′47″N, 20°11′07″E), Zemun municipality, on winter wheat cultivated in accordance with standard agronomic practices. The experiment included three treatments:

- T1 – Control (no pesticide application)
- T2 – Pesticide application using a UAV system
- T3 – Pesticide application using a conventional field sprayer

Each treatment plot covered an area of 0.12 ha, with 10 m isolation zones established between adjacent plots to minimize the risk of pesticide drift and cross-contamination. The boundaries of the experimental units were precisely marked immediately after sowing, ensuring clear spatial separation of treatments and preserving the integrity of the experiment.

Before sowing, the soil was plowed to a depth of 20 cm, and a starter fertilizer NPK (6:24:12) was applied at a rate of 300 kg/ha. The wheat variety used in this study was 'Sofru-RWA' (*Triticum aestivum L.),* a medium-early cultivar originating from Austria, characterized by an average plant height of 82 cm, good winter hardiness, resistance to lodging, and tolerance to common foliar diseases such as septoria and rust.
Sowing was carried out on October 21 at a seeding rate of 240 kg/ha, and crop emergence was observed approximately four weeks later. Successful overwintering enabled the continuation of vegetative growth in spring.

During the growing season, the crop was fertilized three times: at the beginning of stem elongation with 250 kg/ha of urea (46% N), before flowering with 100 kg/ha of calcium ammonium nitrate (CAN, 27% N), and again at the onset of flowering with an additional 100 kg/ha of CAN. Harvest took place at the beginning of July.

Two application systems were used for wheat protection. The first was a Kubota XTS326 field sprayer mounted on a Kubota M135GX tractor. This system operated with a spray volume of 200 l/ha, travels speed of 5 m/s, and a nozzle height of 0.5 m above the crop canopy. The main advantages of this system are its high field capacity and suitability for treating large areas. The second system was the DJI Agras T30 UAV, which applied a considerably lower spray volume of 30 l/ha, at a flight speed of 3 m/s and an altitude of 1.5 m above the canopy. The UAV system provides operational flexibility, precise application, and improved droplet deposition due to the additional airflow generated by the propellers. For both systems, the pesticide application was identical and expressed per unit area:

- Fungicide Delaro (1 L/ha)
- Insecticide Decis (0.075 l/ha)
- Adjuvant Inex (0.2 l/ha)

In addition to pesticide application, remote sensing was employed in the study. The entire experimental area was surveyed using a DJI Phantom 4 Multispectral UAV flown at an altitude of 20 m. This UAV system is equipped with a camera containing six CMOS sensors: one RGB and five multispectral bands (blue, green, red, red edge, and near-infrared). It also features a high-precision RTK GNSS module, offering positioning accuracy of 1 cm horizontally and 1.5 cm vertically, making it highly suitable for precise mapping and vegetation analysis.

Imaging was conducted at three time points: before treatment (April 27, 2023), 15 days after application (May 12, 2023), and 30 days after application (May 27, 2023). The acquired images were processed using Solvi software, where three vegetation indices, NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), and SAVI (Soil-Adjusted Vegetation Index), were calculated for each treatment plot. The indices were computed according to the following formulas:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad .....[1]$$

where is

NIR – reflectance in the near-infrared region of the spectrum
Red – reflectance in the red region of the spectrum

$$SAVI = \frac{1.5*(NIR-Red)}{(NIR-Red+0.5)} \qquad \text{...........[2]}$$

where is

NIR – reflectance in the near-infrared region of the spectrum
Red – reflectance in the red region of the spectrum
1.5 – coefficient that enhances the distinction between vegetation and soil
0.5 – soil adjustment factor added to reduce the influence of bare soil on the index

$$\text{EVI} = 2.5 * \frac{(NIR-Red)}{(NIR+6*Red-7.5*Blue+1)} \qquad \text{......[3],}$$

where is
NIR – reflectance in the near-infrared region of the spectrum
Red – reflectance in the red region of the spectrum
Blue – reflectance in the blue region of the spectrum
2.5 – coefficient that increases the sensitivity of the index to vegetation differences
7.5 – coefficient that adjusts the influence of blue reflectance
6 – coefficient that adjusts the influence of red reflectance
1 – coefficient added to prevent division by zero in the denominator

The analysis included mean, minimum, and maximum values, and changes relative to the pretreatment state were also expressed in relative terms (15 DAPA and 30 DAPA).

RESULTS AND DISCUSSION

The analysis of NDVI values indicated that before pesticide application, all three treatments displayed high average values, signifying well-developed vegetation (see Table 1). The control group (T1) recorded the lowest NDVI at 0.900, while the protected treatments showed slightly higher values. Notably, the UAV system (T2) achieved the highest average NDVI at 0.921.

At 15 DAPA, the average NDVI values increased slightly across all treatments. Differences among the UAV system (T2, 0.915), the field sprayer (T3, 0.912), and the control (T1, 0.917) were negligible, suggesting that treated crops maintained a vegetative status comparable to the control. However, during this period, the chemically treated plots demonstrated greater stability, whereas the control exhibited a narrower range of minimum and maximum values, which may indicate increased crop heterogeneity. At 30 DAPA, a notable decrease in NDVI values was observed across all treatments, corresponding to the expected reduction in photosynthetically active surface area during the later stages of wheat development. The sharpest decline occurred in the control (T1, 0.625), while the treated plots retained higher NDVI values. The UAV treatment (T2, 0.709) had the highest value, followed closely by the field sprayer (T3, 0.686). Moreover, the UAV treatment showed the narrowest range of NDVI values (0.707–0.711), indicating greater spatial homogeneity and crop uniformity. In contrast, both the control and the sprayer treatments displayed wider NDVI ranges (e.g., T1: 0.571–0.699), reflecting more pronounced variability in vegetation condition.

Table 1. Mean, min., and max. NDVI values in wheat treatments before and after pesticide application

Tr.	27.04.2023.			12.05.2023.			27.05.2023.		
	NDVI_mean	NDVI_min	NDVI_max	NDVI_mean	NDVI_min	NDVI_max	NDVI_mean	NDVI_min	NDVI_max
T1	0.9	0.859	0.947	0.917	0.878	0.959	0.625	0.571	0.699
T2	0.921	0.913	0.943	0.915	0.88	0.952	0.709	0.707	0.711
T3	0.903	0.835	0.972	0.912	0.893	0.935	0.686	0.656	0.736

Before pesticide application, all experimental plots exhibited high SAVI values (Table 2), indicating good vegetation condition. The field sprayer treatment recorded the highest average value (T3 = 0.420), followed by the UAV treatment (T2 = 0.398) and the control (T1 = 0.368). Differences among treatments at this stage were not pronounced and primarily reflected natural crop variability.

At 15 DAPA, SAVI values decreased across all treatments. The UAV treatment recorded the highest average value (T2 = 0.319), while the sprayer (T3 = 0.309) and the control (T1 = 0.288) were lower. These results suggest that the UAV system enabled slightly better preservation of vegetation compared with the other treatments. At 30 DAPA, the average SAVI values further declined. The lowest value was observed in the control (T1 = 0.209), while the protected treatments retained higher values: UAV (T2 = 0.228) and sprayer (T3 = 0.217). In addition to higher mean values, the UAV system showed the smallest reduction relative to the initial state, indicating more stable preservation of leaf biomass.

Overall, the SAVI results confirmed the NDVI findings, with the UAV treatment providing the most favorable vegetative response and the smallest decline in vegetation index over 30 days after application, whereas the control showed the steepest decrease. These findings are consistent with those of Chen et al. (2015) [7], who demonstrated that vegetation indices reliably reflect crop dynamics and can be used to estimate crop development and evapotranspiration coefficients (Kcb), particularly under biotic stress conditions such as stripe rust infection.

Table 2. Mean, min., and max. SAVI values in wheat treatments before and after pesticide application

Tr.	27.04.2023.			12.05.2023.			27.05.2023.		
	SAVI_mean	SAVI_min	SAVI_max	SAVI_mean	SAVI_min	SAVI_max	SAVI_mean	SAVI_min	SAVI_max
T1	0.368	0.299	0.498	0.288	0.113	0.474	0.209	0.075	0.354
T2	0.398	0.314	0.503	0.319	0.154	0.488	0.228	0.121	0.354
T3	0.42	0.328	0.518	0.309	0.156	0.477	0.217	0.116	0.337

Before pesticide application, all three treatments exhibited high EVI values (Table 3), indicating well-developed vegetation. The highest average value was recorded in the field sprayer treatment (T3 = 0.402), while the UAV system (T2 = 0.398) and the control (T1 = 0.384) showed slightly lower values. Differences among treatments at this stage were not significant.

At 15 DAPA, average EVI values decreased across all treatments. The lowest value was observed in the field sprayer treatment (T3 = 0.255), while the control showed intermediate values (T1 = 0.287). The highest EVI was recorded in the UAV treatment (T2 = 0.319), indicating a more favorable vegetative response compared with both the sprayer and the control. These results are consistent with the findings of Zou et al. (2017) [8], who reported that EVI is highly sensitive to changes in vegetation structure and effectively reflects variations in leaf area and photosynthetically active biomass.

At 30 DAPA, EVI values further declined across all treatments, consistent with the physiological reduction of greenness during the later phenophases of wheat development. The UAV system (T2 = 0.209) and the field sprayer (T3 = 0.205) had nearly identical values, while the control recorded slightly lower values (T1 = 0.188). Although the differences between the treated variants were minor, both maintained higher average values than the control, indicating a positive effect of pesticide application on the preservation of leaf biomass.

Table 3. Mean, min., and max., EVI values in wheat treatments before and after pesticide application

Tr.	27.04.2023.			12.05.2023.			27.05.2023.		
	EVI_mean	EVI_min	EVI_max	EVI_mean	EVI_min	EVI_max	EVI_mean	EVI_min	EVI_max
T1	0.384	0.29	0.517	0.287	0.102	0.492	0.188	0.064	0.324
T2	0.398	0.307	0.531	0.319	0.14	0.514	0.209	0.106	0.323
T3	0.402	0.324	0.528	0.255	0.141	0.45	0.205	0.1	0.31

The obtained vegetation index results demonstrated that the UAV system ensured a higher and more stable vegetative response compared with the field sprayer and the control, particularly 30 days after pesticide application (30 DAPA). These findings are consistent with those of Author [9], who reported that decreases in NDVI values directly correlate with the progression of disease symptoms, as well as Authors [10], who confirmed the reliability of vegetation indices in assessing crop vitality. The more stable NDVI, SAVI, and EVI values observed in the UAV treatment suggest a more uniform pesticide distribution and prolonged preservation of leaf biomass.

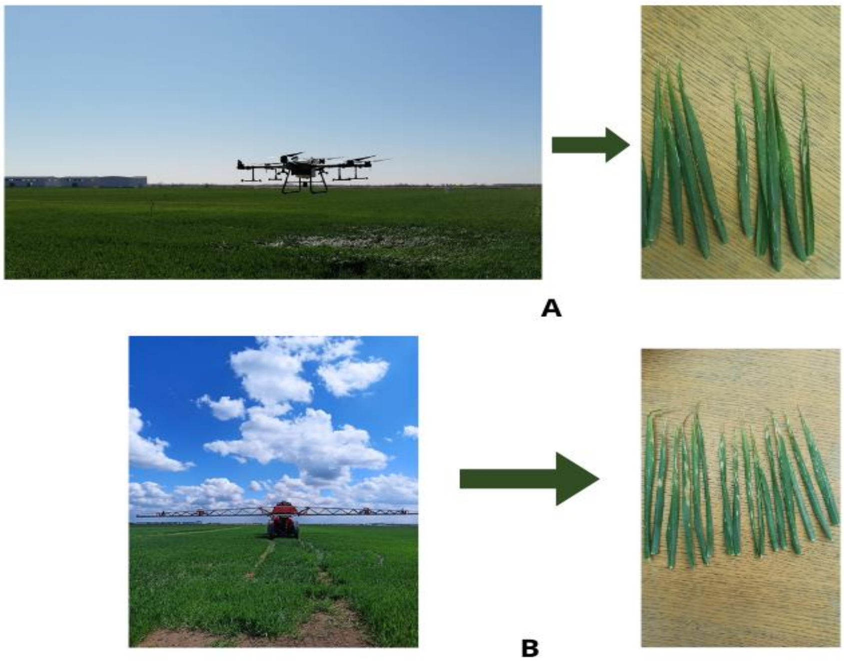

Figure 1. Application systems for heat protection: A – UAV system with crop damage from cereal leaf beetle; B – field sprayer with crop damage from cereal leaf beetle.

In addition to the physiological decline of vegetation indices due to the transition of wheat to later phenophases, the results were also influenced by biotic stress, primarily damage from the cereal leaf beetle (*Oulema melanopus*) and infections caused by leaf rusts (*Puccinia striiformis, P. graminis*). The most pronounced decline in vegetation indices was observed in the control and field sprayer treatments (Figure 1), which can be attributed to poorer coverage and more heterogeneous pesticide deposition [11,12]. In contrast, the UAV treatment exhibited lower variability and a more homogeneous crop structure, as reflected by the narrower range of minimum and maximum values compared with the other treatments.

The results of this study indicate that UAV systems can provide significant advantages in precision agriculture by enabling reduced spray volumes, improved efficiency of pesticide application, and better preservation of vegetation under pest and disease pressure. These findings highlight the potential of UAV technology as a sustainable alternative to conventional field sprayers, while also emphasizing the need for further research across multiple locations and diverse production conditions.

CONCLUSION

The results of this study showed that all vegetation indices (NDVI, SAVI, and EVI) consistently demonstrated the advantages of UAV application compared with the conventional field sprayer and the control.

No significant differences were observed among treatments before pesticide application; however, after application, particularly at 30 DAPA, the UAV treatment recorded higher and more stable index values, along with lower variability within the treated area. The control exhibited the steepest decline across all indices, confirming the importance of pesticide application for maintaining vegetative activity and wheat yield.

The differences observed between the UAV system and the conventional sprayer can be attributed to better leaf coverage and more uniform pesticide deposition achieved with the UAV system, which likely mitigated the negative effects of biotic stress (cereal leaf beetle damage and leaf rust infections). Overall, the findings confirm that UAV systems, in addition to reducing spray volumes, can provide effective and uniform protection of wheat, offering potential for more sustainable crop production.

Future research should involve multiple growing seasons and diverse locations, along with a more detailed quantification of biotic and abiotic stress impacts, to further validate and expand the applicability of these results.

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MULTISPEKTRALNA PROCENA HEMIJSKE ZAŠTITE PŠENICE PRIMENOM UAV SISTEMA I RATARSKE PRSKALICE

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Abstract: Savremena poljoprivreda sve više se oslanja na napredne tehnologije kao što su daljinska detekcija i sistemi bespilotnih letelica (UAV) za praćenje stanja useva i optimizaciju primene pesticida.

Cilj studije bio je da se uporede efekti primene pesticida pomoću UAV sistema DJI Agras T30 sa efektima primene kod konvencionalne zaštite sa agregatom traktor Kubota M135GX i prskalice Kubota XTS326 u proizvodnji pšenice.

Istraživanje je sprovedeno u mestu Grmovci (44°50′47″N, 20°11′07″E), Opština Zemun, Republika Srbija, gde je uticaj pesticida na zdravlje biljaka procenjen pomoću tri vegetaciona indeksa: NDVI, SAVI i EVI.

Podaci su prikupljani u tri vremenske tačke: pre primene pesticida, 15 i 30 dana nakon primene (DAPA), korišćenjem bespilotne letelice DJI Phantom 4 Multispectral.

Rezultati su pokazali da su pre primene pesticida svi tretmani imali visoke vrednosti NDVI indeksa (0,90–0,92). Petnaestog dana nakon primene (15 DAPA) razlike između tretmana bile su minimalne, dok je 30. dana (30 DAPA) UAV sistem zabeležio najviše vrednosti za sve indekse (NDVI = 0,709; SAVI = 0,228; EVI = 0,209), u poređenju sa traktorskim prskalicama (NDVI = 0,686; SAVI = 0,217; EVI = 0,205) i kontrolom (NDVI = 0,625; SAVI = 0,209; EVI = 0,188). Ovi nalazi potvrđuju da je UAV sistem DJI Agras T30 omogućio duže očuvanje zelene biomase i povoljniji vegetativni odgovor u poređenju sa konvencionalnom zaštitom prskanjem i kontrolnim tretmanom.

Rezultati ukazuju na to da UAV sistemi predstavljaju vrednu alternativu u preciznoj poljoprivredi, omogućavajući efikasniju primenu pesticida uz smanjenu potrošnju resursa.

Ključne reči: *Bespilotne letelice, pesticidi, vegetacioni indeksi, daljinska detekcija, precizna poljoprivreda, NDVI.*

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