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Research Article

On the Use of UAVs with a Slantrange Sensor System for Estimation of Crop Safety

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ABSTRACT:

The article addresses applied aspects of using UAVs for monitoring winter wheat crops to assess the aftereffects of herbicides remaining on the culture of the predecessor. The issue has a local specificity related to inconsistencies of plant cultivation technologies and the inadequate study of the impact of modern plant protection products in domestic soil conditions. Restoring the crop yields is possible by timely identification of the causes of stress, but the time for decision-making is limited. This time can be reduced by state-of-the-art monitoring technologies applied at industrial scale. Laboratory studies using phyto cameras and spectral and spectral-spatial monitoring methods unambiguously testified to the stress caused by the aftereffect of herbicides, but did not allow to establish clear criteria. Therefore, we conducted field studies using UAV-mounted Slantrange complex and analyzing the DJI Matrice 200 to define the distribution of stress areas on the field. It was found that the reliability of monitoring data can increased computer data processing and computer training in the search for correlation links between the distribution of stress plants in the field and the implementation of technological operations, terrain topography, etc.

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Introduction

UAVs are innovative tools for the agrarian sector as they are able to provide farmers with fundamentally new opportunities for harvest management. Despite the high cost of products and their services, according to the results presented by Andújar et al.,[1] automated spectral monitoring of UAV crops is economically more attractive than similar land-based implements. In a number of situations UAVs are indispensable, as modern plant practices require operational monitoring of crops associated with the use of plant protection products. One of the main negative factors affecting crop yields are weeds, annual losses amounting to up to 10-15 % of the potential harvest. To prevent this, the intensive introduction of herbicides, the number of which in the world in 2004 according to Gupta [2] is already estimated at 1 million tons per year and continues to grow. At the same time, huge risks come from both counterfeit products and newest mixtures of reagents whose standard effects on future harvests, according to Machado and Martins [3] and Larsson et al.,[4] are imperfect. Special danger to the use of broad-spectrum herbicides is their drift to other crops under the influence of various factors and the effects of herbicides.[5] The strongest aftereffect of herbicide on winter crops is due of the remnants of pesticides for previous crops that did not have time to decompose, as shown by the example of wheat in the works of Lingan Kong et al., [6] Miroslav Jursík et al.,[7] Ionescu et al.,[8] and , for rapeseed, by Kania et al.[9] To restore the metabolism of the affected plants, special tank mixes are used – safeners, whose efficacy is maximal in the initial stages of plant growth according to the data given by Zimdahl [10] and Ian Cummins et al.[11] Remote monitoring based on spectral indices of plantings is complicated by the fact that stress states can be caused due to various factors: shortage of batteries, inappropriate temperature or moisture provision, as well as chemical poisoning with herbicides, etc. There was a hypothesis that it is possible to identify characteristic features in affected plants that will identify the cause of stress. Therefore, the purpose of the research is to improve the method of operational monitoring with the help of UAV production crops of winter crops, for example, wheat in relation to the effects of the aftereffects of herbicides.

Selection of Spectral Sensory Equipment for UAV

The investment attractiveness of precision farming has led to the emergence of a large number of spectral sensory equipment for monitoring from different manufacturers. Some samples of specialized touch-sensitive equipment such as MAPIR Survey, presented by Green et al.[12] and Sentera, described in Lei Deng et al., [13] were built on the basis of non-specialized digital cameras used for leaflet diagnostics.

In order to calibrate such cameras for lighting changes we used artificial ground-based optical patterns or techniques based on measurements of the camera's full-time exposure meter, as described in V. Lysenko et al. [14] and Korobiichuk et al.[15] More convenient, given the speed of data processing when creating orthophotomaps, there are specialized sunshine sensors that are equipped with Parrot SEQUOIA spectral systems described by Deng and co-authors,[16] and Slantrange is represented by Enciso et al.[17] and Dolia et al.[18] In this case, the Slantrange system, unlike analogues, does not require the use of calibration panels at all, and is able to process data during the flight, which ensures the speed of obtaining finished cards of stress indexes without the involvement of cloud services. Since the effective use of gauging panels is complicated for characteristic areas of 80-100 hectares for Ukraine, the Slantrange system will have advantages. In the initial stages of vegetation, when the safe application of safeners is possible, spectral monitoring will record many plots that are caused by the soil itself, which should be taken into account when calculating stress indices. When processing photos, soil filtration can be done using cascading filters as shown in Lysenko et al.,[19] the Slantrange system provides the user with ready-made maps of stress indices, however, in contrast to the presented analogues, it provides the possibility to filter data based on user choices. Given that the Slantrange system is positioned on the market as an industrial-scale rather than laboratory equipment, it was chosen as the base equipment for the monitoring methodology on a production scale.

Selection of Diagnostic Parameters of Winter Wheat Crops

When remote monitoring of planting plants is used several separate approaches and their combinations:

- Vegetative indices based on purely spectral indices in winter wheat harvest management technologies are most often used to determine the state of nitrogen nutrition as shown in Duan et al.,[20] Lysenko et al.[21] and wet state provided by Gago et al.[22] The difference in indices is, first of all, in the choice of spectral ranges and mathematical equations that are chosen to meet the needs of the experiment.
- Stress indices that take into account the size of plants. In Jibo Yue et al.,[23] biomass was calculated based on the UAV spectral indices when empirical coefficients were introduced, which is inconvenient considering the number of plant varieties and the differences in the color of the soil. Measurement of plant size using UAV at the initial stages of vegetation is carried out at pixel analysis of images, when the percentage of image pixels is determined, which corresponds to the plants, as shown in the work of Lysenko et al.[24]
- Spectral-spatial monitoring. A spatial analysis of the nature of the distribution of stress areas is usually used to determine plantations affected by fungal infections[25] and viral diseases.[26] At the same time, they are considered as the object of study of the plot area. Consideration not of individual plots, but of their totality as a research object was carried out on images of UAVs in the automated determination of lines for monitoring of perturbation was considered in the work of Senthilnath et al.[27] The work of Shvorov et al.[28] considered portraits of fields obtained with pixel analysis for navigating the UAV in the absence of GPS positioning were considered.

Therefore, to identify the causes of the stress of winter wheat crops, it is possible to use spectral indices, pixel analysis of plant sizes and evaluate the nature of the distribution of stress areas along the field at the initial stages of vegetation.

Methods

For experimental studies on spectral indices and plant sizes, phytocamera and stationary field studies may be used, and the study of the distribution of stress areas in the field with acceptable accuracy of measurements is possible only in the production fields. The soil cover of Ukraine has about 300 types and subtypes of soils, therefore, in order to increase the reproducibility of experimental data, it is expedient that the production fields and experimental hospital were on the same subtype of soil. In addition, the precise introduction of herbicides into relatively small experimental areas of the field hospital cannot be made using industrial tools for making tank mixtures. Therefore, for conducting studies on the effect on the spectral and dimensional parameters of wheat aftereffects of herbicides, the use of phytocameras was limited.

To carry out an experiment in a phytoroom (Fig. 1), the soil was recruited on a field where for preplant crops (potatoes) were artificially created areas with a normalized and doubled herbicide dose. Soils were harvested in areas determined by visual landmarks in the area at least 50 meters from the margins of the field and the limits of the different dosage of the herbicides. A layer of soil depth of up to 15 cm was removed. Taking soil samples was carried out at the end of September 2018 on the eve of winter wheat. Taking soil samples was carried out at the end of September 2018 on the eve of winter wheat sowing. Samples of wheat seeds (Mulan variety) provided by the holding were removed from a batch of seed material that was used for crops in 2018-2019.

Before filling the vessels, the soil was thoroughly mixed, cleaned of large inclusions, sifted through a sieve with a diameter of 5 mm holes. We dropped big pieces, pebbles, crop residues, roots, and the like. To produce vegetation experiments, special vessels were used, which consisted of two parts: a vessel and a pallet. The geometric dimensions of the vessel were: diameter 20 cm, height 25 cm. At the bottom of the receptacle, a sheet of filter paper, the size of which corresponded to the size of the bottom of the vessel, was placed before filling the soil. The bottom of the vessel has openings for removing gravity water.

Results

Spectral investigations were carried out according to the method described in V. Lysenko et all (2017)[29] with the use of an optical template to take account of the difference in illumination. The results obtained are presented in Table 1.

As seen from the spectral data presented, the greatest difference in the intensity of the component colors is observed on the red and green channels. The length of leaves in samples that was affected by the effect of herbicides was less than 2 times. However, such external manifestations may also be the result of

Figure 1: Phytocamer of the Department of Agrochemistry and Quality of Plant Products NUBiP with a study on the effects of the aftereffects of herbicides and wheat in different precursor cultures.

their causes, as shown by Zhang et al.[30] or, as Helman et al.[31] pointed out, by deficiencies in water availability. Thus, based on experimental data, purely spectral or spectral-dimensional approaches in remote sensing cannot reliably determine that the stress state of winter wheat is due precisely to the effect of herbicides.

The distance between the designated meteorological station and the fields where the survey was carried out does not exceed 16 km, taking into account the flat nature of the area, the data can be considered sufficiently precise.

In land surveys, it was recorded that in areas affected by herbicide, the average size of plants on average was twice lower than in crops where a normalized dose of herbicide was introduced in the culture of the precursor. In the visual examination, no significant difference was observed in the colored plants, that is, the results coincided with the data obtained in the use of fito-chimneys.

For spectral field monitoring, the Slantrane 3p system, which was mounted on the basis of the DJI Matrice 200 fireplaces, was used. Lighting changes for the Slantrange complex were implemented using built-in algorithms for equipment developers using a standard anti-aircraft sensor. The adjustment of the exposure duration was carried out by a measuring complex for each channel separately, which was later used to calibrate the creation of stress indices. Data processing and mapping of stress indexes were performed by SlantView software ver. 2.9.0.1086 from the developer of the Slantrange system. The maps of the standard stress indexes RedNDVI, GreenNDVI, RedEdgeNDVi, and proposed

Figure 2: Experimental samples of winter wheat with the effect of the herbicide (on the left) and without the action of the herbicide (on the right). Date taken 19.04.2019.

Table 1. Spectral and dimensional parameters of experimental wheat samples.

№	Aftereffect +							Aftereffect -						
	Wheat			Template			h	Wheat			Template			H
	R	G	B	R	G	B		R	G	B	R	G	B	
1	48	82	32	192	194	193	20	36	48	30	191	191	198	42
2	65	83	54	194	196	208	22	50	57	31	182	183	192	44
3	69	94	28	195	196	196	24	45	55	38	183	183	192	46
4	62	75	36	187	188	200	23	48	63	35	189	188	200	42
5	54	67	40	188	190	202	26	52	60	29	186	189	188	50

by the stress developer Stress, Veg. fraction are obtained, and are presented in Fig. 3 together with Yield potential, Chlorophyll.

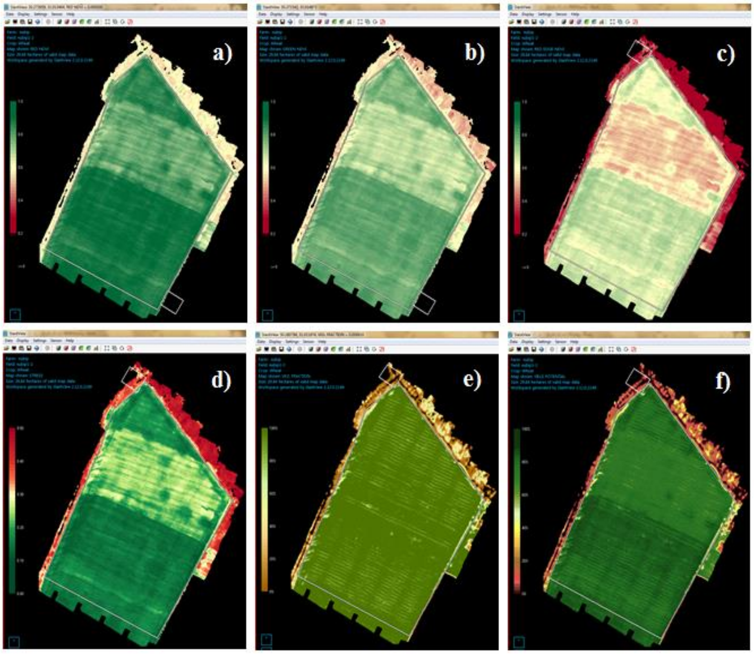

Figure 3: Cards of stress indices obtained using the system Slantrange 3p when: a) Red NDVI, b) Green NDVI, c) Red edge NDVI, d) Stress, e) Veg. fraction, f) Yield potential.

As can be seen from the data presented, the largest difference was recorded for Stance stress index, but the equation of this index is not provided by the company and accordingly it cannot be calculated on the basis of results from other equipment suppliers. Based on the prospective possibility of comparing the results from UAVs and satellite monitoring data, a standard index "Red edge NDVI" was chosen for further computer analysis.

Table 2. Significance of stress indexes for winter wheat, depending on the effect of herbicides.

Index	Aftereffect +			Aftereffect -			Difference %
	min	max	average	min	max	average	
RedNDVI	0,65	0,69	0,67	0,78	0,82	0,8	13
GreenNDVI	0,75	0,8	0,775	0,89	0,92	0,905	13
Red edge NDVI	0,5	0,55	0,525	0,65	0,7	0,675	15
Stress	0,23	0,26	0,245	0,14	0,16	0,15	19
Veg. fraction	0,94	1	0,97	0,94	1	0,97	0
Yield potential	0,72	0,76	0,74	0,82	0,86	0,84	10

To analyze the distribution of stress areas in the field, the resulting maps were saved to image files with the extension png. Since the introduction of herbicides was carried out by machine method, it was assumed that the distribution of stress areas caused by the effects of herbicides should correlate with the technological ways of moving equipment for its introduction. In the absence of interference with the movement of equipment is linear in nature, so when analyzing images focused on the search for just linear functions.

For analysis, a wavelet analysis was performed using the Wavelet Toolbox extension in the Matlab package version 7.0.1. The task of image recognition was to compare the coefficients obtained from the wavelet decay of the test image, with the coefficients obtained in the decomposition of several reference images. When analyzing the maximum number of coefficients, the test image was considered identical to one of the standards, as shown by Korobiichuk et al.[32]

When processing images, we have two-dimensional arrays S (x, y) given in the space V = {x,y} є R2. This wavelet will look like:

$$\frac{1}{\sqrt{a_1 a_2}}\psi\left(\frac{x-b_1}{a_1},\frac{x-b_2}{a_2}\right), \quad (1)$$

where a1 & a2, b1 & b2 – values for each measurement.

Two-dimensional wavelets will look like:

$$\begin{cases} 2^{-m}\varphi(2^{-m}x-k)\varphi(2^{-m}y-l), 2^{-m}\varphi(2^{-m}x-k)\psi(2^{-m}y-l), \\ 2^{-m}\psi(2^{-m}x-k)\varphi(2^{-m}y-l), 2^{-m}\psi(2^{-m}x-k)\psi(2^{-m}y-l). \end{cases} \quad (2)$$

where m – scale parameter, k and l – numbers that characterize the displacements along the axis.

Therefore, the analysis runs horizontally, vertically and diagonally. The wavelet coefficients found are decomposed in the space of eigenvectors:

$$\tilde{a}_j = \sum_{k=1}^{S} \lambda_k x_{jk} y_k + \Delta_{js}, s < r, \Delta_{js} = \sum_{k=s+1}^{r} \lambda_k x_{jk} y_k \quad (3)$$

This produces the feature vector for the input image w. The following are the distances between the received feature vector and each of the training sample vectors using the Euclidean metric. The output image shows the boundary of the inhomogeneous field by comparing the coefficients with the reference images. The recognition process was to compare the main components of the synthesized image with the components of all known images.

An example of implementation is presented in Fig. 4 where the green lines defined the boundary between the stress areas that coincided with the limits of the introduction of an increased number of herbicides for the culture of the predecessor.

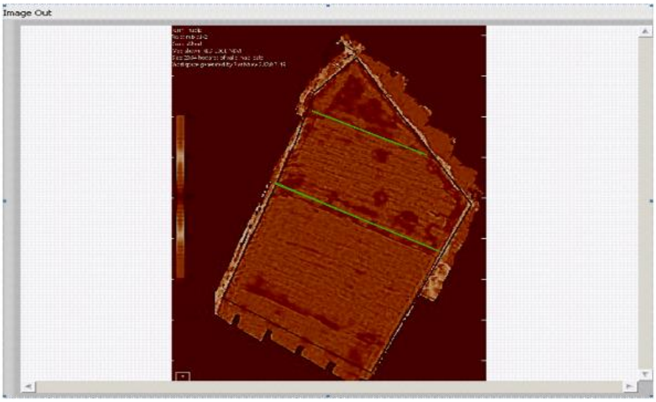

Figure 4: Determination of the boundary of heterogeneous distribution of stress areas in the field.

In fig. 4 on stress maps “Veg. fraction” and “Yield potential” and, to a lesser extent, the rest can see the linear distribution of stress areas directed perpendicular to the technological tracks. According to the given economy in 2017-2018, such a direction of technological tracks was used and the distribution of stress areas was caused by a certain difference in the state of mineral nutrition. That is, data with a high resolution of the UAV will allow agrarian practices to track and interpret those processes occurring on the fields.

On maps of different versions of NDVI and Stress, it was recorded that in areas where the excess culture of excess herbicides was present, oval areas with no plants were present. The explanation for this is the presence of depressions where the raised humidity of the soil formed, which led to the washing of herbicide residues. Therefore, it is advisable, together with the maps of the distribution of stress indices, to investigate the terrain and to take these data into account in ‘big data’ technologies, where data from the UAV can be supplemented with data from satellites and ground sensory equipment.

Conclusions

- With purely spectral and spectral-spatial monitoring of winter wheat, it was not possible to reliably identify the stressful nature of the resulting aftereffects of herbicides, that is, ground platforms for spectral sensory equipment are ineffective.

- Stress index cards obtained on the basis of high-resolution UAVs can be considered as a separate research object for interpreting the causes of stress of complex biotechnical objects such as crop crops.

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References

1 Dionisio Andújar, Hugo Moreno, José M. Bengochea-Guevara, Ana de Castro, and Angela Ribeiro, "Aerial Imagery or On-ground Detection? An Economic Analysis for Vineyard Crops," *Computers and Electronics in Agriculture* 157 (2019):351–358.

2 P. Gupta, "Pesticide Exposure," *Toxicology Consulting Services Inc*., 198 (2004): 83–90.

3 Simone Caetani Machado and Isarita Martins, "Risk Assessment of Occupational Pesticide Exposure: Use of Endpoints and Surrogates," *Regulatory Toxicology and Pharmacology* 98 (2018):276–283.

4 Martin Olof Larsson, Vibe Sloth Nielsen, Niels Bjerre, Frank Laporte, and Nina Cedergreen, "Refined Assessment and Perspectives on the Cumulative Risk Resulting from the Dietary Exposure to Pesticide Residues in the Danish Population," *Food and Chemical Toxicology* 111 (2018): 207–267.

5 Haibo Yao, Yanbo Huang, Zuzana Hruska, Steven J.Thomson, and Krishna Reddy, "Using Vegetation Index and Modified Derivative for Early Detection of Soybean Plant Injury from Glyphosate," *Computers and Electronics in Agriculture* 89 (2012): 145–157.

6 Lingan Kong, Jisheng Si, Bo Feng, Jisheng Si, Fahong Wang, and Ken Sayre, "Differential Responses of Two Types of Winter Wheat (Triticum aestivum L.) to Autumn- and Spring-applied Mesosulfuron-methyl," *Crop Protection* 28, no. 5 (2009): 387–392.

7 Miroslav Jursík, Michaea Kolářová, and Josef Soukup, "Competition, Reproduction Ability, and Control Possibilities of Conventional and Clearfield® Volunteer Oilseed Rape in Winter Wheat," *Crop Protection* 122 (2019): 30–34.

8 Nicolae Ionescu and Aurelian Penescu, "Aspects of Winter Wheat Physiology Treated with Herbicides," *Agriculture and Agricultural Science Procedia* 6 (2015): 52–57.

9 Joanna Kania, Agnieszka Mączyńska, Mariola Głazek, Tomasz Krawczyk, Danuta M. Gillner, "The Influence of Chosen Fungicides on the Activity of Aminopeptidases in Winter Oilseed Rape during Pods Development," *Pesticide Biochemistry and Physiology* 148 (2018): 166–174.

10 Robert L. Zimdahl, "Properties and Uses of Herbicides," in *Fundamentals of Weed Science,* Fifth edition (Academic Press, 2018), 463-499.

11 Ian Cummins, Melissa Brazier-Hicks, Maciej Stobiecki, Rafa Fraǹski, and Robert Edwards, "Selective Disruption of Wheat Secondary Metabolism by Herbicide Safeners," *Phytochemistry* 67, no. 16 (2016): 1722–1730.

[12] David R. Green, Jason J. Hagon, Crisina Gómez, Billy J. Gregory, "Using Low-Cost UAVs for Environmental Monitoring, Mapping, and Modelling: Examples From the Coastal Zone," in *Coastal Management: Global Challenges and Innovations*, edited by R. R. Krishnamurthy, M. P. Jonathan, S. Srinivasalu, and B. Glaeser (Elsevier, 2019), 465–501.

[13] Lei Deng, Zhihui Mao, Xiaojuan Li, Zhuowei Hu, Fuzhou Duan, and Yanan Yan, "UAV-based multispectral remote sensing for precision agriculture: A comparison between different cameras," *ISPRS Journal of Photogrammetry and Remote Sensing* 146 (2018): 124–136.

[14] Vitaliy Lysenko, Dmitruy Komarchuk, Olexey Opryshko, Natalia Pasichnyk, and Natalia Zaets, "Determination of the Not uniformity of Illumination in Process Monitoring of Wheat Crops by UAVs," 4th International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T), 2017, pp. 265–267.

[15] Igor Korobiichuk, Vitaliy Lysenko, Olexey Opryshko, Dmitruy Komarchuk, Natalia Pasichnyk, and Andrzej Juś, "Crop monitoring for nitrogen nutrition level by digital camera, Automation 2018," *Advances in Intelligent Systems and Computing* 743 (Springer, Cham, 2018), 595–603.

[16] Lei Deng, Zhihui Mao, Xiao-juan Li, Zhuowei Hu, Fuzhou Duan, and Yanan Yan, "UAV-based Multispectral Remote Sensing for Precision Agriculture," *ISPRS Journal of Photogrammetry and Remote Sensing* 146 (December 2018): 124-136, https://doi.org/10.1016/j.isprsjprs.2018.09.008.

[17] Juan Enciso, Carlos A. Avila, Jinha Jung, Sheren Elsayed-Farag, Anjin ChangJunho Yeom, Juan Landivar, Murilo Maeda, and Jose C. Chavez, "Validation of Agronomic UAV and Field Measurements for Tomato Varieties," *Computers and Electronics in Agriculture* 158 (2019): 278–283.

[18] Mycola Dolia, Vitaliy Lysenko, Natalia Pasichnyk, Olexey Opryshko, Dmitruy Komarchuk, Volodymyr Miroshnyk, Taras Lendiel, and Artem Martsyfei, "Information Technology for Remote Evaluation of after Effects of Residues of Herbicides on Winter Crop Rape," Proceedings of the 3rd International Conference on Advanced Information and Communications Technologies (AICT), Lviv, Ukraine, 2-6 July 2019, pp. 469-473.

[19] Vitaliy Lysenko, Dmitruy Komarchuk, Natalia Pasichnyk, Olexey Opryshko, Michal Awtoniuk, and Artem Martsyfei, "Information Support of Remote Monitoring of Grain Crops Biomass Amount as the Feedstock to Load Biogas Reactors," Proceedings of the 2018 International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T), Kharkiv, Ukraine, 2018, pp. 35–38.

[20] Tao Duan, Scott C. Chapman, Y. Guo, and Bangyou Zheng, "Dynamic Monitoring of NDVI in Wheat Agronomy and Breeding Trials Using an Unmanned Aerial Vehicle," *Field Crops Research* 210 (2017): 71–80.

[21] Vitaliy Lysenko, Olexey Opryshko, Dmitruy Komarchuk, Natalia Pasichnyk, Natalia Zaets, and Alla Dudnyk, "Usage of Flying Robots for Monitoring Nitrogen in Wheat Crops," The 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), Bucharest Romania, 21-23 September 2017, vol. 1, pp. 30–34.

[22] Jorge Gago, Cyril Douthe, Rafael E. Coopman, Pedro Pablo Gallego, Miquel Ribas-Carbo, Jaume Flexas, José Mariano Escalona, and José Mariano Escalona, "UAVs Challenge to Assess Water Stress for Sustainable Agriculture," *Agricultural Water Management* 153 (2015): 9–19.

[23] Jibo Yue, Guijun Yang, Qingjiu Tian, Haikuan Feng, Kaijian Xu, and Chengquan Zhou, "Estimate of Winter-Wheat Above-ground Biomass based on UAV Ultrahigh-ground-resolution Image Textures and Vegetation Indices," *ISPRS Journal of Photogrammetry and Remote Sensing* 150 (2019): 226–244.

[24] Vitaliy Lysenko, Olexey Opryshko, Dmitruy Komarchuk, Natalia Pasichnyk, and Natalia Zaets, "Information Support Of The Remote Nitrogen Monitoring System In Agricultural Crops*," International Journal of Computing* 17, no. 1 (2018):47–54.

[25] Rocio Calderón, Juan Navas-Cortés, Carlos Lucena, and Pablo Zarco-Tejada, "High-resolution Airborne Hyperspectral and Thermal Imagery for Early Detection of Verticilliumwilt of Olive Using Fluorescence, Temperature and Narrow-band Spectral Indices," *Remote Sensing of Environment* 139 (2013): 231–245.

[26] Sarah MacDonald, Matthew Staid, Melissa Staid, and Monica Cooper, "Remote Hyperspectral Imaging of Grapevine Leafroll-associated Virus 3 in Cabernet Sauvignon Vineyards," *Computers and Electronics in Agriculture* 130 (2016):109–117.

[27] J. Senthilnath, Manasa Kandukuri, Akanksha Dokania, and Ramesh Kestur, "Application of UAV Imaging Platform for Vegetation Analysis Based on Spectral-Spatial Methods," *Computers and Electronics in Agriculture* 140 (2017):8–24.

[28] Sergey Shvorov, Dmitruy Komarchuk, Natalia Pasichnyk, Olexey Opryshko, Yurii Gunchenko, and Svitlana Kuznichenko, "UAV Navigation and Management System Based on the Spectral Portrait of Terrain," Proceedings of 2018 IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), Kiev, Ukraine, 16-18 October 2018, pp. 68–71.

[29] Lysenko, Opryshko, Komarchuk, et al., "Usage of Flying Robots for Monitoring."

[30] Hai-Yan Zhang, Xing-Xu Ren, Yi Zhou, Ya-Peng Wu, Li He, Ya-Rong Heng, Wei Feng, and Chen-Yang Wang, "Remotely Assessing Photosynthetic Nitrogen Use Efficiency within Situhyperspectral Remote Sensing in Winter Wheat," *European Journal of Agronomy* 101 2018): 90–100.

[31] David Helman, Itamar Lensky, David Bonfil, "Early prediction of wheat grain yield production from root-zone soil water content at heading using Crop RS-Met," *Field Crops Research* 232 (2019): 11–23.

[32] Igor Korobiichuk, Vitaliy Lysenko, Volodymyr Reshetiuk, Taras Lendiel, and Marcin Kamiński, "Energy-efficient Electrotechnical Complex of Greenhouses with Regard to Quality of Vegetable Production," In International Conference on Systems, Control and Information Technologies, Warsaw, Poland, 20-21 May 2016, pp. 243–251.

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