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USE OF DRONE FOR MONITORING AND PRODUCTION ESTIMATING IN AGRICULTURAL CROPS; CASE STUDY IN WHEAT

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Abstract

The study aimed to estimate wheat production based on aerial images taken with drone. The wheat crop, Alex cultivar, was fertilized with variable doses of nitrogen, in the range 0 - 250 kg ha^{-1} N active substance (a.s.). During the vegetation, drone images were taken on the experimental variants, between April and July 2018. The digital images, jpeg format, were analyzed and the values of the RGB parameters were obtained (R-red, B-blue, G-green; RGB colour system). At the time of biological maturity, wheat production was harvested, which recorded values between 1,896.64 kg ha^{-1} (V1-control), and 4,787.50 ka ha^{-1} (V9). Regression analysis was used to estimate production based on RGB parameters obtained from digital images, taken at four different times. Production prediction (Y_P) was possible in statistical safety conditions (R^2 = 0.997, p <0.001, images from April 29; R^2 = 0.993, p <0.001, images from May 13; R^2 = 0.990, p <0.001, images from 28 May; R^2 = 0.968, p <0.001, images from 1 July). 3D and isoquants models were obtained, which expressed the variation of production according to the R and G parameters. RMSEP, as a prediction safety parameter and the F-test showed different levels of accuracy in predicting wheat production based on parameters R and G (RMSEP = 183.5859 for April 29; RMSEP = 330.3418 for May 13; RMSEP = 386.3834 for May 28; RMSEP = 703.9887 for July 1). The use of drones to obtain information about agricultural land is very useful at farm level, and the study can be adapted to different crops.

Key words: *fertilizers, model, UAV, wheat, yield prediction*

INTRODUCTION

Wheat is one of the first species of plants "domesticated" and cultivated by humans in order to provide food resources [9], [21].
Wheat is grown worldwide on large areas, in different climatic and soil conditions and is one of the main crops for ensuring food security [56], [3], [17], [20].
The high ecological plasticity has made possible the cultivation of wheat in different eco-climatic conditions, and the production of biological material with different adaptations to stress factors, soil types and conditions, agricultural systems, cultivation technologies, productivity and quality indices [52], [44], [45], [51], [15].
Market studies on wheat production, along with other cereals, were also carried out, due to the importance and share of wheat in the trade balance of agricultural products [14], [46], [47], [1], [34].
Wheat is suitable to be cultivated in different agricultural production systems. The elements of technology have evolved a lot, in relation to new genotypes, more productive, more adapted to soil and climate conditions, to stress factors, with better baking and industrialization indices [5], [25], [2], [10], [19].
Cultivation technologies require a series of inputs, and the elements of technology are permanently adapted in relation to the soil as a nutrient medium [7], [26], [39], range of agricultural machinery [37], [28], [40], water regime, water consumption and crop irrigation [33], [4], fertilization (fertilizer assortments, methods and application techniques) [6], [11], plant protection [36], [12], [27].
Wheat goes through a long period of vegetation, from sowing to harvesting, and crop monitoring is necessary to manage the vegetation in order to obtain profitable yields [66], [13].
Wheat crop management integrates infor-mational, decision-making and operational elements, in order to achieve the proposed objectives at the level of agricultural crops

and the farm.

Agricultural crops have variable areas, in relation to the agricultural system and the type of farm. Agricultural crop management requires knowledge of the status of each crop, and this involves monitoring crops for which different techniques and methods have been developed and implemented [18], [54], [41], [60], [42]. Crop monitoring based on satellite or aerial imagery has a number of advantages [29], [58], [62], [8], [38]. The present study used aerial images, taken with a drone, in order to estimate wheat production.

MATERIALS AND METHODS

The experiment was organized within the Didactic and Experimental Resort, BUASVM, Timisoara, in the agricultural year 2017 - 2018. The Alex wheat cultivar was grown in a medium fertility chernozem soil conditions.

Fertilization was performed with different doses of ammonium nitrate, in the range 0 - 250 kg a.s. N ha^{-1} (a.s. - active substance). Based on fertilization, 11 experimental variants were performed (Figure 1).

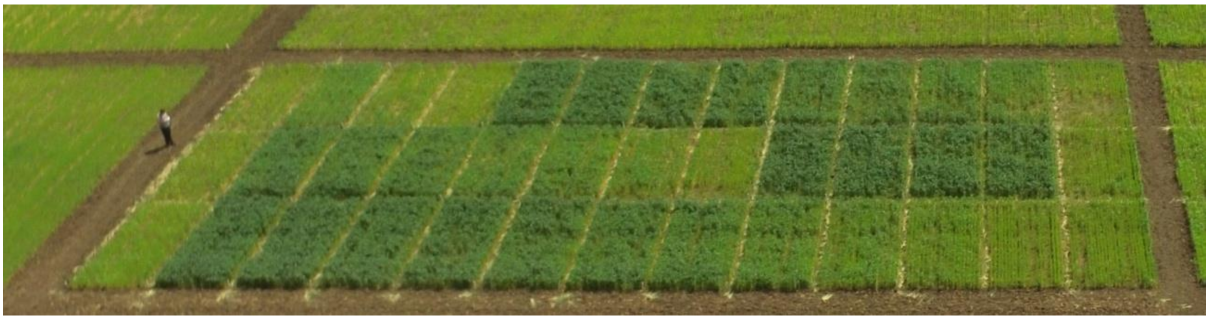

Fig. 1. Aspect from the experimental field, spring 2018
Source: original image, author's image.

A DJI Phantom series drone was used to capture aerial images.

The images were captured between April and July 2018 at different moments of vegetation of the wheat crop, Alex cultivar.

The digital images were analyzed to obtain the spectral information in the RGB system [48].

The experimental results were analyzed in terms of statistical safety (ANOVA test). Regression analysis was used to find models for estimating production, such as some equations, in relation to RGB values from digital images. Statistical safety parameters of the obtained equations were taken into account to certify the degree of safety of the obtained models (p, R^2, F-test). RMSEP, equation (1), was also used to comparatively evaluate the safety of the production prediction based on the RGB values obtained in relation to the images date.

$$RMSEP = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2} \quad (1)$$

PAST software [22] was used for statistical data analysis. Wolfram Alpha (2020)[64] was used to generate the graphs.

RESULTS AND DISCUSSIONS

Nitrogen-controlled fertilization, with variable doses in the range 0 - 250 kg ha^{-1} N a.s. (active substance) determined the differentiated growth and development of the plants on the experimental variants. This led to the variation of production between 1,896.64 kg ha^{-1} (V1) and 4,787.50 kg ha^{-1} (V9) (Table 1).

In response to variable fertilization, wheat plants had a differentiated growth and development, and this aspect was reflected in the images taken with the drone at different times of vegetation.

The taken digital images were analyzed, and the values of the RGB colour parameters were obtained, with graphical representation in Figures 2 - 5.

Table 1. Experimental variants and values of wheat production, Alex cultivar

Experimental Variants	N (kg ha^{-1})	Y (kg ha^{-1})
V1 (Ct)	0	1,896.64
V2	25	2,262.42
V3	50	3,131.25
V4	75	3,937.50
V5	100	4,018.75
V6	125	4,375.00
V7	150	4,512.64
V8	175	4,750.00
V9	200	4,787.50
V10	225	4,562.50
V11	250	4,181.25

Source: Original data from the experimental field.

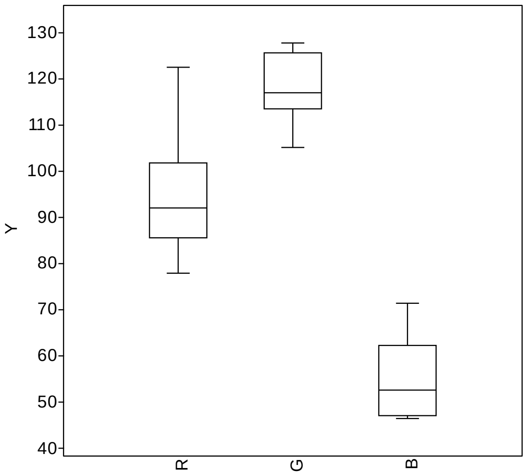

Fig. 2. Distribution of RGB values resulting from the analysis of images captured on April 29, 2018
Source: Original data, obtained from the analysis of digital images.

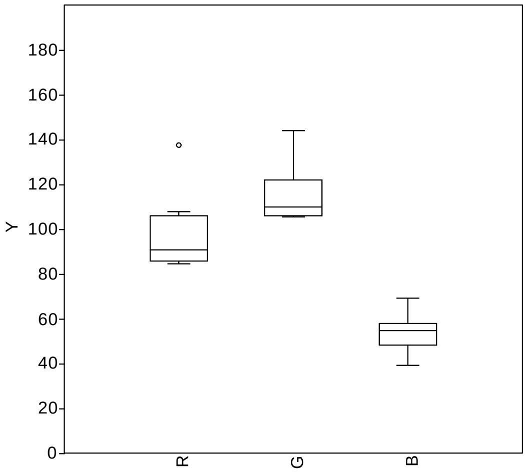

Fig. 3. Distribution of RGB values resulting from the analysis of images captured on May 13, 2018
Source: Original data, obtained from the analysis of digital images.

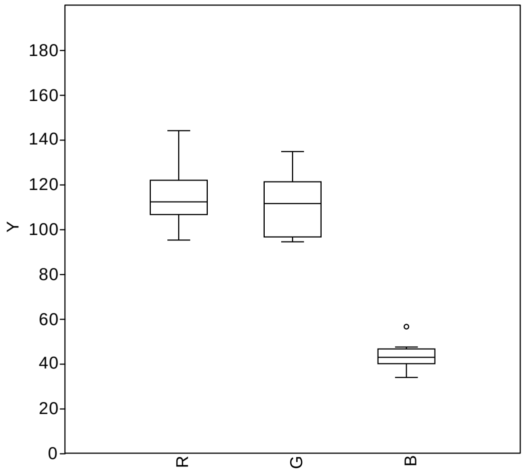

Fig. 4. Distribution of RGB values resulting from the analysis of images captured on May 28, 2018
Source: Original data, obtained from the analysis of digital images.

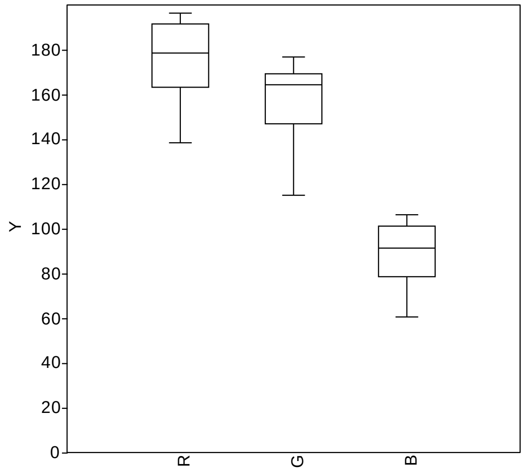

Fig. 5. Distribution of RGB values resulting from the analysis of images captured on July 01, 2018
Source: Original data, obtained from the analysis of digital images.

Through regression analysis, the possibility of estimating wheat production based on colour parameters (RGB) obtained from aerial image analysis was tested.

The estimation of wheat production (Y_P) based on the values of RGB parameters obtained from the images taken at different dates, was possible in relation to R and G, in statistical safety conditions; $R^2 = 0.997$, $p < 0.001$, date April 29; $R^2 = 0.993$, $p < 0.001$, date 13 May; $R^2 = 0.990$, $p < 0.001$, date 28 May; $R^2 = 0.968$, $p < 0.001$, date 01 July, according to the general relation of the type of equation (2).

$$Y_P = ax^2 + by^2 + cx + dy + exy + f \quad (2)$$

where:
Y_P - wheat production predicted;
x – R – red colour parameter;
y – G – green colour parameter;
a, b, c, d, e, f - coefficients of the equation (2).

The values are shown in Table 2.
The graphical distributions of the Y_P values in relation to R and G, at different images dates, are presented in Figures 6 - 9.

Table 2. The values of the coefficients of the equation (2) in relation to the date of taking the images

Coefficients of the equation	Date taken of the images			
	April 29	May 13	May 28	July 01
a	2.1158926	-24.2122337	-56.6921688	-4.7607285
b	6.2395442	-32.6728229	-54.2965244	-2.1216543
c	851.3914815	-2047.8901262	690.7087314	655.6380987
d	-518.2509759	1857.9479580	-606.6228166	-732.1025761
e	-10.8542525	58.1380359	110.6000609	7.3470566
f	0	0	0	0

Source: Original values resulting from the analysis of experimental data.

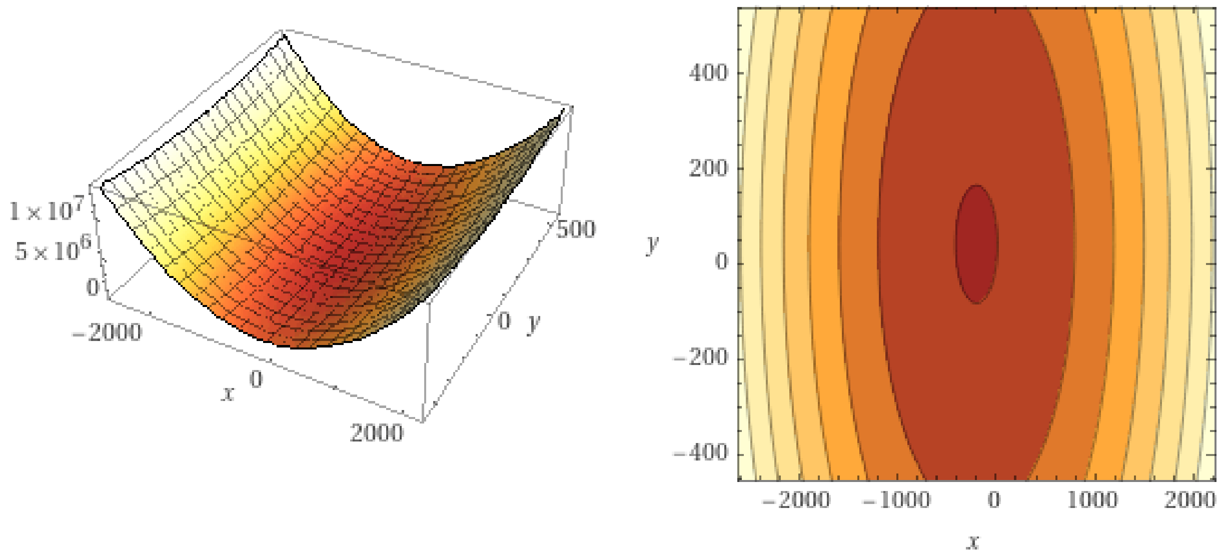

Fig. 6. Graphic distribution, as 3D model and isoquants, of Y_P in relation to R (x-axis) and G (y-axis) parameters, Alex wheat cultivar (images captured on April 29)
Source: original graphs generated based on experimental data.

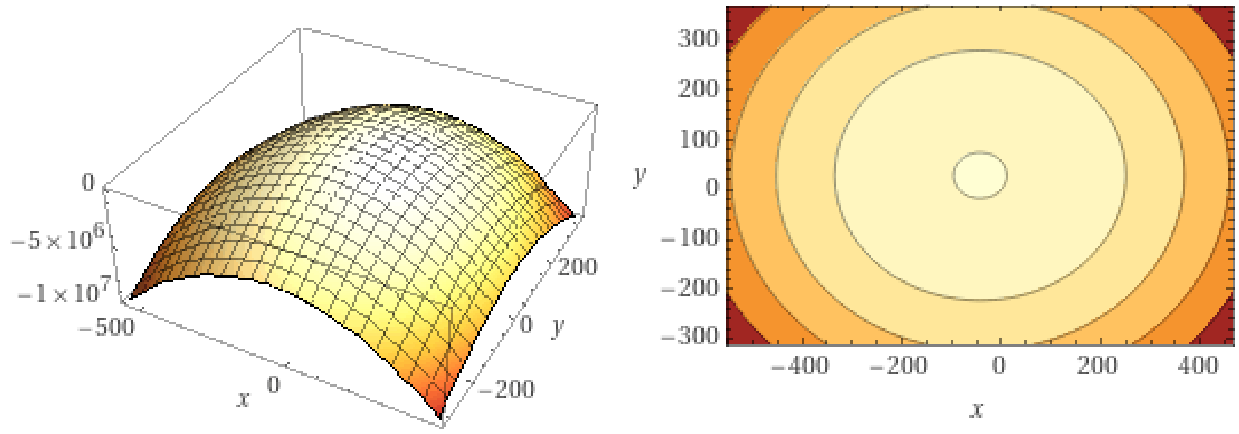

Fig. 7. Graphic distribution, as 3D model and isoquants, of Y_P in relation to R (x-axis) and G (y-axis), Alex wheat cultivar (images captured on May 13)
Source: original graphs generated based on experimental data.

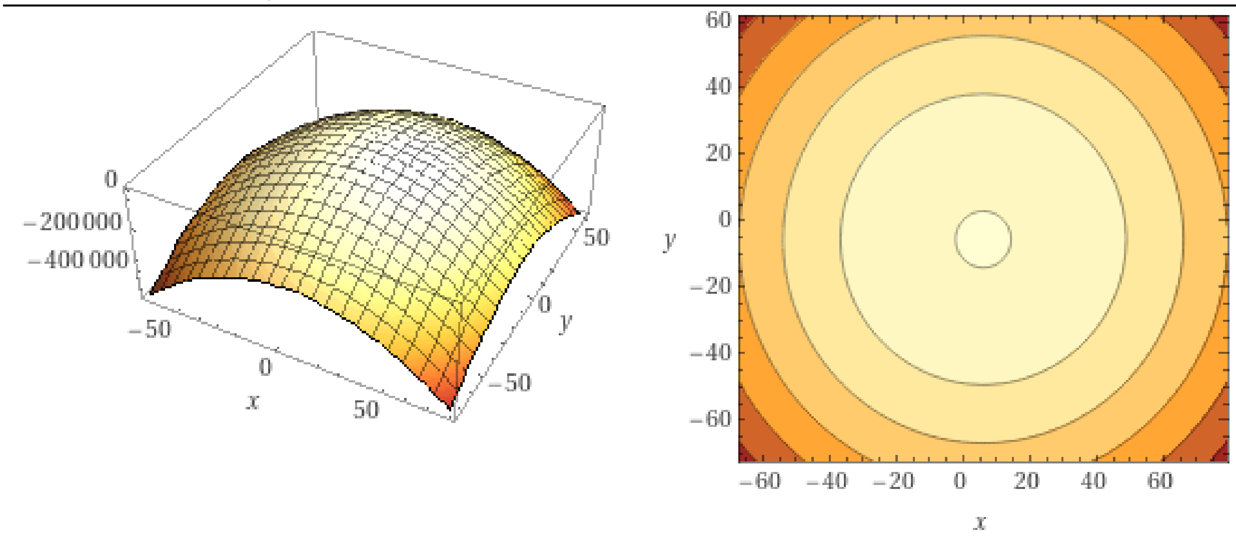

Fig. 8. Graphic distribution, as 3D model and isoquants, of Y_P in relation to R (x-axis) and G (y-axis), Alex wheat cultivar (images captured on May 28)
Source: original graphs generated based on experimental data.

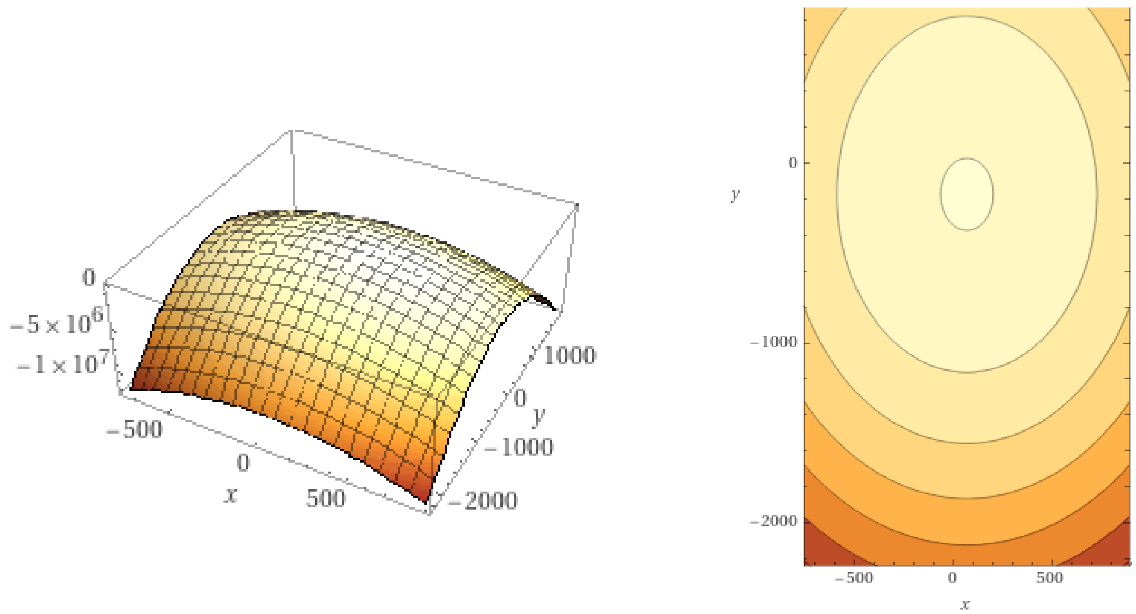

Fig. 9. Graphic distribution, as 3D model and isoquants, of Y_P in relation to R (x-axis) and G (y-axis), Alex wheat cultivar (images captured on Julay 01)
Source: original graphs generated based on experimental data.

The assessment of the prediction certainty of the production predicted (Y_P) in relation to the R and G values, obtained from the analysis of digital images, was made based on the R^2, F-test and RMSEP values, relation (1). The values obtained are presented in Table 3.
In addition, the predictive error was taken into account, as an average value, on each experimental variant, in relation to the real production (Y) (Figure 10).

Table 3. Values of the parameters R^2, F-test and RMSEP, in relation to the predicted production, based on R and G, Alex wheat cultivar

Statistical Parameters	Date taken of the images			
	April 29	May 13	May 28	July 01
R^2	0.997	0.993	0.990	0.968
F-test	560.2515	172.206	125.5518	36.9821
RMSEP	183.5859	330.3418	386.3834	703.9887

Source: Own data resulting from the analysis of experimental data.

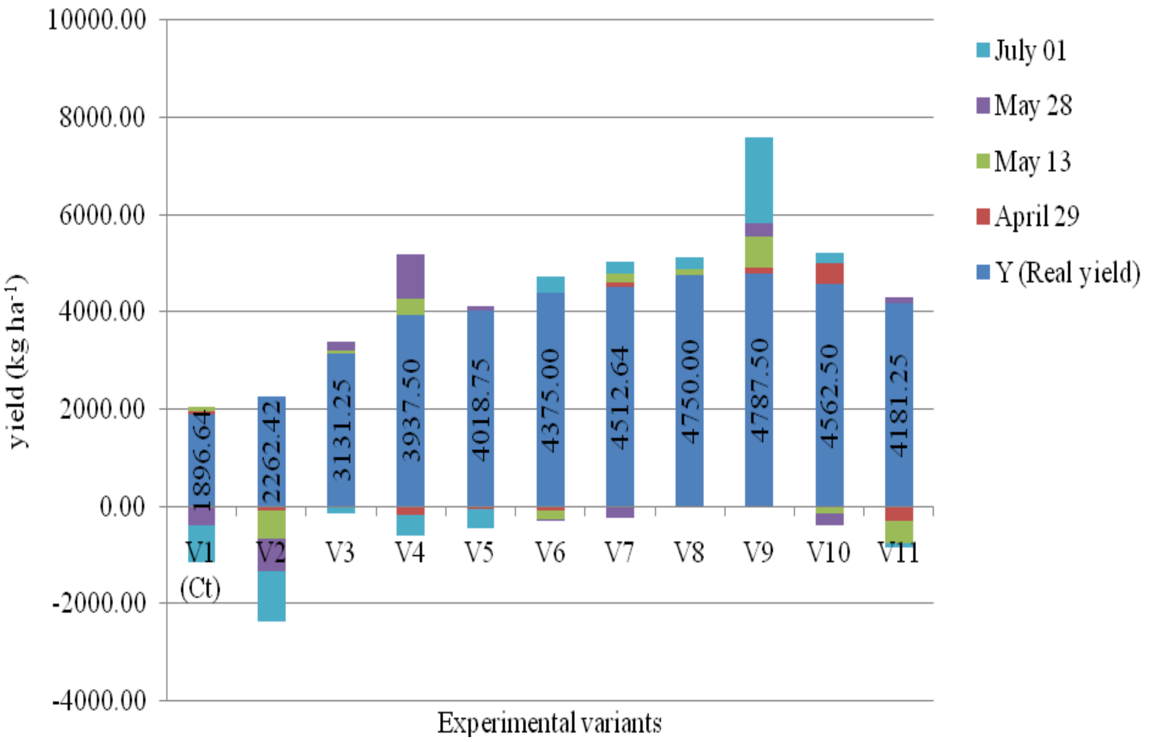

Fig. 10. Graphical representation of the real yield (Y) and of the estimation errors in relation to the date of taking over the digital images
Source: original graphs generated based on experimental data.

From the overall analysis of the values of the determined safety parameters, it was found that it was possible to predict the wheat production (Y_P) based on the analyzed images, regardless of the time of sampling.

However, a comparative analysis of the values of the respective parameters (Table 2), found the variation of the estimated accuracy of the production Y_P, but in conditions of statistical security for all cases.

Overall, the higher safety was recorded based on the images from April 29, and subsequently, as a result of a variation of the plants, the prediction accuracy was reduced, but in conditions of statistical safety (R^2=0.997 to R^2=0.968).

RMSEP confirms the higher accuracy of production prediction based on parameters R and G, the lowest value being recorded for the calculation based on images from April 29 (RMSEP = 183.5859).

A practical advantage of this approach is given by the fact that in the respective vegetation phase, plant nutrition can be corrected by supplementing high amounts of nitrogen fertilizers (the mineral element considered in this study).

Subsequently, in more advanced phases of vegetation, plant nutrition can be corrected, but with lower doses of fertilizers and, usually, with foliar application.

Fertilizers are an important factor in increasing agricultural production, and fertilization has been studied in wheat crops in relation to different genotypes, soil and climate conditions, fertilizers, methods and techniques of application, quantitative and quality indices of production [49], [50], [32], [59], [65].

Nitrogen is the nutrient that contributes most consistently to plant growth and development, and to the formation of agricultural production.

Compared to the control variant (V1) for all fertilized variants, a variation of the studied colour parameters (RGB) was found, associated with a better state of plant nutrition.

The nutritional status was reflected in the plant density, the biomass achieved, and the light reception properties, and this was highlighted in the RGB colour parameters studied.

Estimation of production in agricultural crops is of interest and different estimation models have been developed in relation to different influencing factors [61], [30], [23], [63].

Mathematical models, based on different types of equations (polynomials, logistics, etc.), are important because they facilitate the analysis of multiple data series, summations and the calculation of optimal values in relation to the variables taken into account [53], [35], [31], [55], [57].

In the present study, the regression analysis facilitated the obtaining of a mathematical model, such as equation (2), which facilitated the estimation of wheat production, Alex cultivar, based on the colour parameters R and G taken into account.

At the same time, a variation of the precision safety was found, in relation to the moment of taking the images, but the statistical safety was maintained.

With the introduction and promotion of techniques based on satellite, aerial, or terrestrial imaging, the advantages of crop monitoring were obvious, and this facilitated the predictive modeling and estimation of total biomass production or useful production, in high precision conditions [24], [16], [43].

The present study used spectral information, the RGB system, from aerial imagery to obtain models for wheat production estimation, and contributed to the development of the database and information for farm-level crop management.

Through the data obtained, it provides researchers and farmers with information and methods of approach in order to monitor the crops and facilitate real-time decisions.

CONCLUSIONS

Differentiated nitrogen fertilization generated a specific variation of RGB parameters, as spectral information associated with aerial images.

The regression analysis facilitated the estimation of wheat production, Alex cultivar, based on RGB colour parameters obtained from aerial images, taken at different times by vegetation.

Compared to the date the images were taken, the production estimation safety showed different levels of accuracy, but in statistical safety conditions. Images from earlier stages of vegetation facilitated production estimation with higher statistical certainty.

The data obtained can be integrated into decision models for wheat crop management and can be extended to other agricultural crops.

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REFERENCES

[1]Anteneh, A., Asrat, D., Moral, M.T., 2020, Wheat production and marketing in Ethiopia: Review study, Cogent Food Agric., 6(1):1778893.

[2]Ayed, S., Othmani, A., Bouhaouel, I., Teixeira da Silva, J.A., 2021, Multi-environment screening of durum wheat genotypes for drought tolerance in changing climatic events, Agronomy, 11:875.

[3]Balkovič, J., van der Velde, M., Skalský, R., Xiong, W., Folberth, C., Khabarov, N., Smirnov, A., Mueller, N.D., Obersteiner, M., 2014, Global wheat production potentials and management flexibility under the representative concentration pathways, Glob. Planet. Change, 122:107-121.

[4]Berca, M., Robescu, V.-O., Horoias, R., 2021, Winter wheat crop water consumption and its effect on yields in southern Romania, in the very dry 2019-2020 agricultural year, Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 49(2):12309.

[5]Beres, B.L., Hatfield, J.L., Kirkegaard, J.A., Eigenbrode, S.D., Pan, W.L., Lollato, R.P., Hunt, J.R., Strydhorst, S., Porker, K., Lyon, D., Ransom, J., Wiersma, J., 2020, Toward a better understanding of genotype × environment × management interactions - A global wheat initiative agronomic research strategy, Front. Plant Sci., 11:828.

[6]Bhardwaj, A.K., Rajwar, D., Yadav, R.K., Chaudhari, S.K., Sharma, D.K., 2021, Nitrogen availability and use efficiency in wheat crop as influenced by the organic-input quality under major integrated nutrient management systems, Front. Plant Sci., 12:634448.

[7]Bhatt, R., Kukal, S.S., Busari, M.A., Arora, S., Yadav, M., 2016, Sustainability issues on rice–wheat

cropping system, Int. Soil Water Conserv. Res., 4(1):64-74.
[8]Challinor, A.J., Müller C., Asseng, S., Deva, C., Nicklin, K.J., Wallach, D., Vanuytrecht, E., Whitfield, S., Ramirez-Villegas, J., Koehler, A.-K., 2018, Improving the use of crop models for risk assessment and climate change adaptation, Agric. Syst., 159:296-306.
[9]Charmet, G., 2011, Wheat domestication: Lessons for the future, C. R. Biol., 334(3):212-220.
[10]Collins, B., Chenu, K., 2021, Improving productivity of Australian wheat by adapting sowing date and genotype phenology to future climate, Clim. Risk Manag., 32:100300.
[11]De Silva, S.H.N.P., Takahashi, T., Okada, K., 2021, Evaluation of APSIM-wheat to simulate the response of yield and grain protein content to nitrogen application on an andosol in Japan, Plant Prod. Sci., DOI: 10.1080/1343943X.2021.1883989
[12]Donatelli M., Magarey, R.D., Bregaglio, S., Willocquet, L., Whish, J.P.M., Savary, S., 2017, Modelling the impacts of pests and diseases on agricultural systems, Agric. Syst., 155:213-224.
[13]Döring, T.F., Neuhoff, D., 2021, Upper limits to sustainable organic wheat yields, Sci. Rep., 11:12729.
[14]Enghiad, A., Ufer, D., Countryman, A.M., Thilmany, D.D., 2017, An overview of global wheat market fundamentals in an era of climate concerns, Int. J. Agron., 2017:3931897.
[15]Fatiukha, A., Deblieck, M., Klymiuk, V., Merchuk-Ovnat, L., Peleg, Z., Ordon, F., Fahima, T., Korol, A., Saranga, Y., Krugman, T., 2021, Genomic architecture of phenotypic plasticity in response to water stress in tetraploid wheat, Int. J. Mol. Sci., 22(4):1723.
[16]Fu, Z., Jiang, J., Gao, Y., Krienke, B., Wang, M., Zhong, K., Cao, Q., Tian, Y., Zhu, Y., Cao, W., Liu, X., 2020, Wheat growth monitoring and yield estimation based on multi-rotor Unmanned Aerial Vehicle, Remote Sens., 12(3):508.
[17]Giraldo, P., Benavente, E., Manzano-Agugliaro, F., 2019, Worldwide research trends on wheat and barley: A bibliometric comparative analysis, Agronomy, 9:352.
[18]Govedarica, M., Ristic, A., Herbei M.V., Sala, F., 2015, Object oriented image analysis in remote sensing of forest and vineyard areas, Bulletin of UASVM Cluj-Napoca, Horticulture 72(2):362-370.
[19]Gowayed, S.M.H., El-Moneim, D.A., 2021, Detection of genetic divergence among some wheat (*Triticum aestivum* L.) genotypes using molecular and biochemical indicators under salinity stress, PLoS ONE, 16(3):e0248890.
[20]Grote, U., Fasse, A., Nguyen, T.T., Erenstein, O., 2021, Food security and the dynamics of wheat and maize value chains in Africa and Asia, Front. Sustain. Food Syst., 4:617009.
[21]Haas, M., Schreiber, M., Mascher, M., 2019, Domestication and crop evolution of wheat and barley: Genes, genomics, and future directions, J. Integr. Plant Biol., 61(3):204-225.
[22]Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001, PAST: Paleontological statistics software package for education and data analysis, Palaeontol. Electron., 4(1):1-9.
[23]Hara, P., Piekutowska, M., Niedbała, G., 2021, Selection of independent variables for crop yield prediction using artificial neural network models with remote sensing data, Land, 10:609.
[24]Herbei, M., Sala, F., 2016, Biomass prediction model in maize based on satellite images, AIP Conf. Proc., 1738:350009-1 – 350009-4.
[25]Herrera, J.M., Häner, L.L., Mascher, F., Hiltbrunner, J., Fossati, D., Brabant, C., Charles, R., Pellet, D., 2020, Lessons from 20 years of studies of wheat genotypes in multiple environments and under contrasting production systems, Front. Plant Sci., 10:1745.
[26]Ishaq, S.L., Seipel, T., Yeoman, C.J., Menalled, F.D., 2020, Soil bacterial communities of wheat vary across the growing season and among dryland farming systems, Geoderma, 358:113989.
[27]Jalli, M., Huusela, E., Jalli, H., Kauppi, K., Niemi, M., Himanen, S., Jauhiainen, L., 2021, Effects of crop rotation on spring wheat yield and pest occurrence in different tillage systems: A multi-year experiment in finnish growing conditions, Front. Sustain. Food Syst. 5:647335.
[28]Keller, T., Sandin M., Colombi, T., Horn, R., Or, D., 2019, Historical increase in agricultural machinery weights enhanced soil stress levels and adversely affected soil functioning, Soil Till. Res., 194:104293.
[29]Kraaijvanger, R., Sonneveld, M., Almekinders, C., Veldkamp, T., 2015, Comparison of methods to identify crop productivity constraints in developing countries. A review, Agron. Sustain. Dev., 35:625-637.
[30]Lv, Z., Liu, X., Cao, W., Zhu, Y., 2017, A model-based estimate of regional wheat yield gaps and water use efficiency in main winter wheat production regions of China, Sci. Rep., 7:6081.
[31]Mahallati, M.N., 2020, Chapter 9 - Advances in modeling saffron growth and development at different scales, Saffron, Science, Technology and Health Woodhead Publishing Series in Food Science, Technology and Nutrition, 139-167.
[32]Mandic, V., Krnjaja, V., Tomic, Z., Bijelic, Z., Simic, A., Muslic, D.R., Gogic, M., 2015, Nitrogen fertilizer influence on wheat yield and use efficiency under different environmental conditions, Chilean J. Agric. Res., 75(1):92-97.
[33]Meleha, A.M.I., Hassan, A.F., El-Bialy, M.A., El-Mansoury, M.A.M., 2020, Effect of planting dates and planting methods on water relations of wheat, Int. J. Agron., 2020:8864143.
[34]Mengistu, M., 2021, Review on the determinants of the market supply of wheat in Ethiopia, Int. J. Bus. Econ. Res., 10(3):94-98.
[35]Michel, L., Makowski, D., 2013, Comparison of statistical models for analyzing wheat yield time series, PLoS ONE, 8(10):e78615.
[36]Mouron, P., Calabrese, C., Breitenmoser, S., Spycher, S., Baur, R., 2016, Sustainability assessment of plant protection strategies in Swiss winter wheat and potato production, Agriculture, 6:3.
[37]Muazu, A., Yahya, A., Ishak, W.I.W., Khairunniza-Bejo, S., 2014, Machinery utilization and

production cost of wetland, direct seeding paddy cultivation in Malaysia, Agric. Agric. Sci. Procedia, 2:361-369.

[38]Mugiyo, H., Chimonyo, V.G.P., Sibanda, M., Kunz, R., Masemola, C.R., Modi, A.T., Mabhaudhi, T., 2021, Evaluation of land suitability methods with reference to neglected and underutilised crop species: A scoping review, Land, 10(2):125.

[39]Nabiollahi, K., Heshmat, E., Mosavi, A., Kerry, R., Zeraatpisheh, M., Taghizadeh-Mehrjardi, R., 2020, Assessing the influence of soil quality on rainfed wheat yield, Agriculture, 10:469.

[40]Nath Jha, R., Ansari, M.S., Thakur, M., Islam, M.M., Hossen, M.A., 2019, Study the impact of different agricultural machinery uses on wheat cultivation practices at Agricultural Machinery Testing and Research Centre (AMTRC), Sarlahi, Nepal, Eco-friendly Agril. J., 12(11):100-111.

[41]Ouaadi, N., Jarlan, L., Ezzahar, J., Zribi, M., Khabba, S., Bouras, E., Bousbih, S., Frison, P.-L., 2020, Monitoring of wheat crops using the backscattering coefficient and the interferometric coherence derived from Sentinel-1 in semi-arid areas, Remote Sens. Environ., 251:112050.

[42]Pal, P., Sharma, R.P., Tripathi, S., Kumar, C., Ramesh, D., 2021, Genetic algorithm optimized node deployment in IEEE 802.15.4 potato and wheat crop monitoring infrastructure, Sci. Rep., 11:8231.

[43]Paliwal, A., Jain, M., 2020, The accuracy of self-reported crop yield estimates and their ability to train remote sensing algorithms, Front. Sustain. Food Syst., 4:25.

[44]Pardey, P.G., 2011, A strategic look at global wheat production, productivity and R&D developments, Czech J. Genet. Plant Breed., 47(Special Issue):S6-S19.

[45]Parent, B., Bonneau, J., Maphosa, L., Kovalchuk, A., Langridge, P., Fleury, D., 2017, Quantifying wheat sensitivities to environmental constraints to dissect genotype x environment interactions in the field, Plant Physiol., 174:1669-1682.

[46]Popescu, A., 2018, Maize and wheat - top agricultural products produced, exported and imported by Romania, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 18(3):339-352.

[47]Popescu, A., Dinu, T.A., Stoian, E., 2018, Sorghum - an important cereal in the world, in the European Union and Romania, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 18(4):271-284.

[48]Rasband, W.S., 1997, Image J. U. S. National Institutes of Health, Bethesda, Maryland, USA, pp. 1997-2014.

[49]Rawashdeh, H.M., Sala, F., 2013, The effect of foliar application of iron and boron on early growth parameters of wheat (*Triticum aestivum* L.), Res. J. Agric. Sci., 45(1):21-26.

[50]Rawashdeh, H.M., Sala, F., 2014, Foliar application of boron on some yield components and grain yield of wheat, Academic Research Journal of Agricultural Science and Research, 2(7):97-101.

[51]Rispail, N., Montilla-Bascon, G., Sanchez-Martin, J., Flores, F., Howarth, C., Langdon, T., Rubiales, D., Prats, E., 2018, Multi-environmental trials reveal genetic plasticity of oat agronomic traits associated with climate variable changes, Front. Plant Sci., 9:1358.

[52]Sadras, V.O., Reynolds, M.P., de la Vega, A.J., Petrie, P.R., Robinson, R., 2009, Phenotypic plasticity of yield and phenology in wheat, sunflower and grapevine, Field Crop Res., 110(3):242-250.

[53]Sala, F., Boldea, M., 2011, On the optimization of the doses of chemical fertilizers for crops, AIP Conf. Proc., 1389:1297-1300.

[54]Schirrmann, M., Giebel, A., Gleiniger, F., Pflanz, M., Lentschke, J., Dammer, K.-H., 2016, Monitoring agronomic parameters of winter wheat crops with low-cost UAV imagery, Remote Sens., 8(9):706.

[55]Sharma, N., Kumar, S., Mani, N., 2020, Analysis on present mathematical model for predicting the crop production, International Journal of Innovative Technology and Exploring Engineering (IJITEE), 9(12):168-170.

[56]Shiferaw, B., Smale, M., Braun, H.J., Duveiller, E., Reynolds, M., Muricho, G., 2013, Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security, Food Sec., 5:291-317.

[57]Shin, T., Ko, J., Jeong, S., Shawon, A.R., Lee, K.D., Shim, S.I., 2021, Simulation of wheat productivity using a model integrated with proximal and remotely controlled aerial sensing information, Front. Plant Sci., 12:649660.

[58]Sud, U.C., Ahmad, T., Gupta, V.K., Chandra, H., Sahoo, P.M, Aditya, K. Singh, M., Biswas, A., 2015, Gap analysis and proposed methodologies for estimation of crop area and crop yield under mixed and continuous cropping, Global Strategy Working, 4:88 pp.

[59]Tabak, M., Lepiarczyk, A., Filipek-Mazur, B., Lisowska, A., 2020, Efficiency of nitrogen fertilization of winter wheat depending on sulfur fertilization, Agronomy, 10:1304.

[60]Vavlas, N.-C., Waine, T.W., Meersmans, J., Burgess, P.J., Fontanelli, G., Richter, G.M., 2020, Deriving wheat crop productivity indicators using Sentinel-1 time series, Remote Sens., 12(15):2385.

[61]Wang, X., Cai, D., Grant, C., Hoogmoed, W.B., Oenema, O., 2015, Factors controlling regional grain yield in China over the last 20 years, Agron. Sustain. Dev. 35:1127-1138.

[62]Wang R., Zhang L., Dong, L., Lu X., 2016, The development and application of crop evaluation system based on GRA, Math. Probl. Eng., 2016:1815240.

[63]Whetton, R.L., Zhao, Y., Nawar, S., Mouazen, A.M., 2021, Modelling the Influence of soil properties on crop yields using a non-linear NFIR model and laboratory data, Soil Syst., 5:12.

[64]Wolfram, Research, Inc., Mathematica, Version 12.1, Champaign, IL (2020).

[65]Xu, A., Li, L., Xie, J., Wang, X., Coulter, J.A., Liu, C., Wang, L., 2020, Effect of long-term nitrogen addition on wheat yield, nitrogen use efficiency, and

residual soil nitrate in a semiarid area of the Loess Plateau of China, Sustainability, 12:1735.

[66]Zhao, Y., Potgieter, A.B., Zhang, M., Wu, B., Hammer, G.L., 2020, Predicting wheat yield at the field scale by combining high-resolution Sentinel-2 satellite imagery and crop modelling, Remote Sens., 12:1024.