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USING SATELLITE DATA TO IDENTIFY HETEROGENEITY IN WHEAT CROP DEVELOPMENT FROM ORGANIC EINKORN

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Abstract
The BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical) scale was used to determine crop phenology. Ground data were collected in phases BBCH 29, 45 and 75. In phase BBCH 29, zones with three differences in the vegetation index NDVI were determined, respectively NDVI – 0.86, 0.74 and 0.63. In the field, in the three zones with different NDVI values, a permanent plot of 10 × 10 m was organized, at the end of which markers were placed, permanent plots were organized and GPS coordinates were taken. From these four permanent plots, during the phenological phases BBCH 29, 45 and 75, biometric measurements were performed. Statistical processing of the data proved the differences in the field. This suggests that vegetation indices can be generated and studied from data generated by the Sentinel-2 satellite to describe crop condition as described by land mass values.

Keywords: *Remote sensing, Sentinel-2, Organic farming, Einkorn, GIS*

INTRODUCTION

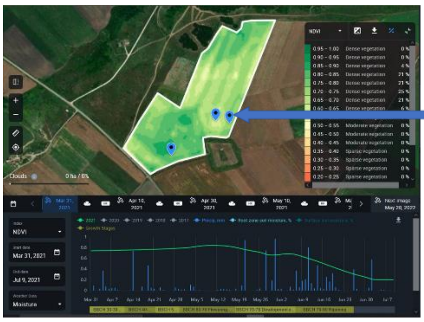
Einkorn wheat (Triticum monococcum L. subsp. monococcum) was first domesticated in Southeastern Turkey during the Pre-Pottery Neolithic era, subsequently spreading through the Near East, the Balkans, Central and Mediterranean Europe, North Africa, and eventually reaching Western and Northern Europe. Its cultivation had a significant impact on the development of agriculture in these regions before it was replaced by bread wheat. Today, interest in this crop has been renewed due to its nutritional qualities, adaptability to low-input farming, high resilience to pests and diseases, and suitability for organic agriculture (Zaharieva & Monneveux, 2014).

Satellite platforms have become increasingly accessible, with diverse applications in various fields such as forest monitoring, wetland monitoring, snow cover and glacier monitoring, pollution monitoring of the atmosphere and Earth, burned area monitoring, as well as lunar surface studies (Dimitrov et al., 2018; Spasova et al., 2018; Ivanova et al., 2019; Stankova, N. 2023; Spasova & Avetisyan 2023; Trenchev et al., 2023; Ivanov & Filchev 2024). In agriculture, satellite data is utilized to track various crop parameters like LAI, fAPAR, fCover, and assess the biochemical variables within the crops (Dimitrov et al., 2019; Kemenova & Dimitrov 2021). Satellite data is also used for differentiating between types of agriculture. Data from Sentinel 2, with its generated vegetation indices, can capture the differences in growth dynamics and development of cereal crops cultivated in organic, biodynamic, and conventional fields, aiding in distinguishing between different agricultural practices (Atanasova et al., 2021).

This study aims to establish the possibilities of using satellite data to determine heterogeneity in an organic einkorn crop. A second objective of this research is also to establish the possibility of determining yields.

MATERIALS AND METHODS

The study was conducted during the 2020-2021 agricultural year in the area of Byala Reka village, Parvomai municipality, in central southern Bulgaria. The study was conducted in an organically certified einkorn production field of 13.6 hectares. To determine the phenology of the crop, the BBCH scale was used (Meier, U. 2001). Ground data were collected in phases BBCH 29, 45 and 75. In the BBCH 29 phase, zones were defined with three differences in the vegetation index NDVI, respectively NDVI – 0.86, 0.74 and 0.63. The EOS Crop-monitoring platform Fig. 1 was used to generate NDVI. The pixels are 20 × 20 m in size, and in each of them a permanent test plots with dimensions of 10 × 10 m Fig. 2 is organized at the end of which markers are placed and GPS coordinates are taken. From these four permanent plots, during the phenological phases BBCH 29, 45 and 75, all plants were taken from 4 meter plots measuring 0.25 × 0.25 m, the einkorn plants in the meter plots were first counted, weighed, dried and weighed again (dry matter). Counting of the weeds is also carried out, as from the 4 meter plots of 0.25 × 0.25 m the weeds are weighed, dried and weighed again (dry in th). The obtained values are recalculated to 1 m^2 by multiplying by four. Biometric studies were done according to the methodology of Shanin (1977).



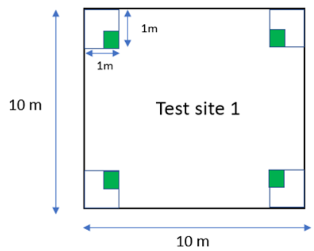


Figure 1 Fild in EOS Crop-monitoring platform BBCH 29 *Fig. 2 Layout of the sample plots and quadrats*

Remote sensing data and methods

The platform for agricultural crop monitoring that uses data from the EOS Crop-monitoring (EOS Data Analytics inc., CA, USA) is a specialized Sentinel-2 satellite. The *.kmz file created in Google Earth is imported into it, and a file with the name of the field is created in it. After creating the field vector files, the corresponding field to be surveyed is selected and after its appearance on the screen, the date of sowing and the date of harvesting, respectively, are entered. The function for generating VI NDVI is set in the system. After calculating the NDVI index, the function is set to calculate the percentage area distribution of each NDVI value in the surveyed field. The resulting images are saved in *.TIF files. Images for each of the phenophases studied are downloaded from the adjacent image timeline. The created polygon is exported to a *.kmz file, which is used when working with the Land Viewer platform (EOS Data Analytics inc., CA, USA) and ArcGis Pro software.

Statistical analysis

Multifactor analysis of variance was applied to establish statistically reliable relationships between the studied factors and differences between the tested variants. The data were recorded and processed with the statistical package SAS JMP© Statistical Software, with which a Fit Model analysis was performed to prove the differences statistically.

RESULTS

Table 1 presents the results of the studied indicators during the heading stage (BBCH 29). The values of the vegetation index NDVI were obtained and analyzed in three statistically significant differences: 0.86, 0.74, and 0.63. The average NDVI value for the field is 0.74, with low variation (VC% = 2.70%). The fresh biomass weight of the plants in the first difference has the highest values compared to the other two differences. On average, the einkorn biomass in the field is 27.48 g/m^2 with an average variation (VC% = 19.07%). The ratio of dry matter per square meter is similar among all three differences, with the highest value in the first difference at 14.59 g/m^2. No statistically significant differences were found in terms of dry matter percentage. The values in all three differences vary slightly around the average value for the crop.

Analyzing the results for the number of einkorn plants per square meter at stage BBCH 29, a statistically significant difference is found in the second difference, with the highest number of plants (247). The third difference occupies an intermediate position with 239 plants. The lowest value of the studied indicator is found in the first difference (207 plants). The higher NDVI values of fresh and dry biomass in the first difference are negatively correlated with the number of plants per square meter, suggesting that the less dense crop allows for more vegetative mass formation.

Table 1 also provides data on the available fresh and dry biomass of the weeds, as well as their dry matter percentage and number per square meter. In the conditions of organic farming, weeds constitute a significant portion of the total green plant mass during stage BBCH 29.

Table 1 Results from fresh weight, dry weight, percentage of dry matter, and number of plants and weeds in a organic einkorn production plot during the BBCH 29 phase

Variation	NDVI	Fresh weight of plants (g/m^2)	Dry weight of plants (g/m^2)	% dry matter in plants	Number of plants (m^2)	Weed fresh weight (g/m^2)	Dry weight of weeds (g/m^2)	% dry matter in weeds	Number of weeds (m^2)	Fresh weight of green mass (g/m^2)
т1	0.86 a	39.88 a	14.59 a	36.46 a	207 b	36.55 b	8.54 a	23.21 a	56 c	76.43 a
т2	0.74 b	26.54 b	9.67 b	36.42 a	247 a	43.94 a	10.16 a	23.23 a	138 b	70.48 b
т3	0.63 c	16.02 c	5.73 c	35.80 a	239 ab	35.21 b	9.03 a	25.56 a	160 a	51.23 c
mean	0.74	27.48	10	36.22	231	38.57	9.24	24	118	66.05
LSD	0.05	8.34	2.55	5.83	37.53	3.85	2.67	6.13	17.44	4.72
VC%	2.7	19	16	10.08	10.17	6.33	18.18	16	9.25	4.48

Since the vegetation index NDVI reads the green biomass of the crop, the value of the index represents a sum of the green biomass of the einkorn and the green biomass of the weeds. Statistically proven differences between the differences in fresh mass of weeds have been established. The highest values were reported in the second difference - 43.94 g/m^2, followed by the first difference 36.55 g/m^2 and the third difference 35.21 g/m^2. The dry mass of weeds has the same proportional ratios in all three differences, as well as the fresh mass. There are no proven differences in the percentage of dry matter in weeds and einkorn in the three differences. The same relationship is observed in the number of weeds as in the plants, namely in the differences with higher values of the fresh mass, a smaller number of weeds is established. The most representative information about the available green biomass per m^2 in the investigated phase is given by the sum of the indicators in plants and weeds. The average fresh weight of plants and weeds in a einkorn crop is 66.05 g/m^2. The variation of the fresh weight is weak (VC% = 4.48%). The highest values of the fresh weight of the green biomass were established in the first difference 76.43 g/m^2, followed by the fresh mass in the second difference 70.48 g/m^2 and the third difference 51.23 g/m^2.

Table 2 presents data on the amount of fresh mass of einkorn and weeds per m^2 in a organic einkorn crop during the heading phase (BBCH 45). As in the BBCH 29 phase, the average weight of the fresh green mass of einkorn lags behind the fresh weight of weeds. This trend is most pronounced in the first difference. The fresh weight of einkorn in the heading phase is statistically different in the three measurement points. The highest values are in the first difference - 154.68 g, and the lowest in the third difference (87.60 g). Based on the LSD values, the values of the second difference occupy an intermediate group - ab. The variation of the indicator is strong (VC%=26.75%). The percentage of dry matter in einkorn is statistically highest in the first difference (40.03%), while there are no proven differences in the other two differences. In weeds, it is proven to be higher in the first and second difference and with the lowest values in the third. The total% of dry matter in plants and weeds has no proven differences between differences. The number of einkorn plants and weeds, as well as their total number, is proven to be smaller in the first difference and larger in the second and third difference. The trend is the opposite of the fresh and dry weight of plants and weeds. The established is explained by the fact that a rarer crop has created more fresh and dry mass of einkorn plants and weeds.

Table 2 Results from the fresh, dry weight, percentage of dry matter, and number of plants and shoots in organic einkorn production cultivation at the regrowth phase BBCH 45

Variation	Fresh weight of plants (g/m^2)	Dry weight of plants (g/m^2)	% dry matter in plants	Number of plants (m^2)	Weed fresh weight (g/m^2)	Dry weight of weeds (g/m^2)	% dry matter in weeds	Number of weeds (m^2)	Fresh weight of green mass (g/m^2)
т1	154.68 a	57.79 a	40.03 a	207 b	293.01 a	69.79 a	23.87 a	56 b	447.69 a
т2	110.04 ab	38.11 b	35.59 b	247 a	83.74 b	21.22 b	25.38 a	136 a	193.78 b
т3	87.60 b	30.47 c	36.35 b	239 a	76.04 b	15.73 c	20.70 b	160 a	163.64 b
mean	117.44	42.12	37.33	231	150.93	35.58	23.32	117	268.37
LSD	50.2	3.39	11.53	20.02	17.09	1.51	1.65	50.94	57.79
VC%	26.75	5.03	1.93	5.42	7.09	2.64	4.42	27.21	13.47

Table 3 presents the investigated indicators during the milk ripeness stage (BBCH 75). The data show an increase in the values of the indicators compared to the previous two phases – budding and flowering, which is fully explainable since the milk ripeness stage is already in an advanced stage of development. The average value of the fresh weight of einkorn (218.23 g/m^2) for the three differences is higher than the average value of the fresh weight of weeds (163.58 g/m^2). During this stage of development, einkorn out-compete weeds, with most of them being in early stages of development. The highest values of fresh weight were found in the first difference (253.93 g/m^2), while the lowest values were found in the third difference (173.52 g/m^2). The values of the indicator in the second difference occupy a middle position (227.24 g/m^2). The dry weight of einkorn in m2 during milk ripeness maintains the same ratio as the fresh weight. The percentage of dry matter in einkorn averaged for the phase is 52.30%, which shows that the water content in the plants has significantly decreased. It is assumed that most of them have yellowed and ripened. Comparing the data from einkorn with the percentage of dry matter in weeds, it becomes clear that it is 17.12% lower, with an average value of 35.18%. This shows that the share of green mass during this phase is mainly due to weed vegetation.

Table 3 Results from fresh weight, dry weight, percentage of dry matter, and number of plants and weeds in a organic einkorn production plot during the milk ripeness stage BBCH 75

Variation	Fresh weight of plants (g/m^2)	Dry weight of plants (g/m^2)	% dry matter in plants	Number of plants (m^2)	Weed fresh weight (g/m^2)	Dry weight of weeds (g/m^2)	% dry matter in weeds	Number of weeds (m^2)	Fresh weight of green mass (g/m^2)
т1	253.93 a	134.42 a	52.97 a	207 b	207.21 a	84.66 a	40.96 a	27 b	461.14 a
т2	227.24 ab	116.93 ab	51.68 a	247 a	157.12 b	50.55 b	32.69 ab	52 a	384.36 b
т3	173.52 b	91.15 b	52.25 a	239 a	126.41 c	39.90 c	31.93 b	56 a	299.93 c
mean	218.23	114.17	52.3	231	163.58	58.37	35.18	45	381.81
LSD	71.55	38.35	6.15	26.8	22.85	9.08	8.86	12.09	72.5
VC%	20.52	21.02	7.36	7.26	8.74	9.75	15.75	16.69	11.88

This trend fully explains the convergence of the NDVI vegetation index step in the three differences of the einkorn plot and indicates the ripening of the cultural plants. On the other hand, the results fully explain the behavior of the soil mass in the organic einkorn production plot in the specific meteorological conditions of the year. During the period of May 1st to June 1st in the region, 41 liters of rain fell, which significantly delayed the ripening of the einkorn and stimulated secondary weed growth. According to the number of einkorn plants, weeds, and total plants, the trend observed in the previous two phases is maintained. In the first difference, where the highest values of fresh and dry weight are found, the number of plants and weeds is statistically proven to be the smallest.

Table 4 presents the results of the indicators related to productivity and the yield obtained in a einkorn plot grown in organic agriculture. The data are from the three differences in the field, established with the NDVI index at the end of the phenological phase of budding. The height of the plants is an indicator that is not an element of productivity, but is indirectly related to it. It has been established that a higher sowing correlates positively with a higher yield (Dimova 2015; Bonchev 2017). In the specific study, the height of the plants is the highest in the first difference - 114.25 cm. Based on the LSD values, the second difference occupies an intermediate group, while the third is the lowest with an average height of 95.30 cm. Analyzing the values of the yield, it is also proven to decrease from the first to the third difference, which suggests that there is a positive correlation between the height of the plants. The length of the einkorn class in the three differences is from 4.81 cm to 4.86 cm, with no established differences between the three differences. From the data in Table 7, it can be seen that there is no direct correlation between the length of the class and the decrease in yield in the differences. The indicator itself is a more constant value in grain crops, including einkorn (Bonchev 2017). According to the number of class-bearing stems per m^2, it is proven that there are differences between the three differences. The largest number of them is found in the first difference - 331.20, followed by the second - 296.40. The smallest number of them is found in the third difference - 262.90. The decrease in their number by differences follows the decrease in yield in them, which suggests a strong positive correlation between the two indicators. Such a correlation has been established by other researchers (Dimova 2015).

Table 4. Results from indicators related to productivity and yield of an einkorn plot in organic agriculture

Variation	Plant height (cm)	Length of ear of wheat (cm)	Number of spike-bearing stems of m^2	Number of grains in the class	Weight of grains in one class (g)	Grain weight per plant (g)	Mass per 1000 grains (g)	Yield kg/da
т1	114.25 a	4.86 a	331.20 a	18.70 a	0.78 a	1.25 a	41.41 a	265 a
т2	104.66 ab	4.85 a	296.40 b	14.13 b	0.49 b	0.58 b	35.59 ab	240 b
т3	95.30 b	4.81 a	262.90 c	13.79 b	0.45 b	0.51 b	30.83 b	215 c
mean	104.74	4.84	296.83	15.54	0.57	0.78	35.94	240
LSD	12.57	1.09	33.34	1.99	0.14	0.23	7.80	23.46
VC%	7.50	13.84	7.03	7.98	15.79	17.95	13.60	6.11

In the specific study, the height of the plants is the highest in the first difference - 114.25 cm. Based on the LSD values, the second difference occupies an intermediate group, while the third is the lowest with an average height of 95.30 cm. Analyzing the values of the yield, it is also proven to decrease from the first to the third difference, which suggests that there is a positive correlation between the height of the plants. The length of the einkorn class in the three differences is from 4.81 cm to 4.86 cm, with no established differences between the three differences. From the data in Table 4, it can be seen that there is no direct correlation between the length of the class and the decrease in yield in the differences. The indicator itself is a more constant value in grain crops, including einkorn (Bonchev 2017). According to the number of class-bearing stems per m^2, it is proven that there are differences between the three differences. The largest number of them is found in the first difference - 331.20, followed by the second - 296.40. The smallest number of them is found in the third difference - 262.90. The decrease in their number by differences follows the decrease in yield in them, which suggests a strong positive correlation between the two indicators. Such a correlation has been established by other researchers (Dimova 2015).

The results for the number of grains in the class show that based on the LSD values, there are differences between the first difference and the others. The difference between the second and third is insignificant and they fall statistically proven in one group (b). The largest number of grains in the class is established in the first difference, with an average of 18.70. The difference in yield between the second and third differences is not due to the number of grains in the class. The largest number of grains in the class is established in the first difference, with an average of 18.70. The weight of the grain in the class is from the indicators that are directly related to yield, but here also observed insignificant differences between the second and third differences. The heaviest classes are in the first difference - 0.78 g, while in the second and third differences, the differences are insignificant, respectively, with an average of 0.49 g and 0.45 g. Regarding the indicator weight of the grain from the plant, the same dependence is established as for the indicator weight of the grain from the class. The mass of 1000 grains in the three differences varies, with an average (VC%=13.60%), from 41.41 g in the first difference to 30.83 g in the third difference. The decrease in the size of the grain by differences is in a direct correlation with the decrease in yield in the three differences. The reported yield from dka in the einkorn plot, grown in the conditions of organic agriculture, is statistically proven to be different in the three differences. The average yield for the field is 240 kg/da, with the highest being in the first difference - 265 kg/da and the lowest in the third - 215 kg/da.

CONCLUSION

In conclusion, it can be summarized that the organic einkorn production plot is a complex system consisting of a diverse composition of plants and weeds, in different proportions depending on the differences in sowing and the stage of einkorn development. Based on the generated values of the vegetation index NDVI (BBCH29), the differences in sowing vary from well-groomed parts with potential for high yield to weaker areas. The obtained yield and values of the elements of productivity follow the established differences during the stages of development from budding to milk ripeness. The statistical processing of the data proves that the differences in sowing exist. This provides a basis for generating and investigating vegetation indices that describe the state of the sowing, just as the values of the soil mass do.

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