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Article

# Remote Sensing Data as an Effective Tool for Evaluation of Ancient Khorasan and Modern Kabot Spring Wheat Varieties under Different Tillage

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**Abstract:** With the changing climate, there is an increasing emphasis on drought-resistant varieties including the ability to maintain quality production. As there is also interest in ancient wheat varieties, the aim of this study was to evaluate the ancient Khorasan (Kamut®) with the modern Kabot spring wheat variety using remote sensing data. Images from unmanned aerial vehicles during four growing seasons were processed. Based on vegetation indices, the growth of these varieties and their response to meteorological conditions were evaluated, as well as the ability to resist drought and higher temperatures with respect to specific soil conditions under conventional (CT), minimum (MTC) and minimization (MTD) tillage. It was found that the Khorasan had the lowest values of the vegetation indices on the CT variant in the dry years 2022 and 2023. On the contrary, in the previous wet years 2020 and 2021, both varieties showed similar results. Regarding to water stress, the CT variant was also the least suitable for ancient Khorasan (average CWSI = 0.38). On the contrary, this variant seems to be suitable for the modern Kabot variety (CWSI = 0.29), while no significant difference between tillage variants was found for this variety. In general, water stress was easily detectable by the observed parameters in the growth phase of stem elongation ( $R^2$  up to 0.88).

**Keywords:** Khorasan wheat; soil tillage; UAV; spectral indices

## 1. Introduction

Wheat belongs to one of the world's most important commodities and has been a basic strategic food for more than 800 years [1,2]. According to grain acreage and total production volume, wheat is the second largest grain worldwide. Compared to the previous year, there was an increase in production in 2022/23 by about four million tons [3]. However, as the population grows, so does its consumption. The demand for plant production will increase by up to 70 % by 2050, as show the predictions [4]. According to Singh et al. [5], climate change and the increasing pressure of diseases and pests threaten the production of wheat and other important crops every year. Kurunc et al. [6] stated, that all the mentioned stress factors significantly affect the losses of the average yield by more than 50 % of the agricultural production all over the world. The most important factor that influence plant production and yield is water [7]. Therefore, the knowledge about the influence of water in the form of precipitation or artificial irrigation on plant growth in different growing conditions (habitat, method of tillage) is essential [6]. It is also important to choose a suitable drought-resistant variety, as research points out Nakforosh et al. [8], when Khorasan wheat (*T. turanicum*) responds to reduced annual rainfall during the growing season by having a later canopy. However, its high yield stability provides an underutilized genetic potential that can be a source of interesting adaptation processes for future breeding material that will have improved properties with respect to drought tolerance. Modern wheat varieties, such as the Kabot variety used in our case, are bred for high yields.

Nevertheless, only sometimes high inputs are needed to achieve them, and in the case of genetic material, they are narrowly homogeneous and do not provide a wide range of different adaptive properties [9,10]. In today's changing environment, the necessary diversity of species and varieties, which store valuable genetic material, is preserved [11]. A plant is a complex organism, constantly forced to respond to fluctuating water intake and other factors. As a result of these abiotic stresses, plant performance deteriorates, resulting in loss of vitality and lower yield [12]. It is therefore necessary to monitor plant vitality in real time, which can be done noninvasively for the environment using remote sensing [13].

Currently, unmanned aerial vehicles (UAVs) equipped with multispectral or thermal camera are very useful tool for monitoring of crop conditions in precision agriculture [14]. The data obtained from these devices can quickly and effectively provide information on the occurrence of diseases and pests [15]. Virnodkar et al. [16] reported, that the obtained data can also be used to predict yield or detect water stress during vegetation. The spectral properties of plants are significantly influenced by the content of chlorophyll in the plant tissue, which can be well monitored in the near infrared band [17]. The condition of the plant canopy is most often evaluated using vegetation indices, as a ratio of reflectance in two or more bands. Vegetation indices are mostly based on strong reflectance in the near-infrared part and strong absorption in the red part of the electromagnetic spectrum [18], as e.g., Normalized Difference Vegetation Index (NDVI). This vegetation index is generally used to evaluate the structure, vitality and various biophysical processes of plants joint with health status [19]. In addition, Domínguez et al. [20] stated that the advantage of NDVI is its easy readability, as the obtained values clearly indicate the state of the canopy. In general, values below 0.25 indicate bare soil; higher values, on the other hand, indicate a different level of plant coverage and the vitality of the monitored crops, the most vital plants then have a value as close as possible to 1 [2]. Green NDVI (GNDVI), developed by Gitelson et al. [21], uses the near-infrared and green electromagnetic parts of the spectrum in different proportions. This vegetation index is commonly used for a wide range of crops such as garlic, grapevines, potatoes, oats, and others [22] for the purpose of chlorophyll and nitrogen content monitoring in green vegetation. Mangeva et al. [23] mentioned, that this index is characterized by its high sensitivity to chlorophyll and reduces non-photosynthetic effects. In addition, it is also used for valuable and complex information for landscape evaluation [24]. Another index that enables to measure the chlorophyll content is Chlorophyll Index Red Edge (CIR), which is much more sensitive even to small changes in the content in the canopy and the detection of senescent processes [25]. Water stress is an increasingly monitored parameter in plants, which is often calculated by Crop Water Stress Index (CWSI) designed by Idso et al. [26]. CWSI is normalized by the temperature difference between the canopy and the air by the vapor pressure deficit (VPD), which allows comparison of water status of the plant in a wide range of crops (vines, wheat, rice, sunflower, corn or cotton) under different terms and conditions [27]. After editing the index by Jonesem et al. [28], reference temperatures  $T_{dry}$  and  $T_{wet}$  were added for more accurate interpretation of the results. Many authors stated CWSI potential for crop irrigation [29]. However, the best choice of thermal indices for accurate information on water stress is still unclear [30].

Tillage is an important part of agriculture. It is characterized by many field operations that fundamentally affects the chemical and physical properties of the soil and thus the subsequent vitality, growth and crops [31]. The most common tillage includes the conventional tillage (CT), where the basic working tool is a plow, which can turn the soil well and at the same time loosen it, which increases humus and provides mineral contributions [32]. Almagro et al. [33] warns, that intensive soil cultivation results in a greater sensitivity of the soil to increasingly extensive climate changes. Melero et al. [34] showed that CT improves bulk soil mass after harvest the most. At the same time, they also pointed out that CT prevails especially in areas that have a larger amount of precipitation during the year. In some areas, for example in the Mediterranean, this method is not suitable and has a negative effect on the organic fractions of the soil and its biochemical quality [34]. Conventional tillage is the most widely used method in the Czech Republic. In 2016, 66.5% of arable land was cultivated with a plow, 32.1% with conservation technology and 1.4% with zero tillage [2]. On the other hand, according to Statistical yearbook of the environment of the Czech Republic 2021

[35] the acreage of agricultural land in organic farming and the number of ecologically managed entities are constantly growing on average by 0.5% share of the agricultural land fund.

Minimum tillage (MTC) is based on reducing the depth or intensity of processes, at the same time, this method is characterized by a reduction in the number of individual operations [36]. In Cheřan et al. [37] study, MTC minimum treatment (chisel treatment) in maize cultivation can be considered comparable to CT, as the results showed negligible differences between yields. The research of Chiriřa et al. [38] pointed to good yields in winter wheat with MTC when this variant was treated with high doses of fertilization. Minimalization tillage (MTD) with the use of a disc cultivator is another alternative method of tillage. According to Özpınar & ay [39], MTD can ensure a higher rate of bulk density than CT during wheat cultivation. They also found out that at the same time, there were differences in hydraulic conductivity (Ks) during vegetation, when Ks was higher in MTD than in CT, on the contrary, during harvest, Ks was higher in CT than in MTD. řıp et al. [40] stated, that minimal tillage is becoming more and more popular in the Czech Republic, especially in areas with higher heat and dryness, and lighter soil. Different tillage methods have their advantages and disadvantages. In general, it is important to choose one that suits the current requirements and site-specific conditions, as it affects the physical properties of the soil, such as bulk density of the soil, a parameter often used to de-scribe levels of soil compaction [27,41].

Therefore, the objective of this study was to assess Khorasan and Kabot spring wheat varieties using remote sensing data during the entire four growing seasons with different meteorological conditions and to evaluate the growth of these varieties with respect to specific soil conditions under conventional, minimum and minimalization tillage.

## 2. Materials and Methods

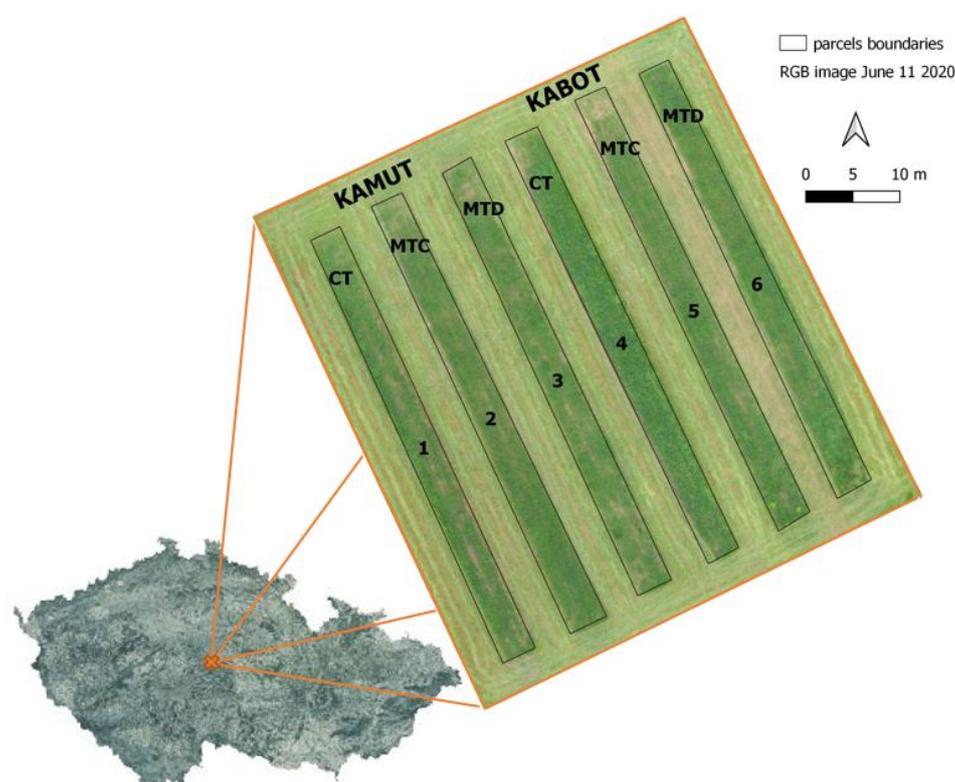
### 2.1. Experimental plot design

The study was undertaken from 2020 to 2023, four entire growth seasons, in six regular plots of 4 x 50 m near enovice (N 49°47'42.78", E 15°6'35.94"), Central Bohemia region in the Czech Republic. The average annual temperature was between 6 and 7 degrees Celsius. The average annual precipitation was between 650 and 750mm. Monthly temperatures and precipitation for selected years are given in Table 1. The experimental area had a southeastern aspect with a 2.63° slope and an average elevation of 481 m a.s.l. The soil type was Cambisol, according to the World Reference Base (WRB), containing 15.1% clay, 30.9% silt, 9.2% very fine sand, 14.3% fine sand, 12.1% medium sand, 9.4% coarse sand, and 9% very coarse sand. Soil texture determination was performed on a Horiba LA-960 device (laser diffraction, dry dispersion). The soil had low levels of threat from compaction and wind erosion. Before the plot establishment, there was a long-term permanent grassland. The experimental area was divided into six plots, each 4 x 50 m (200 m<sup>2</sup>) in size, with a 4 m wide handling gap in between. First wheat variety Khorasan (Kamut®–*Triticum turgidum* ssp. *Turanicum*) was sown in one-half of the trial area (plots 1–3) and the second wheat variety Kabot (*Triticum aestivum*) in the other half (plots 4–6). The results from 1–6 plots are sorted according to the variants, where 1 and 4 were cultivated using conventional tillage with moldboard plowing at a depth of 20–25 cm, 2 and 5 were cultivated with minimum tillage using a colter cultivator twice (at a depth of 15 cm), and 3 and 6 were cultivated with minimization tillage using a disc cultivator twice (at a depth of 12 cm) (see Figure 1). Machines used for soil tillage were as follows: CT– moldboard plow, manufacturer: ROSS UNIVERSUM s.r.o., type: 5–PHX–35; MTC– coulter cultivator, manufacturer: OpaLL–AGRI s.r.o., type: MERKUR II. (4m); MTD– disc cultivator, type: BDT (4m).

**Table 1.** Average monthly temperatures and the sum of precipitation during the growing seasons of the monitored crops.

Month	Average temperature (°C)				Sum precipitation (mm)			
	2020	2021	2022	2023	2020	2021	2022	2023
April	9.8	5.1	6.0	6.2	17.27	13.71	39.88	83.82
May	11.3	10.2	14.0	12.4	166.64	35.3	43.12	35.78

<b>June</b>	15.7	19.8	18.3	16.5	206.23	144.53	86.84	45.77
<b>July</b>	18.3	19.4	18.2	19.4	136.65	135.36	58.47	68.27
<b>August</b>	18.0	16.7	18.7	18.5	148.48	174.76	117.32	140.37



**Figure 1.** Experimental plot according to varieties and tillage variants (CT—conventional tillage; MTC—minimum tillage; and MTD—minimization tillage).

## 2.2. Agrotechnical operations

Sowing of Khorasan and Kabot spring wheat varieties took place on 12.4. in 2020 27.4. in 2021, 22.4.2022 in 2022 and 8.5. 2023. After leveling the soil surface using harrows, the NPK fertilizer was manually scattered on the individual plots at a rate of  $200 \text{ kg}\cdot\text{ha}^{-1}$  (4 kg per plot). Further fertilization using NPK took place during the tillering of crops (end of May). Herbicide Mustang™ Forte (CORTEVA™ agriscience) was applied against the developed dicotyledonous weeds 14 days after sowing. A dose of  $200 \text{ kg}\cdot\text{ha}^{-1}$  of ammonium saltpeter with limestone (LAV) fertilizer was applied manually during elongation growth stage. The crop was harvested using the FORTSCHRITT E516B or New Holland CX 8080 combine harvesters for individual plots. The combine harvester hopper was emptied onto an unfolded tarpaulin, and the contents of each plot were separated and weighed.

## 2.3. UAV campaigns

UAV campaigns corresponding to the main growth phases of spring wheat were carried out in four growing seasons 2020–2023. Meteorological and phenological information at the time of scanning is given in Table 2. Fixed wing eBeeX drone equipped with two types of camera payloads—multispectral MicaSense RedEdge MX (AgEagle Aerial Systems Inc., Wichita, KN, USA) and thermal Duet T dual camera (senseFly SA, Route de Geneve 38, Cheseauxsur- Lausanne, Switzerland), comprised an infrared sensor developed by FLIR technology and S.O.D.A. camera in visible part of electromagnetic spectra for reference of thermal sensor, were used for scanning the experimental area (detail in Table 3).

**Table 2.** Meteorological and phenological information at the time of scanning.

Date of scanning	Growth stage	Temperature in time of measurement (°C)
18 May 2020	BBCH 25 tillering	18.2
11 June 2020	BBCH 35 stem elongation	18.4
2 July 2020	BBCH 68 flowering	20.9
14 July 2020	BBCH 75 spikes forming	24.5
24 May 2021	BBCH 26 tillering	11.8
23 June 2021	BBCH 49 end of stem elongation	21.2
8 July 2021	BBCH 67 flowering	19.7
21 July 2021	BBCH 79 spikes forming	19.2
16 May 2022	BBCH 25 tillering	26.3
8 June 2022	BBCH 38 stem elongation	23.4
13 July 2022	BBCH 69 flowering	23.1
30 May 2023	BBCH 25 tillering	19.9
13 June 2023*	BBCH 35 stem elongation	20.5
11 July 2023	BBCH 68 flowering	29.5

\* Measured only with multispectral Micasense RedEdge MX camera, not with Duet T camera due to bad meteorological conditions.

Stable conditions for the entire campaign were ensured by choosing calm days. The crop scanning was always done at the same time around noon when the sun was in nadir. The flight parameters and postflight corrections were set in eMotion SW, following the sensor producer's recommendations to ensure good results for deriving the final product as spectral indices or orthophoto for data analysis.

**Table 3.** Spectral properties of sensors used in this study, setting flight parameters and spatial resolution of the resulting images.

Sensor/Camera	MicaSense RedEdge MX	S.O.D.A. / DuetT	IR sensor / DuetT
BLUE (nm)	475 (20)	450 (100)	-
GREEN (nm)	560 (20)	520 (100)	-
RED (nm)	668 (10)	660 (130)	-
RED EDGE (nm)	717 (10)	-	-
NIR (nm)	840 (40)	-	-
Thermal (µm)	-	-	7.5-13.5
Lateral overlap	75 %	83 %	75 %
Longitudinal overlap	75 %	84 %	80 %
Flight height	88 m AED	91.8 m AED	91.8 m AED
Spatial resolution	6.0 cm/px	2.1 cm/px	12 cm/px

AED = above elevation data.

The resulting products reached an average accuracy of 4.7 cm. The images were corrected using VRS.MAX-CZEPOS (master auxiliary stations, RTCM 3.1. correction format) provided by the Czech Office for Surveying, Mapping and Cadastre of the Czech Republic.

The images were processed in Pix4D SW (Pix4D S.A., Lausanne, Switzerland), where spectral indices (details in Table 4) were calculated. The resulting indices in the form of raster data (GeoTIFF, WGS84 UTM Zone 33N coordinate system) were analyzed in QGIS SW using zonal statistics and advanced tools focused on individual parcels. Digital Terrain Model (DTM) was derived from orthophoto. The data were then statistically processed in Statistica SW (TIBCO Software Inc. (2018). Statistica (data analysis software system), version 13. <http://tibco.com>).

**Table 4.** Spectral indices and parameters evaluated in this study.

Spectral Index	Algorithm	Developed by	References
Normalized Difference Vegetation Index (NDVI)	$(\text{NIR}-\text{RED})/(\text{NIR} + \text{RED})$	Biomass, structure, vigor	Rouse et al. (1974)
Green Normalized Difference Vegetation Index (GNDVI)	$(\text{NIR}-\text{GREEN})/(\text{NIR}+\text{GREEN})$	Chlorophyll	Gitelson et al. (1996)
Chlorophyll Index Red Edge (CIR)	$(\text{NIR}/\text{RedEdge})-1$	Chlorophyll	Gitelson et al. (2005)
Digital Terrain Model (DTM)		Terrain a.s.l. (m)	
Crop Water Stress Index (CWSI)	$\frac{(\text{Tc} - \text{Ta}) - (\text{Tcl} - \text{Ta})}{(\text{Tcu} - \text{Ta}) - (\text{Tcl} - \text{Ta})}$	Water stress	Katimbo et al. (2022)

Where RED, GREEN, BLUE = reflectance in visible part of electromagnetic spectra; Red Edge and NIR = reflectance in near infrared part of electromagnetic spectra according to the MicaSense RedEdge MX sensor properties; Tc (°C) = measured canopy temperature, Ta (°C) = air temperature, Tcl (°C) = canopy temperature of well transpiring or non-stressed crop (i.e., minimum Tc), and Tcu (°C) = the canopy temperature of a nontranspiring or severely stressed crop (i.e., maximum Tc). Terms (Tcu-Ta) and (Tcl-Ta) are referred to as upper and lower limits.

CWSI was derived from thermal images for the individual terms of canopy scanning (see Table 2). The calculation was done in QGIS SW using CWSI plugin [42]. The equation is based on calculation of Jones et al. [43]. Since Tdry and Twet were not available, the calculation according to Irmak et al. [44] was used. They use a default value of 5°C for workflow calculation.

### 3. Results and discussion

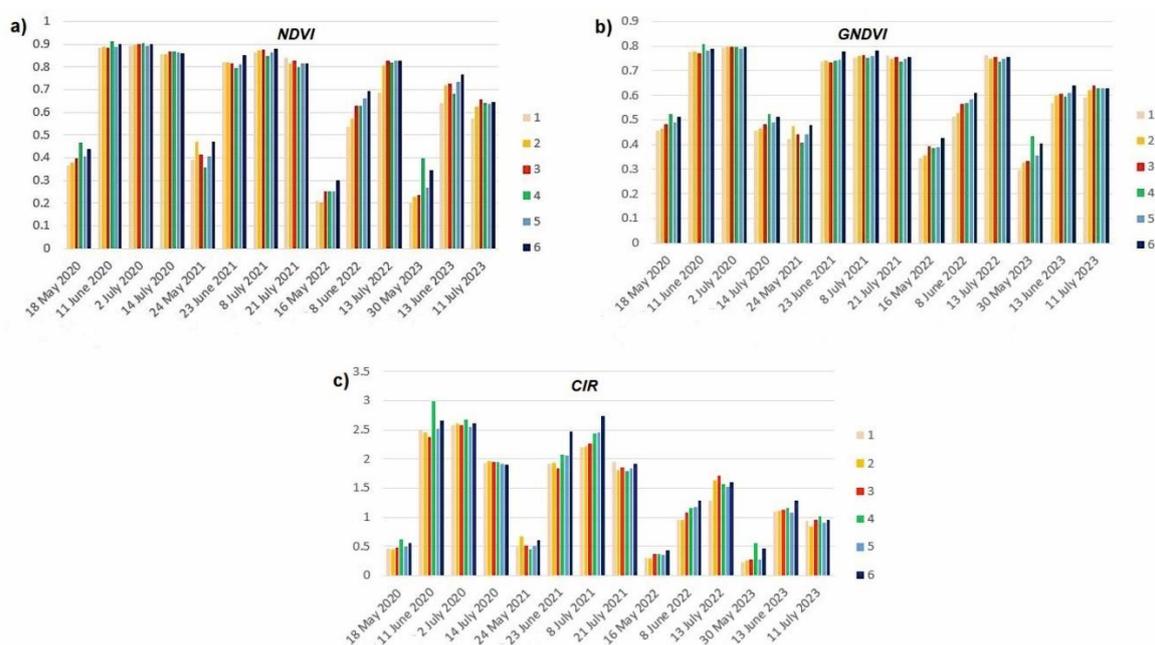
#### 3.1. Evaluation of the crops and variants using spectral indices

The development of NDVI, GNDVI and CIR spectral indices of Khorasan and Kabot spring wheat growing in different tillage for evaluated four vegetation seasons is given in Figure 2. Although these vegetation indices are based on different spectral bands (see Table 4), the course of the values was very similar for each index with an emphasis on the properties which are evaluated, e.g., NDVI is measure of vigor and structure of the crops and GNDVI and CIR then measure of chlorophyll content. It is evident that the development of the crops was dependent on weather conditions, how it was described in Kumhálová et al. [45]. In generally, the drier seasons 2022 and 2023 showed lower values of structural, and chlorophyll parameters expressed in calculated spectral indices. The mean values for each plot showed that the development of the crops was also dependent on phenological phases. In dates corresponding to tillering growing stage, ancient Khorasan variety had lower values in comparison with Kabot for each index (see Figure 2). The research Nakhforoosh et al. [8] showed that Khorasan wheat had the lowest cultivability compared to Einkorn and Zanduri wheat varieties. At the same time, its response to drought was a height reduction and loss of seed weight. However, rapid canopy development and soil cover by plants has a positive effect on reducing water evaporation from the soil and increasing competitiveness against weeds [46,47].

Regarding to the tillage, the lowest values were in the variant of CT. The variants were evaluated for the whole parcels, therefore lower values in this growth stage mean that Khorasan generally tillered later and worse especially in the CT variant. Stem elongation growth stage was in June. In comparison with previous years, 2022 and 2023 showed lower values which could be caused by low and uneven distribution of precipitation and different water ability in soil under various types of tillage. The last growth stage when the canopy was monitored was flowering and spikes forming in July. The weather conditions, especially distribution and amount of precipitation and the air temperatures, are strongly reflected in the values of the spectral indices in this later period of growth

stages. Lower values mean a lower proportion of green tissue as the crops mature, as can be seen from the CIR plot (see Figure 2, c). Significantly lower values of Khorasan, the CT variant, were in the dry years of 2022 and 2023. Conversely, the previous years 2020 and 2021, rich on water availability showed similar values for both varieties.

In terms of tillage, the results showed that the crops achieved the best condition during these four seasons in the variant MTD and CT for the modern Kabot variety. The selected tillage could affect a whole range of physical soil properties and thus affect the growth and vitality of plants, especially in the early stages of crop development [48]. Physical properties due to tillage played a more significant role during the growing season in the drier years 2022 and 2023. According to Woźniak & Rachoń [49], the no-tillage system had a positive effect on limiting water evaporation from the field surface. This statement agrees with Micucci & Taboada [50]. They stated in their study that plowing (CT) resulted in greater aeration of the soil, which facilitated faster mineralization of the organic component and thus nutrient loss.



**Figure 2.** Evaluation of selected spectral indices: Normalized Difference Vegetation Index (NDVI), Green NDVI (GNDVI) and Chlorophyll Index Red Edge (CIR) for monitored seasons.

### 3.2. Evaluation of the crops and variants using crop water stress index

Resulting values of Crop Water Stress Index derived from thermal images for the individual terms of canopy scanning and the average for the whole period and individual monitored growing stages are given in Table 5. The CWSI values are based on the current state of the vegetation, which is influenced by meteorological variables. As shown in Table 5, the average values of CWSI for all experimental measurements showed that the Khorasan variety showed a higher level of stress than the Kabot variety. Regarding the individual methods of tillage and water stress, the ancient variety Khorasan did the worst on the CT variant. The MTC and MTD of the tillage were very close to the CWSI values. However, MTD appeared to be the best tillage method for Khorasan cultivation in terms of water management. Likewise, the modern Kabot variety showed the best results in water management on the MTD variant. Within the monitored growth phases, it turned out that MTD is the most suitable for tillering in terms of water stress, on the contrary, the stands on the CT variant showed the greatest water stress. During stem elongation, the CWSI values were almost equal for each tillage variant in both cultivars, however, the Khorasan variety showed a greater susceptibility to water stress in this growth phase compared to the modern Kabot variety. The late phases followed the same trend. While the ancient Khorasan did the worst on the CT variant, this variant was the most suitable for the modern variety Kabot. These results agree with Farooq study [51], they stated

that drought stress reduced biomass volume and root proliferation, fundamentally disrupted plant water relations and reduced water use efficiency. This trend is also supported by Kumhálová et al. [52]. The influence of topographical attributes e.g., flow accumulation on resulting yield was evaluated in this study. They found out that lack of precipitation during flowering growing stage led to accumulating water only to lower terrain of the plot. The reason of resulting low yield of winter wheat was caused by combination of soil compaction due heavy machinery cultivation and the dry period. These led to poor root system and bad vitality of crops. Shorter plants, smaller leaf area and conversely higher root biomass led to less damage caused by drought stress were mentioned also in study of Richards [53]. According to Ali et al. [54] it is good to use IR-based thermal imaging because it can identify sensitive plants at the onset of drought stress or determine the stress tolerance of different cultivars. In general, plants that have cooler surfaces than others are more demanding of the water they consume and release.

**Table 5.** Crop Water Stress Index (CWSI) derived for the whole four season 2020–2023 in monitoring dates and individual variants; average for the whole period and for the individual monitored growing stages (tillering, stem elongation and later stages = flowering and spikes forming).

Plots		Average	Tillering	Stem Elongation	Late stages
Khorasan 1 CT		0.38	0.45	0.30	0.37
Khorasan 2 MTC		0.34	0.37	0.32	0.33
Khorasan 3 MTD		0.32	0.36	0.31	0.31
Kabot 1 CT		0.29	0.40	0.23	0.26
Kabot 2 MTC		0.30	0.37	0.23	0.30
Kabot 3 MTD		0.28	0.32	0.22	0.28

	Plots	18 May	11 June	2 July	14 July	24 May	23 June	8 July	21 July	16 May	8 June	13 July	30 May	11 July
		2020	2020	2020	2020	2021	2021	2021	2021	2022	2022	2022	2023	2023
Khorasan	CT	0.61	0.12	0.58	0.16	0.1	0.13	0.09	0.17	0.66	0.64	0.31	0.42	0.92
	MTC	0.46	0.15	0.52	0.12	0.11	0.14	0.11	0.18	0.5	0.67	0.24	0.39	0.82
	MTD	0.53	0.17	0.57	0.15	0.01	0.15	0.13	0.16	0.39	0.62	0.23	0.52	0.59
Kabot	CT	0.64	0.08	0.35	0.09	0.08	0.16	0.14	0.19	0.37	0.44	0.21	0.49	0.56
	MTC	0.32	0.17	0.46	0.09	0.11	0.15	0.17	0.15	0.33	0.37	0.19	0.72	0.71
	MTD	0.18	0.15	0.43	0.12	0.12	0.09	0.24	0.13	0.23	0.41	0.19	0.73	0.58

Where CT = conventional tillage; MTC = minimum tillage; MTD = minimalization tillage.

Coefficients of correlation (R) and determination ( $R^2$ ) between Crop Water Stress Index and selected spectral indices, DTM and dates of scanning as independent variables were calculated based on forward stepwise linear regression (FSLR). The results of calculation are evaluated for individual variants and growth stages and are given in Table 6. These independent variables were selected as indicators of both the current state of the vegetation in terms of structure and vitality (NDVI), as well as the chlorophyll content or nitrogen supply with respect to the spectral bands included in the calculation (GNDVI, CIR). Since the individual parcels are located on a gentle slope, the influence of DTM also played a certain role here. In the same way, the date of scanning for individual years was an important parameter, especially during tillering, as it reflected meteorological conditions and the development of the stand in terms of phenological phases.

From the point of view of the influence of the variables on the water stress of the stands, it is clear from Table 6 that these variables had a greater influence in the ancient Khorasan variety. In general, the results of Table 6 have the opposite trend to the results of Table 5, when the direct effect of tillage on plant water management was assessed. The variables in Table 6 are then indirect indicators of the state of the stand for varieties and tillage variants.

During tillering, the date of crop scanning, which indicates the structure including crop density (NDVI), and the phenological phase reflected in the degree of greenness as an expression of chlorophyll content in leaves (GNDVI) or chlorophyll content in cellular tissues (CIR) had the greatest influence on water stress. This agrees with the study of Hoffmann et al. [55]. They found out that NDVI best represented Leaf Area Index (LAI) measurements as indicator of crop greenness and served for detection of the developmental stage of crops in the late growing season. DTM played no role here, meaning that the stand was equally stressed regardless of location.

**Table 6.** Multiple coefficients of correlation (R) and coefficients of determination (R<sup>2</sup>) between Crop Water Stress Index (CWSI) and variables as NDVI = Normalized Difference Vegetation Index; GNDVI = Green NDVI; CIR = Chlorophyll Index Red Edge; DTM = Digital Terrain Model; Date = Date of Scanning resulting from forward stepwise linear regression (FSLR) for individual variants and growth stages. All coefficients are significant at 5% significance level.

Tillering											
Var	Mul R	Var	Mul R	Var	Mul R	Var	Mul R	Var	Mul R	Var	Mul R
Khorasan 1 CT		Khorasan 2 MTC		Khorasan 3 MTD		Kabot 1 CT		Kabot 2 MTC		Kabot 3 MTD	
Date	0.31	Date	0.47	Date	0.36	Date	0.08	Date	0.18	CIR	0.24
NDVI	0.48	NDVI	0.64	NDVI	0.5	CIR	0.32	CIR	0.33	GNDVI	0.44
GNDVI	0.74	GNDVI	0.74	GNDVI	0.58	GNDVI	0.42	GNDVI	0.68	NDVI	0.44
DTM	0.75	CIR	0.76	CIR	0.62	NDVI	0.48	NDVI	0.68	Date	0.44
CIR	0.76	DTM	0.76	DTM	0.62	DTM	0.51	DTM	0.68	DTM	0.44
<b>R<sup>2</sup></b>	<b>0.57</b>		<b>0.58</b>		<b>0.38</b>		<b>0.26</b>		<b>0.46</b>		<b>0.2</b>
Stem Elongation											
GNDVI	0.92	GNDVI	0.9	GNDVI	0.86	GNDVI	0.8	GNDVI	0.71	NDVI	0.75
CIR	0.93	DTM	0.91	CIR	0.087	Date	0.8	Date	0.73	DTM	0.76
DTM	0.94	NDVI	0.92	DTM	0.87	DTM	0.81	DTM	0.75	Date	0.77
Date	0.94	CIR	0.93	Date	0.88	NDVI	0.81	CIR	0.76	GNDVI	0.78
NDVI	0.94	Date	0.93	NDVI	0.88	CIR	0.81	NDVI	0.76	CIR	0.79
<b>R<sup>2</sup></b>	<b>0.88</b>		<b>0.86</b>		<b>0.77</b>		<b>0.65</b>		<b>0.58</b>		<b>0.63</b>
Flowering											
Date	0.81	NDVI	0.82	NDVI	0.7	NDVI	0.7	NDVI	0.8	NDVI	0.81
GNDVI	0.86	Date	0.85	DTM	0.76	DTM	0.75	DTM	0.84	Date	0.82
CIR	0.86	DTM	0.87	CIR	0.77	Date	0.76	Date	0.86	GNDVI	0.83
DTM	0.87	GNDVI	0.88	Date	0.78	CIR	0.77	GNDVI	0.86	CIR	0.84
NDVI	0.87	CIR	0.88	GNDVI	0.79	GNDVI	0.77	CIR	0.86	DTM	0.84
<b>R<sup>2</sup></b>	<b>0.76</b>		<b>0.77</b>		<b>0.62</b>		<b>0.59</b>		<b>0.75</b>		<b>0.7</b>

Var =Variable; Mul R = Multiple Coefficient of Correlation.

The stem elongation phenological phase was characterized by the detection of water stress in the canopy, which refers to a different degree of crop development within the scope of this growth phase. The DTM also had a greater influence here. During the phenological phase of flowering on all variants except Khorasan (CT), total stand structure (NDVI) and DTM played a significant role in influencing water stress. It follows that most variants depended on the stage of flower development, because the canopy, as top part of crops, was scanned. Feiziasl et al. [56] also concluded in their study that NDVI as indicator of vegetation cover had the main effect on Water Deficit Index (WDI) variation.

In general, it can be summarized that water stress was easily detectable by monitored parameters in the growth phase of stem elongation, when the surface of the stand consists of layers of leaves or a flag leaf.

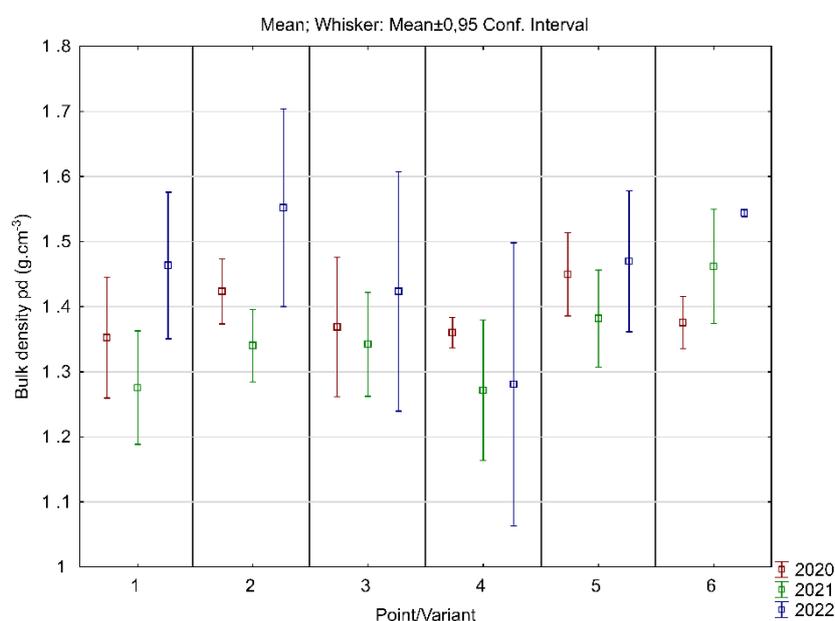
### 3.3. Results of intact soil samples

The soil bulk density graph (in Figure 3) presents the results from the three measured years 2020-2022. All years showed interesting results in ploughed variants. In the first year, CT variants were the lowest values of bulk density, followed by MTD with almost the same average values, and the highest values of bulk density were measured for MTC tillage. The second year (2021) differed in the swapping order of the MTD and MTC variants. It means that the order from lowest to highest in the second year is CT, MTC, and MTD, where the variant sown with Kabot variety with MTD tillage showed significantly higher value than other variants with statistically significant difference compared to CT variants.

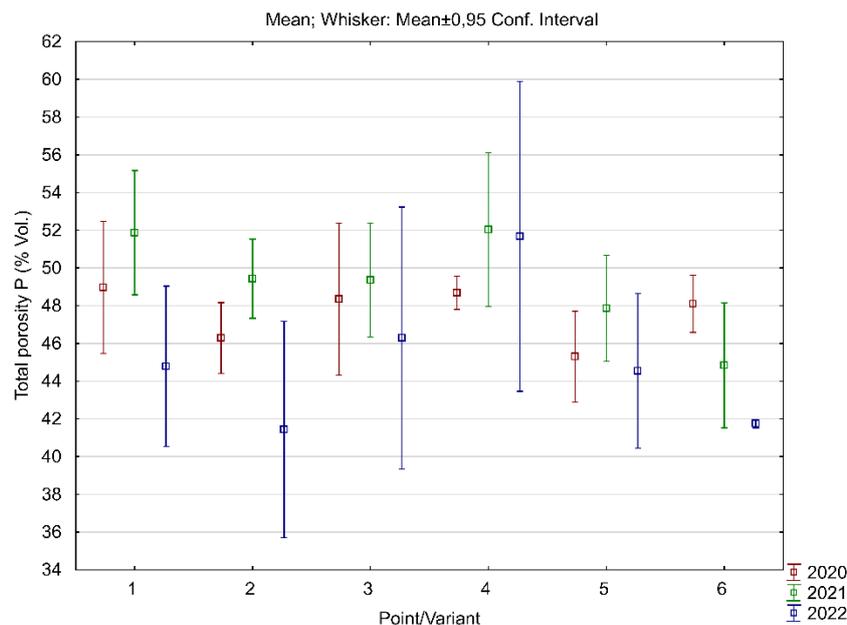
In the last measured year 2022, the variant sown with Khorasan wheat copied the order of year 2021, where the lowest values are for CT followed by MTD and the highest value of bulk density for MTC. In contrast to the second variant sown with Kabot wheat, the MTD tillage system did the worst.

However, the best results were achieved mainly in ploughing, which agrees with most authors [57–59]. On the other hand, variants 3 and 6 (MTD–Khorasan and Kabot) were almost identical to CT in terms of bulk density in the first year of the experiment. This could suggest that under certain conditions (such as soil type, temperature, precipitation, crop, etc.), some no-tillage technologies can achieve the same [16] and perhaps in some cases better results than CT [60]. This was also stated in the publication of Woźniak & Rachoń [49], where suitable soil conditions for plant growth were created by CT mainly on medium-moist soils, while on dry and semi-arid soils it was better to choose systems without plowing. The graph of the total porosity from the experimental plots can be seen in Figure 4. As expected, the results mirror the bulk density of the soil, which means that the CT variants showed the highest proportion of pores in the first and second year (2020 and 2021) of measurement. According to a study by Mehra et al. [48], soil porosity was greater in the CT system than in the no-till system, moreover, the macropore content was dominant in the CT system, which is in line with our study. In 2022, the MTC tillage system for the variant sown with Khorasan wheat had a higher pore content than CT, while the variant sown with the modern Kabot wheat variety showed the MTC system with the lowest pore content.

The total porosity and bulk density results were consistent with the CWSI results (Table 5) and are consistent with the following statements. According to Woźniak & Rachoń [49], greater pore content and soil compaction in CT indicated higher soil loosening and resulted in greater soil water loss. Plants that did not have as much available water responded by changing leaf size or reducing stem elongation and stomatal closure to reduce evapotranspiration, increasing their stress [51]. According to Luan & Vico [61], water stress resulted in an increase in leaf/canopy temperature ( $T_c$ ). This is also stated in the research of James et al. [62], where transpiration was an important factor influencing overall plant temperature during water stress. Liebhard et al. [63] stated that it depends on soil cultivation, which affects the development of plants and their roots, and at the same time affects water in-take and evapotranspiration itself. Different tillage methods have a key influence on the gradual development, vitality and yield of plants, as they are closely related to local climatic and soil conditions, as it was presented in the study of Blanco-Canqui & Wortmann [64].



**Figure 3.** Graph of soil bulk density for the years 2020, 2021 and 2022.



**Figure 4.** Graph of total porosity for the years 2020, 2021 and 2022.

#### 4. Conclusions

The results showed that the method of tillage plays a significant role for the selected wheat varieties Khorasan and Kabot, as it affects their growth and vitality during the growing season. The condition of the stands was monitored using a UAV and selected calculated indices (NDVI, GNDVI, CSWI, CIR). It is clearly seen from the results that in Khorasan wheat, all values were lower in BBCH tillering than in Kabot wheat.

The dry years affected both varieties, especially the content of chlorophyll and crop structure. The values of calculated spectral indices were lower than in years with higher rainfall totals. In addition, the CT variant caused the worse retention capacity of the soil, which was reflected in the CWSI results, when the plowed variants did the worst, while the MTD variants did the best. The results of Bulk density and Total porosity were consistent with the results of NDVI and CWSI. Due to greater evaporation from the soil in the CT variant, there was less plant growth and a higher degree of stress due to stomatal closure. The results showed that crops can be effectively monitored during the growing seasons with the help of selected indices, and it is then possible to react flexibly to changes, deficiencies or other problems.

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#### References

- Bordon, A.; Danesi, F.; Di Nunzio, M.; Taccari, A.; Valli, V. Ancient Wheat and Health: A Legend or the Reality? A Review on KAMUT Khorasan Wheat. *Int J Food Sci Nutr* **2017**, *68*, 278–286. <https://doi.org/10.1080/09637486.2016.1247434>.
- Balážová, K.; Chyba, J.; Kumhálová, J.; Mašek, J.; Petrásek, S. Monitoring of Khorasan (*Triticum Turgidum* Ssp. *Turanicum*) and Modern Kabot Spring Wheat (*Triticum Aestivum*) Varieties by UAV and Sensor

- Technologies under Different Soil Tillage. *Agronomy* **2021**, *11*, 1348. <https://doi.org/10.3390/agronomy11071348>.
3. M. Shanbandeh Wheat–Statistics and Facts Available online: <https://www.statista.com/topics/1668/wheat/#topicOverview> (accessed on 6 November 2023).
  4. Ghose, B. Food Security and Food Self-sufficiency in China: From Past to 2050. *Food Energy Secur* **2014**, *3*, 86–95. <https://doi.org/10.1002/fes3.48>.
  5. Singh, R.; Krishnan, P.; Singh, V.K.; Das, B. Estimation of Yellow Rust Severity in Wheat Using Visible and Thermal Imaging Coupled with Machine Learning Models. *Geocarto Int* **2023**, *38*. <https://doi.org/10.1080/10106049.2022.2160831>.
  6. Kurunc, A.; Tezcan, N.Y.; Bimurzayev, N. Determination of Water Stress in Wheat Crops by Thermal Images Under Mediterranean Conditions. *Commun Soil Sci Plant Anal* **2023**, *54*, 1713–1726. <https://doi.org/10.1080/00103624.2023.2211089>.
  7. Kabiri, R.; Nasibi, F.; Farahbakhsh, H. Effect of Exogenous Salicylic Acid on Some Physiological Parameters and Alleviation of Drought Stress in *Nigella Sativa* Plant under Hydroponic Culture. *Plant Protection Science* **2014**, *50*, 43–51. <https://doi.org/10.17221/56/2012-PPS>.
  8. Nakhforoosh, A.; Grausgruber, H.; Kaul, H.-P.; Bodner, G. Dissection of Drought Response of Modern and Underutilized Wheat Varieties According to Passioura's Yield-Water Framework. *Front Plant Sci* **2015**, *6*. <https://doi.org/10.3389/fpls.2015.00570>.
  9. Newton, A.C.; Akar, T.; Baresel, J.P.; Bebeli, P.J.; Bettencourt, E.; Bladenopoulos, K.V.; Czembor, J.H.; Fasoula, D.A.; Katsiotis, A.; Koutis, K.; et al. Cereal Landraces for Sustainable Agriculture. A Review. *Agron Sustain Dev* **2010**, *30*, 237–269. <https://doi.org/10.1051/agro/2009032>.
  10. Ficiciyan, A.; Loos, J.; Sievers-Glotzbach, S.; Tschardtke, T. More than Yield: Ecosystem Services of Traditional versus Modern Crop Varieties Revisited. *Sustainability* **2018**, *10*, 2834. <https://doi.org/10.3390/su10082834>.
  11. Tsegaye, B.; Berg, T. Utilization of Durum Wheat Landraces in East Shewa, Central Ethiopia: Are Home Uses an Incentive for on-Farm Conservation? *Agric Human Values* **2007**, *24*, 219–230. <https://doi.org/10.1007/s10460-006-9055-8>.
  12. Kapoor, D.; Bhardwaj, S.; Landi, M.; Sharma, A.; Ramakrishnan, M.; Sharma, A. The Impact of Drought in Plant Metabolism: How to Exploit Tolerance Mechanisms to Increase Crop Production. *Applied Sciences* **2020**, *10*, 5692. <https://doi.org/10.3390/app10165692>.
  13. Mulla, D.J. Twenty Five Years of Remote Sensing in Precision Agriculture: Key Advances and Remaining Knowledge Gaps. *Biosyst Eng* **2013**, *114*, 358–371. <https://doi.org/10.1016/j.biosystemseng.2012.08.009>.
  14. Amaral, L.R. do; Zerbato, C.; Freitas, R.G. de; Barbosa Júnior, M.R.; Simões, I.O.P. da S. UAV Applications in Agriculture 4.0. *Revista Ciência Agronômica* **2020**, *51*. <https://doi.org/10.5935/1806-6690.20200091>.
  15. Lei, S.; Luo, J.; Tao, X.; Qiu, Z. Remote Sensing Detecting of Yellow Leaf Disease of Aracanut Based on UAV Multisource Sensors. *Remote Sens (Basel)* **2021**, *13*, 4562. <https://doi.org/10.3390/rs13224562>.
  16. Virnodkar, S.S.; Pachghare, V.K.; Patil, V.C.; Jha, S.K. Remote Sensing and Machine Learning for Crop Water Stress Determination in Various Crops: A Critical Review. *Precis Agric* **2020**, *21*, 1121–1155. <https://doi.org/10.1007/s11119-020-09711-9>.
  17. Kazemi, F.; Ghanbari Parmehr, E. Evaluation of RGB Vegetation Indices Derived from UAV Images for Rice Crop Growth Monitoring. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **2023**, *X-4/W1-2022*, 385–390. <https://doi.org/10.5194/isprs-annals-X-4-W1-2022-385-2023>.
  18. Khan, A.; Upadhyay, C.S.; Gerritsma, M. Spectral Element Method for Parabolic Interface Problems. *Comput Methods Appl Mech Eng* **2018**, *337*, 66–94. <https://doi.org/10.1016/j.cma.2018.03.011>.
  19. Kamenova, I.; Dimitrov, P. Evaluation of Sentinel-2 Vegetation Indices for Prediction of LAI, FAPAR and FCover of Winter Wheat in Bulgaria. *Eur J Remote Sens* **2021**, *54*, 89–108. <https://doi.org/10.1080/22797254.2020.1839359>.
  20. Domínguez, J.A.; Kumhálová, J.; Novák, P. Winter Oilseed Rape and Winter Wheat Growth Prediction Using Remote Sensing Methods. *Plant Soil Environ* **2015**, *61*, 410–416. <https://doi.org/10.17221/412/2015-PSE>.
  21. Gitelson, A.A.; Kaufman, Y.J.; Merzlyak, M.N. Use of a Green Channel in Remote Sensing of Global Vegetation from EOS-MODIS. *Remote Sens Environ* **1996**, *58*, 289–298. [https://doi.org/10.1016/S0034-4257\(96\)00072-7](https://doi.org/10.1016/S0034-4257(96)00072-7).

22. Frampton, W.J.; Dash, J.; Watmough, G.; Milton, E.J. Evaluating the Capabilities of Sentinel-2 for Quantitative Estimation of Biophysical Variables in Vegetation. *ISPRS Journal of Photogrammetry and Remote Sensing* **2013**, *82*, 83–92. <https://doi.org/10.1016/j.isprsjprs.2013.04.007>.
23. Mangewa, L.J.; Ndakidemi, P.A.; Alward, R.D.; Kija, H.K.; Bukombe, J.K.; Nasolwa, E.R.; Munishi, L.K. Comparative Assessment of UAV and Sentinel-2 NDVI and GNDVI for Preliminary Diagnosis of Habitat Conditions in Burunge Wildlife Management Area, Tanzania. *Earth* **2022**, *3*, 769–787. <https://doi.org/10.3390/earth3030044>.
24. Funghi, C.; Heim, R.H.J.; Schuett, W.; Griffith, S.C.; Oldeland, J. Estimating Food Resource Availability in Arid Environments with Sentinel 2 Satellite Imagery. *PeerJ* **2020**, *8*, e9209. <https://doi.org/10.7717/peerj.9209>.
25. Potter, C.; Li, S.; Huang, S.; Crabtree, R.L. Analysis of Sapling Density Regeneration in Yellowstone National Park with Hyperspectral Remote Sensing Data. *Remote Sens Environ* **2012**, *121*, 61–68. <https://doi.org/10.1016/j.rse.2012.01.019>.
26. Idso, S.B.; Jackson, R.D.; Pinter, P.J.; Reginato, R.J.; Hatfield, J.L. Normalizing the Stress-Degree-Day Parameter for Environmental Variability. *Agricultural Meteorology* **1981**, *24*, 45–55. [https://doi.org/10.1016/0002-1571\(81\)90032-7](https://doi.org/10.1016/0002-1571(81)90032-7).
27. Alchanatis, V.; Cohen, Y.; Cohen, S.; Moller, M.; Sprinstin, M.; Meron, M.; Tsipris, J.; Saranga, Y.; Sela, E. Evaluation of Different Approaches for Estimating and Mapping Crop Water Status in Cotton with Thermal Imaging. *Precis Agric* **2010**, *11*, 27–41. <https://doi.org/10.1007/s11119-009-9111-7>.
28. Jones, H.G.; Stoll, M.; Santos, T.; de Sousa, C.; Chaves, M.M.; Grant, O.M. Use of Infrared Thermography for Monitoring Stomatal Closure in the Field: Application to Grapevine. *J Exp Bot* **2002**, *53*, 2249–2260. <https://doi.org/10.1093/jxb/erf083>.
29. Costa, J.D.O.; Coelho, R.D.; Barros, T.H.D.S.; Fraga Júnior, E.F.; Fernandes, A.L.T. Canopy Thermal Response to Water Deficit of Coffee Plants under Drip Irrigation. *Irrigation and Drainage* **2020**, *69*, 472–482. <https://doi.org/10.1002/ird.2429>.
30. Pou, A.; Diago, M.P.; Medrano, H.; Baluja, J.; Tardaguila, J. Validation of Thermal Indices for Water Status Identification in Grapevine. *Agric Water Manag* **2014**, *134*, 60–72. <https://doi.org/10.1016/j.agwat.2013.11.010>.
31. Wang, H.; Li, X.; Li, X.; Wang, J.; Li, X.; Guo, Q.; Yu, Z.; Yang, T.; Zhang, H. Long-Term No-Tillage and Different Residue Amounts Alter Soil Microbial Community Composition and Increase the Risk of Maize Root Rot in Northeast China. *Soil Tillage Res* **2020**, *196*, 104452. <https://doi.org/10.1016/j.still.2019.104452>.
32. Debska, B.; Jaskulska, I.; Jaskulski, D. Method of Tillage with the Factor Determining the Quality of Organic Matter. *Agronomy* **2020**, *10*, 1250. <https://doi.org/10.3390/agronomy10091250>.
33. Almagro, M.; Garcia-Franco, N.; Martínez-Mena, M. The Potential of Reducing Tillage Frequency and Incorporating Plant Residues as a Strategy for Climate Change Mitigation in Semiarid Mediterranean Agroecosystems. *Agric Ecosyst Environ* **2017**, *246*, 210–220. <https://doi.org/10.1016/j.agee.2017.05.016>.
34. Melero, S.; Panettieri, M.; Madejón, E.; Macpherson, H.G.; Moreno, F.; Murillo, J.M. Implementation of Chiselling and Mouldboard Ploughing in Soil after 8 Years of No-till Management in SW, Spain: Effect on Soil Quality. *Soil Tillage Res* **2011**, *112*, 107–113. <https://doi.org/10.1016/j.still.2010.12.001>.
35. Ing. Andrea Hrabalová *YEARBOOK 202-Organic Farming in the Czech Republic*; Ministry of Agriculture of the Czech Republic: Prag, 2023; Vol. 80;.
36. Mašek, J.; Novák, P.; Kroulík, M.; Chyba, J. The Quality Evaluation of Different Soil Tillage Technologies. *Agronomy Research* **2014**, *12*.
37. Cheţan, F.; Rusu, T.; Călugăr, R.; Cheţan, C.; Şimon, A.; Ceclan, A.; Bărdaş, M.; Mîntaş, O. Research on the Interdependence Linkages between Soil Tillage Systems and Climate Factors on Maize Crop. *Land (Basel)* **2022**, *11*, 1731. <https://doi.org/10.3390/land11101731>.
38. Chirita, S.; Rusu, T.; Urda, C.; Chetan, F.; Racz, I. Winter Wheat Yield and Quality Depending on Chemical Fertilization, Different Treatments and Tillage Systems. *AgroLife Scientific Journal* **2023**, *12*, 34–39. <https://doi.org/10.17930/AGL202315>.
39. Özpınar, S.; Anil Çay Effects of Minimum and Conventional Tillage Systems on Soil Properties and Yield of Winter Wheat (*Triticum Aestivum* L.) in Clay-Loam in the Çanakkale Region. *Turkish journal of agriculture and forestry* **2005**, *29*, 9–18.
40. Šíp, V.; Růžek, P.; Chrpová, J.; Vavera, R.; Kusá, H. The Effect of Tillage Practice, Input Level and Environment on the Grain Yield of Winter Wheat in the Czech Republic. *Field Crops Res* **2009**, *113*, 131–137. <https://doi.org/10.1016/j.fcr.2009.04.013>.

41. Noor, R.S.; Hussain, F.; Umair, M. EVALUATING SELECTED SOIL PHYSICAL PROPERTIES UNDER DIFFERENT SOIL TILLAGE SYSTEMS IN ARID SOUTHEAST RAWALPINDI, PAKISTAN. *Journal CleanWAS* **2020**, *4*, 56–60. <https://doi.org/10.26480/jcleanwas.02.2020.56.60>.
42. Florian Ellsäßer CWSI Is a QGIS3 Plugin That Helps to Calculate the CWSI (Crop Water Stress Index) from Thermal Images.
43. Jones H.G. *Plants and Microclimate (Second Edition)*; Cambridge University Press: Cambridge, 1992; Vol. 428;.
44. Irmak, S.; Haman, D.Z.; Bastug, R. Determination of Crop Water Stress Index for Irrigation Timing and Yield Estimation of Corn. *Agron J* **2000**, *92*, 1221–1227. <https://doi.org/10.2134/agronj2000.9261221x>.
45. Kumhálová, J.; Kumhála, F.; Kroulík, M.; Matějková, Š. The Impact of Topography on Soil Properties and Yield and the Effects of Weather Conditions. *Precis Agric* **2011**, *12*, 813–830. <https://doi.org/10.1007/s11119-011-9221-x>.
46. Mullan, D.J.; Reynolds, M.P. Quantifying Genetic Effects of Ground Cover on Soil Water Evaporation Using Digital Imaging. *Functional Plant Biology* **2010**, *37*, 703. <https://doi.org/10.1071/FP09277>.
47. Kaur, S.; Kaur, R.; Chauhan, B.S. Understanding Crop-Weed-Fertilizer-Water Interactions and Their Implications for Weed Management in Agricultural Systems. *Crop Protection* **2018**, *103*, 65–72. <https://doi.org/10.1016/j.cropro.2017.09.011>.
48. Mehra, P.; Kumar, P.; Bolan, N.; Desbiolles, J.; Orgill, S.; Denton, M.D. Changes in Soil-Pores and Wheat Root Geometry Due to Strategic Tillage in a No-Tillage Cropping System. *Soil Research* **2021**, *59*, 83. <https://doi.org/10.1071/SR20010>.
49. Woźniak, A.; Rachoń, L. Effect of Tillage Systems on the Yield and Quality of Winter Wheat Grain and Soil Properties. *Agriculture* **2020**, *10*, 405. <https://doi.org/10.3390/agriculture10090405>.
50. Micucci, F.G.; Taboada, M.A. Soil Physical Properties and Soybean (*Glycine Max*, Merrill) Root Abundance in Conventionally- and Zero-Tilled Soils in the Humid Pampas of Argentina. *Soil Tillage Res* **2006**, *86*, 152–162. <https://doi.org/10.1016/j.still.2005.02.004>.
51. Farooq, M.; Wahid, A.; Kobayashi, N.; Fujita, D.; Basra, S.M.A. Plant Drought Stress: Effects, Mechanisms and Management. *Agron Sustain Dev* **2009**, *29*, 185–212. <https://doi.org/10.1051/agro:2008021>.
52. Kumhálová, J.; Kumhála, F.; Novák, P.; Matějková, Š. Airborne Laser Scanning Data as a Source of Field Topographical Characteristics. *Plant Soil Environ* **2013**, *59*, 423–431. <https://doi.org/10.17221/188/2013-PSE>.
53. Richards, R.A.; Rebetzke, G.J.; Watt, M.; Condon, A.G. (Tony); Spielmeier, W.; Dolferus, R. Breeding for Improved Water Productivity in Temperate Cereals: Phenotyping, Quantitative Trait Loci, Markers and the Selection Environment. *Functional Plant Biology* **2010**, *37*, 85. <https://doi.org/10.1071/FP09219>.
54. Ali, F.; Umar, M.; Siddiqui, Z.S. Comparative Physiological Assessment of Some Edible Oil Seed Crops under Drought Stress Environment Using Fluorescence and IR Imaging Techniques. *Pak J Bot* **2021**, *53*. [https://doi.org/10.30848/PJB2021-4\(13\)](https://doi.org/10.30848/PJB2021-4(13)).
55. Hoffmann, H.; Jensen, R.; Thomsen, A.; Nieto, H.; Rasmussen, J.; Friberg, T. Crop Water Stress Maps for an Entire Growing Season from Visible and Thermal UAV Imagery. *Biogeosciences* **2016**, *13*, 6545–6563. <https://doi.org/10.5194/bg-13-6545-2016>.
56. Feiziasl, V.; Jafarzadeh, J.; Sadeghzadeh, B.; Mousavi Shalmani, M.A. Water Deficit Index to Evaluate Water Stress Status and Drought Tolerance of Rainfed Barley Genotypes in Cold Semi-Arid Area of Iran. *Agric Water Manag* **2022**, *262*, 107395. <https://doi.org/10.1016/j.agwat.2021.107395>.
57. Mohammadi, K.; Rokhzadi, A.; Saberali, S.F.; Byzedi, M.; Karimi Nezhad, M.T. Tillage Effects on Soil Properties and Wheat Cultivars Traits. *Arch Agron Soil Sci* **2013**, *59*, 1625–1641. <https://doi.org/10.1080/03650340.2012.750031>.
58. Khorami, S.; Kazemeini, S.; Afzalnia, S.; Gathala, M. Changes in Soil Properties and Productivity under Different Tillage Practices and Wheat Genotypes: A Short-Term Study in Iran. *Sustainability* **2018**, *10*, 3273. <https://doi.org/10.3390/su10093273>.
59. Houshyar, E.; Esmailpour, M. The Impacts of Tillage, Fertilizer and Residue Managements on the Soil Properties and Wheat Production in a Semi-Arid Region of Iran. *Journal of the Saudi Society of Agricultural Sciences* **2020**, *19*, 225–232. <https://doi.org/10.1016/j.jssas.2018.10.001>.
60. Topa, D.; Cara, I.G.; Jitoreanu, G. Long Term Impact of Different Tillage Systems on Carbon Pools and Stocks, Soil Bulk Density, Aggregation and Nutrients: A Field Meta-Analysis. *Catena (Amst)* **2021**, *199*, 105102. <https://doi.org/10.1016/j.catena.2020.105102>.

61. Luan, X.; Vico, G. Canopy Temperature and Heat Stress Are Increased by Compound High Air Temperature and Water Stress and Reduced by Irrigation—a Modeling Analysis. *Hydrol Earth Syst Sci* **2021**, *25*, 1411–1423. <https://doi.org/10.5194/hess-25-1411-2021>.
62. James, A.T.; Lawn, R.J.; Cooper, M. Genotypic Variation for Drought Stress Response Traits in Soybean. II. Inter-Relations between Epidermal Conductance, Osmotic Potential, Relative Water Content, and Plant Survival. *Aust J Agric Res* **2008**, *59*, 670. <https://doi.org/10.1071/AR07160>.
63. Liebhard, G.; Klik, A.; Neugschwandtner, R.W.; Nolz, R. Effects of Tillage Systems on Soil Water Distribution, Crop Development, and Evaporation and Transpiration Rates of Soybean. *Agric Water Manag* **2022**, *269*, 107719. <https://doi.org/10.1016/j.agwat.2022.107719>.
64. Blanco-Canqui, H.; Ruis, S.J. No-Tillage and Soil Physical Environment. *Geoderma* **2018**, *326*, 164–200. <https://doi.org/10.1016/j.geoderma.2018.03.011>.

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