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USE OF REMOTE SENSING DATA FOR CROP MONITORING IN PRECISION AGRICULTURE

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ABSTRACT

Precision agriculture is the modern way of farming that uses knowledge of the heterogeneity of soil conditions and crop vigour within the fields for site-specific crop management. In this study, various multispectral remote sensing methods are compared for monitoring of crop development and plant diagnosis. The primary source of information is freely available data from the Sentinel-2 satellite system, which records the earth's surface in 13 spectral bands, including bands with high sensitivity to vegetation parameters (red-edge). The revisit time is approximately 3-4 days, and the spatial resolution is 10 m (Blue light-B, Green light - G, Red light - R, Near Infrared - NIR) and 20 m per pixel (Red-Edge - RE, Short-wave infrared - SWIR). The results of the assessment of crop condition from the field experiments carried out in 2021-2023 at two sites in the Czech Republic funded by research projects AF-IGA2023-IP-036 and TAČR SS01020309 showed a high level of correlation between vegetation indices calculated from multispectral images and vegetation parameters such as aboveground biomass or nitrogen uptake. The highest values were obtained using red-edge vegetation indices, such as Normalized Difference Red Edge Index (NDRE), Normalized Difference Moisture Index (NDMI), Enhanced Vegetation Index (EVI). Thus, satellite data can be used to prepare the prescription maps for variable rate application of fertilizers or growth regulators. If more detailed data are required, or in case of unavailability of satellite data due to cloud cover, multispectral unmanned imaging by drones is an option. It provides high operative monitoring to obtain RGB and multispectral orthomosaics with an ultra-high spatial resolution of a few cm without influence of cloud occurrence.

Keywords: *site-specific crop management, plant diagnosis, multispectral imaging, vegetation indices, Sentinel-2, UAV.*

INTRODUCTION

The main objective of precision agriculture, as an integrated approach to farming, is to optimize and efficiently use resources to determine the crop requirements, leading to sustainability while protecting the environment. It is a holistic approach using a combination of advanced technologies such as Geographic Information Systems (GIS) and Global Navigation Satellite Systems (GNSS), aerial and satellite imagery, crop yield maps and other sensor records. The amount of available data supports decision-making on optimal intervention, also we would not do without data processing and evaluation tools (Liaghat and Balasundram, 2010).

For the assessment of vegetation condition, currently remote sensing methods can be used, which offers an efficient and non-destructive tool for fast, repeatable and accurate monitoring of large areas. These include multispectral imaging using satellites such as Sentinel-2, LANDSAT 8/9 with free provided data, or in the form of unmanned aerial vehicle (UAV) surveys. The monitoring is carried out in real time, which allows for an operational response to changes in crop cover variability (Segarra et al., 2020). The data from Sentinel-2 and LANDSAT 8/9 satellites, which image the surface in a wide range of spectral bands, have the great advantage of being free and easily accessible from the Internet, but their disadvantage is the very low resolution in the tens of meters as well as the low period of area sensing, which leads to data degradation when clouds are present (Li and Chen, 2020). Unmanned Aerial Vehicles (UAVs) have the great advantage of multispectral imagery with ultra-high spatial resolution in the range of a few centimetres per pixel and are not dependent on atmospheric clouds as they fly at lower flight levels. The disadvantages of using drones at present are the high acquisition cost and the smaller swath width compared to satellites (Tsouros et al., 2019).

Spectral, or vegetation indices, are calculated by fitting the wavelength values of spectral bands to more or less complex mathematical formulas, which can be divided according to Campbell and Wynne (2011) into ratio and orthogonal, resulting in the quantification of a certain feature in the image according to the user's needs (Bannari et al., 1995). Vegetation indices are in precision agriculture used to assess the nutritional and structural status of vegetation, quantify the amount of biomass per unit area, assess evapotranspiration and the amount of water content in biomass, etc. One of the oldest and most widely used vegetation indices is the Normalized Difference Vegetation Index (NDVI), which is used to assess the amount of biomass (Glenn et al., 2008). Currently, there are several dozen vegetation indices such as EVI (Enhance Vegetation Index), NDRE (Normalized Difference Red Edge Index), NRERI (Normalized Red Edge Index), etc., which detect radiation in the red-edge band, where there is a sharp increase in the reflectance of radiation, which allows the detection of very small changes in chlorophyll content.

Zhao et al. (2019) investigated the possibility of using non-destructive Earth remote sensing techniques to detect nitrogen content in plants as one of the most

important indicators for determining their nutritional status, which directly affects grain quality and grain nitrogen content.
The aim of the study was a verification of Sentinel-2 imagery for assessment of crop development and plant diagnosis of cereals and its comparison to proximal sensing methods in the form of hand devices Trimble Greenseeker Handheld and Yara N-tester.

MATERIAL AND METHODS

The paper is based on data from two years of field experiment with the winter wheat (2022) and winter barley (2023) at the site Uhercice (South Moravia region, Czech Republic) with acreage of 29 ha. The land is located in a maize production area with a warm climate. The long-term average temperature for the period 1981-2010 in this area is 9 °C, in 2022, the average temperature was 10 °C. A system of drainages has been constructed on the site to regulate groundwater and prevent waterlogging of the site, i.e. water dynamics may be affected by the action of these drains.

Field survey

Plant sampling was conducted at 21 selected points corresponding to the field variability determined from the preliminary analysis of the field heterogeneity. Aboveground plant material was taken from a 0.25 m^2 area in the critical developmental stage (heading BBCH 31-35) for laboratory analysis of nitrogen content and weight of fresh and dry biomass. Simultaneously, spectral measurement was performed by proximal (handheld) devices, Yara N-tester contact chlorophyll meter and Trimble Greenseeker 2 Handheld for NDVI index measurements. Based on the estimated crop parameters, nitrogen status as Nuptake and Nitrogen Nutrition Index (NNI) were calculated from dry biomass and N concentration (Ncont).

Earth observation data

As the main source of Earth Observation product, Sentinel-2 multispectral satellite data was downloaded free of charge from the Copernicus Open Access Hub near to the date of plant sampling. Data were acquired as surface reflectance (Level L2A) without a requirement of further radiometric and atmospheric corrections. The images were processed with a suite of tools in Python and modified in ESRI ArcGIS Pro. The set of vegetation indices calculated in the study are listed in Table 1. The values of vegetation indices were extracted per each sampling point.

RESULTS AND DISCUSSION

The application of remote sensing and ground-based vegetation mapping methods in precision agriculture makes it possible to monitor the development of vegetation in individual phenophases within individual plots. To assess the relationship between vegetation indices calculated from remote sensing data and the observed stand parameters, a correlation analysis was performed using Statistica software (Tibco, USA) to determine the relationship between the variables. The vegetation parameters monitored were the NNI index calculated from the current and critical plant nitrogen concentration (Lemaire et al., 2008), NDVI values from the Greenseeker meter, N-tester values (N-tester), plant nitrogen content (Ncont), dry aboveground biomass and nitrogen uptake per hectare. In our study, in the 2023 growing season BBCH 31, the NDRE index (R = 0.846), CIRE index (R = 0.846) and IRECI index (R = 0.854) reached the highest correlation values compared to the Greenseeker value, more than half of the vegetation indices reached high correlations with the biomass value calculated by the non-parametric Spearman test in Statistica. In Horniacek et al. (2020), who dealt with the assessment of crop nutrition status using unmanned systems, achieved high correlation values between the nitrogen nutrition index (NNI) and the vegetation index NDRE R = 0.6 at the BBCH 31 vegetation stage. Then, in the BBCH 51 vegetation phase, the highest correlation values were achieved for the EVI2 (R = 0.774), NRERI (R = 0.813) and NDRE (R = 0.567) indices, with the GNDVI vegetation index achieving high correlation values at all sites studied.

Table 1 Correlation coefficients between winter barley parameters and vegetation indices obtained from Sentinel-2 (BBCH 31, year 2023). Values in bold are significant at the p < .05000 level.

	GS	N-tester	Ncont (%)	Biomass (t/ha)	NNI	N-uptake (kg/ha)
NDRE	**0.846**	0.090	0.340	**0.783**	**0.714**	**0.803**
NRERI	0.311	0.281	0.144	0.523	0.512	0.538
CIRE	**0.846**	0.090	0.340	**0.783**	**0.714**	**0.803**
EVI2	**0.707**	0.116	0.264	**0.761**	0.695	**0.779**
EVI	0.696	0.136	0.258	**0.753**	0.666	**0.756**
GNDVI	**0.787**	0.133	0.291	**0.784**	**0.714**	**0.799**
IRECI	**0.854**	0.086	0.262	**0.723**	0.643	**0.740**
NDMI	0.684	0.044	0.249	**0.765**	0.698	**0.774**
NDVI	**0.707**	0.116	0.264	**0.761**	0.695	**0.779**
SRI	**0.707**	0.116	0.264	0.761	0.695	**0.779**
GS	**1**		-0.775	**0.867**	**0.940**	-0.789
N-tester		**1**	-0.987	0.587	0.695	-0.719

Abbreviations	**Meaning**
NDRE	Normalized Difference Red Edge Index
NRERI	Normalized Red Edge Index
CIRE	Chlorophyll Index – Red-Edge
EVI2	Enhanced Vegetation Index
EVI	Enhanced Vegetation Index
GNDVI	Green Normalized Difference Vegetation Index
IRECI	Inverted Red-Edge Chlorophyll Index
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
SRI	Simple Ratio Index
GS	Trimble Greenseeker Handheld
N-tester	Yara N-tester instrument
Ncont	Nitrogen concentration in plants
NNI	Nitrogen Nutrition Index

The vegetation indices NDMI (R = 0.957), EVI2, NDVI and SRI reached the highest correlation values at the sampling date (BBCH 31, winter wheat) in 2022 compared to the values from the Greenseeker instrument (R = 0.948), with the EVI2 and NDVI indices using radiation in the red and near-infrared part of the spectrum (Kouadio et al, 2014). Also, the vegetation indices reached high correlation values with the NNI parameter and the dried biomass parameter, demonstrating the possibility of using these indices to estimate crop N content. The high correlation values with the NNI and N uptake was also determined by the vegetation index GNDVI, which unlike NDVI, uses a green band instead of a red band and is sensitive to photoactive pigments, also reached high values (Alvino et al. , 2020). Although recent studies marked high performance of NRERI index to the determination of N status (Duffkova et al., 2022), this was not confirmed in our study and NRERI showed the lowest correlation coefficient with NNI and N uptake. Mezera et al. (2021) proved that vegetation indices provided by satellite imagery from Sentinel-2 and proximal crop sensors, such as ISARIA, have a high coincidence and both can be used by farmers for estimation of crop status and preparation of variable rate application of fertilizers. Study of Elbl et al. (2021) describes the positive effects of variable rate application of nitrogen fertilizers to the crop yield in comparison with the traditional uniform application.

Table 2 Correlation coefficients between winter wheat parameters and vegetation indices obtained from Sentinel-2 (BBCH 31, year 2022). Values in bold are significant at the p < .05000 level.

	GS	**N-tester**	**Ncont (%)**	**Biomass (t/ha)**	**NNI**	**N-uptake (kg/ha)**
NDRE	**0.908**	**0.725**	-0.753	**0.784**	**0.832**	-0.687
NRERI	0.209	0.020	0.004	0.185	0.218	-0.315
CIRE	**0.908**	**0.725**	-0.753	**0.784**	**0.832**	-0.687
EVI2	**0.948**	**0.702**	-0.728	**0.818**	**0.871**	-0.755
EVI	**0.939**	**0.728**	-0.749	**0.792**	**0.870**	-0.755
GNDVI	**0.942**	**0.722**	-0.743	**0.802**	**0.867**	-0.767
IRECI	**0.925**	**0.742**	-0.766	**0.795**	**0.862**	-0.710
NDMI	**0.957**	0.676	-0.712	**0.864**	**0.891**	-0.719
NDVI	**0.948**	**0.702**	-0.728	**0.818**	**0.871**	-0.755
SRI	**0.948**	**0.702**	-0.728	**0.818**	**0.871**	-0.755
GS	**1**		**0.941**	**0.972**	**0.971**	**0.793**
N-tester		**1**	-0.102	0.059	-0.030	0.029

Both images show the Uhercice site captured by the Sentinel-2 satellite, the left image is captured on 17.4.2022, the right image is captured on 10.4.2023, the brown dots indicate the sampling locations (Figure 1).

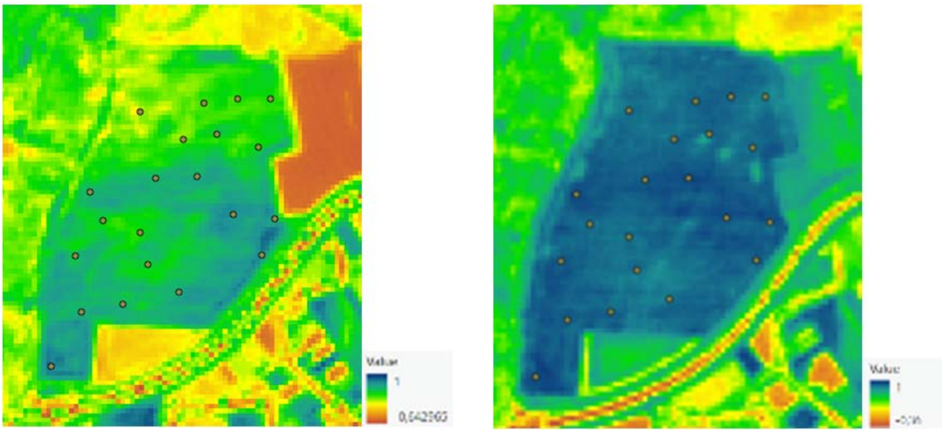

Figure 1. The map of NDVI values from Sentinel-2 data at the experimental site Uhercice for winter wheat (2022, left) and winter barley (2023, right)

CONCLUSIONS

Research carried out in the Czech Republic confirms that it is possible to assess the nutritional status of plants (cereal crops) by remote sensing. The research was based on Sentinel-2 satellite images, which were compared with crop parameters and handheld devices. In 2022, high correlation coefficient values were found for winter wheat between vegetation indices NDMI, EVI, NDVI and SRI compared with the NDVI value obtained from handheld device Trimble_Greenseeker. The correlations confirmed to us that the nitrogen nutrition status can be assessed, as most of the vegetation indices reached high values compared to NNI and desiccated. In 2023, when winter barley was grown on the plot, the vegetation indices NDRE, CIRE and IRECI reached the highest values of correlation coefficients compared to the NDVI values from Greenseeker. Most of the vegetation indices reached high values of correlation coefficients in 2023 compared to the vegetation parameter dried biomass. These findings suggest that despite the medium spatial resolution of Sentinel-2 satellite (10 meters per pixel), the images can be used to assess the nitrogen nutrition status over a large area.

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