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Alternative NDVI combination in maize grain yield estimation

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Abstract. Given the importance of maize production and the wide variation in productivity, early yield estimation might be essential. Several technological devices recently became available and have proven useful in analyzing yield and yield-related traits. In this research, an active multispectral proximal sensor, the Plant-O-Meter (POM), was used in the field trial to provide early yield estimates. The maize crop was grown under field trial conditions with four different levels of nitrogen apply. The purpose of this study was to examine at the effects of three different NDVIs: normalized difference vegetation indices (NDVI), Green NDVI (GNDVI), and Blue NDVI (BNDVI) on maize grain yield estimation over the season. Maize canopy reflectance and various NDVI values were assessed from the fourth leaf growth stage (V4) to the end of the blister stage (R2). Pearson's correlation coefficient (r) was used to evaluate the correlations between grain yield and the various NDVIs obtained throughout the season. Maize grain yield showed a significant positive relationship with various NDVIs throughout the early vegetative stages. The most significant correlation was found between the eight and nine leaf growth stages (V8/V9) and the four leaf growth stage of maize (V4). Among various NDVIs, the BNDVI showed the greatest positive and significant correlation with grain yield. The findings of this study suggest that NDVI measurements could be a useful indicator for assisting in early crop yield estimations.

Keywords: maize crops; yield; spectral reflectance; proximal sensors

INTRODUCTION

Maize is one of the most important grain crops in the world for feed, food, and industrial uses (Mitrović et al., 2020; Revila et al., 2022). Even though the obvious benefits of newly developed varieties, the productive ability of a maize genotype and the potential for maize yield are greatly influenced by a specific combination of various factors, including climate conditions, pests, soil properties, sunlight, crop cultivation practices, seed quality, and the genetic potential of the maize hybrid (Ngoune Tandzi and Mutengva, 2020; Buchaillot et al., 2019; Barošević et al., 2022). Considering the pressure put on modern crop production to maximize yield and minimize inputs, timely monitoring of crop growth status early in the growing season could be of vital importance for in-season site-specific crop management and grain yield estimation, especially in regions characterized by climatic uncertainties (Henik, 2012; Ljubičić et al., 2018; Božović et al., 20018, 2020, 2022; Popović et al., 2013, 2024, 2025). Depending on the crop's function, various methods for predicting maize yields might be utilized over the years. The traditional methods for evaluating these traits

based on direct measurements are usually destructive, time-consuming and could not meet the needs of rapid testing. Different parameters can be used to estimate yield, such the kernel weight at harvest, plot harvested area, plant density and grain moisture level at harvest (Ngoune Tandzi and Mutengwa, 2020). Recent studies suggest that remote sensing has become an important tool in the modernization of field-based high throughput plant phenotyping, including improvements in yield potential, adaptation to abiotic stress and biotic limiting conditions and grain yield estimation (Araus and Cairns, 2014; Pandžić et al., 2019). Compared with remote sensing, proximal sensing, also known as ground-based remote sensing, is carried out by sensors located close to the plants. A large number of spectral reflectance indices (SRI) computed from proximal sensing data has become a useful tool for agricultural monitoring, and assessing within-field crop variability which can support the right decisions in field management. Among various spectral vegetation indices, the Normalised Difference Vegetation Index (NDVI) is one of the oldest and still widely used indexes worldwide. Based on the principle that green vegetation absorbs solar radiation in the red (R) part of the visible electromagnetic spectrum, while strongly reflecting radiation in the near-infrared (NIR) region, NDVI is determined as the difference between the red and near-infrared reflectance divided by their sum (Rouse et al., 1974; Tucker, 1980). Despite the NDVI has been successfully applied in a numerous studies in the last four decades for vegetation monitoring. Since that NDVI is sensitive to variations in atmospheric conditions it does not correct atmospheric effects. It has also short dynamic range and underestimates sparse vegetation because of soil effects and rapidly saturates at very high vegetation density because it weighs the red and near-infrared bands the same in its formula (Solymosi et al., 2019). To resolve the saturation problem which usually occurs with NDVI values, several researchers have explored comparisons to different modified indices based on NDVI, such as a blue NDVI, green NDVI (Huang et al., 2016). Green Normalized Difference Vegetation (GNDVI) is one of the several commonly used vegetation indices for estimating water and nitrogen uptake in plant canopy. It measures plants' greenness or photosynthetic activity. It is a chlorophyll index used later in development because it reaches saturation later than NDVI based on the red band. Blue Normalized Difference Vegetation (BNDVI) based on the blue band, have better capacity to describe leaf density because the blue band is known to be a good descriptor for distinguishing between vegetation and other background imagery. GNDVI is an indicator of the photosynthetic activity of the vegetation cover; primarily used to determine the moisture content and N concentration in plant leaves; for estimationn impact of aging and depressed plants (Yang et al., 2004). However, there have been only a few studies on the use of different combinations of NDVI data to estimate yield. Therefore, throughout the growing season the broad band NDVI and two other NDVI type indices, the blue NDVI (BNDVI) and green NDVI (GNDVI), were calculated with aim to assess the most appropriate NDVIs in maize yield estimation.

MATERIALS AND METHODS

The experiment was performed during the 2021 growing season in a field trial in Ravno Selo, near Novi Sad, Serbia. The field trial was set up at the Chernozem type of soil, in typical semiarid conditions. The present study comprised four different maize cultivars (*Zea mays* L.) of different maturity classes (P9074, P97557, P9889, and P0725) subjected to five different nitrogen applications (0, 70, 140, and 210 kg N ha^{-1}) as pre-plant applications. The field trial was conducted using a randomized block design with three replications. The study examined the relationship between various vegetation indices and grain yield. Plant-O-Meter (POM), an active, multispectral optical sensor created recently by the BioSense Institute in Serbia, was used to measure crops. The Plant-O-Meter device

contains a multispectral source, which combines six light sources in a single optical module. On the basis of six band combinations (Blue: 455 nm; Green: 528 nm; Red: 657 nm; Red Edge: 740 nm; NIR1: 810 nm; and NIR2: 940 nm). The sensor's light source is designed to minimize sunlight in each circumstance (Kitić et al., 2019). Sensor readings were taken throughout the season, from maize's V4 (4 completely developed leaves) to VT/R1 (tasseling and silking). In-field reflectance measurements were made by holding the POM about 60 cm above the crop canopy and screening the two centre rows in continuous mode at a frequency of 1Hz. Before processing the data using GIS software, the central area of each measurement row was chosen, resulting in two middle rows per plot. The broad different spectral wavebands and three different NDVI indices, the red NDVI (NDVI), blue NDVI (BNDVI) and green NDVI (GNDVI) were calculated. Normalized Difference Vegetation Index (NDVI) were calculated based on accounting for the difference between red and NIR reflectance as follows: NDVI = (NIR–RED) / (NIR + RED), where NIR presents a near-infrared band within 810 nm and RED presents a red spectral band within 657 nm. Green Normalized Difference Vegetation Index (GNDVI) were calculated based on the difference between visible green and NIR reflectance as follows: NDVI = (NIR – GREEN)/(NIR + GREEN), where NIR presents near-infrared band within 810 nm and visible green present red spectral band within 528 nm. Blue Normalized Difference Vegetation Index (BNDVI) uses visible blue instead of visible red and near infrared reflectance as follows: BNDVI = (NIR–BLUE)/(NIR+ BLUE), where NIR present near-infra red band within 810 nm and BLUE presents a blue spectral band within 455 nm. Correlation coefficients among yield and the three different vegetation indices were determined. Pearson correlation coefficients were applied to examine the relationship between grain yield and different NDVIs. All the statistical analyses were performed using the STATISTICA program, version 13 (StatSoft Inc., Tulsa, OK).

RESULTS AND DISCUSSION

In present study, the relationship between three NDVI vegetation indices and overall grain yield of maize has been estimated. Average grain yield and NDVI indices of the investigated maize crop are presented in Table 1. The results showed a wide range between the minimum and maximum values for observed NDVI indices throughout the growing stages. The greatest values varied on an overall basis. The greatest values throughout all observed growth stages were observed for index BNDVI (0.814) at the V8/V9 growth stage, while the lowest values were noticed for GNDVI in VT/R1 in the growth stage, having a value of 0.571. In respect to the V4 growth stage, the greatest values were observed for the BNDVI (0.753), NDVI (0.651), and GNDVI (0.626). The standard deviation was the highest for the NDVI (0.073), while the lowest for the BNDVI (0.042). In relation to the V7 growth stage, the greatest values were observed for the BNDVI (0.802), than for the NDVI (0.738), and for the GNDVI (0.638). The standard deviation was the highest for the GNDVI (0.049), while the lowest for the BNDVI (0.031). With respect to the V8/V9 growth stage, the greatest values were observed for the BNDVI (0.814), than for the NDVI (0.759), and for the GNDVI (0.635). The standard deviation was the highest for the GNDVI (0.049), while the lowest for the BNDVI (0.029). In respect to the VT/R1 growth stage, the greatest values were observed for the BNDVI (0.711), than for the NDVI (0.615), and for the GNDVI (0.571). The standard deviation was the highest for NDVI and BNDVI (0.064), while the lowest for the GNDVI (0.054). In respect to the R2 growth stage, the greatest values were observed for the BNDVI (0.665), than for the NDVI (0.664), and for the GNDVI (0.585). The standard deviation was the highest for the NDVI (0.097) and the lowest for the GNDVI (0.074). Regarding the NDVI indices, the overall mean values of the NDVI indices varied from 0.759 at the V4-leaf growth stage (V4) to 0.615 at tasseling and silking (VT/R1). Concerning GNDVI values, the results showed that maximum values of GNDVI were observed during V7-leaf stage, having a value of 0.638, and

V8/V9-leaf growth stage (V9), with observed values of 0.635. The lowest mean values were observed at VT/R1, having values from 0.571. Regarding the BNDVI, the greatest values were observed at V8/V9, having values of 0.814. Through the later growth stages, all NDVI indices gradually declined, reaching the minimum values at the blister stage of maize (R2), Table 1. Observed the greatest values of all observed NDVI indices in V8/V9 stages before tasseling and silking stage (VT/R1) was expected since in this period of intensive growth of maize, the photosynthesis was at the highest point and the leaf area was largest. The NDVI consistently rises during the vegetative until early reproductive stages, notably at the period of maximal leaf area development, which occurs between the V6 and V10 growth stages. This occurs when the plants are completely green and photosynthetically active, which results in higher NDVI values. As the plant matures and passes through the grain-filling stage, NDVI could decline as the leaves begin to senesce. These findings are in agreement with previous reports (Teal et al., 2006, Lu et al., 2011; Lu et al., 2012).

Obtained results indicated that the reflectance of visible wavelengths increased throughout the growth season and towards the end of the season, whereas the reflectance of NIR decreased due to senescence and reduced absorption of visible light in maize leaf surfaces. The findings are consistent with those published by Zhao et al. (2023). Lopes and Reynolds (2012) also found that NDVI depends from several plant traits such as a leaf development, chlorophyll levels, photosynthesis, stay-green traits, grain production and aboveground biomass. The largest values of standard deviation during VT/R1 growth stage should be expected given that the plants displayed the least uniformity during the tasselling and silking stages of maize development. During the reproductive stage, plants frequently exhibit greater variation in leaf color, which ranges ranging from deep green to a light brown. These conclusions are similar to those found by Vian et al. (2018) and Raun et al. (2005).

The results of the correlation analysis between different NDVIs and grain yield of revealed that maize crops responded differently over the vari-

Table 1. The mean values of different NDVIs and grain yield throughout the maize growing season

Growth stage of maize															
V4			**V7**			**V8/V9**			**VT/R1**			**R2**			
NDVI indices															
NDVI	**GNDVI**	**BNDVI**	**NDVI**	**GNDVI**	**BNDVI**	**NDVI**	**GNDVI**	**BNDVI**	**NDVI**	**GNDVI**	**BNDVI**	**NDVI**	**GNDVI**	**BNDVI**
Mean values															
0.651	0.626	0.753	0.738	0.638	0.802	0.759	0.635	0.814	0.615	0.571	0.711	0.664	0.585	0.665
Maximum values															
0.420	0.487	0.623	0.596	0.467	0.691	0.637	0.484	0.669	0.412	0.361	0.393	0.450	0.460	0.508
Minimum values															
0.785	0.716	0.837	0.811	0.738	0.859	0.814	0.725	0.867	0.750	0.706	0.817	0.801	0.676	0.782
Standard deviation															
0.073	0.044	0.042	0.042	0.049	0.031	0.031	0.048	0.029	0.064	0.054	0.064	0.097	0.040	0.074
							GY								
							8,460								

**NDVI: The normalized difference vegetation index; *GNDVI: Green Normalized Difference Vegetation Index; *BNDVI: Blue Normalized Difference Vegetation Index; *GY: Mean grain yield (t ha^{-1}), V4: four developed leaves, V7: seven developed leaves, V8/V9: eight to nine developed leaves, VT/VR1: tasseling and silking stage, R2: blister stage of maize development*

ous stages and different correlations were established between certain NDVIs and grain yield. The estimated correlations of different NDVIs with grain yield showed that highly significant and positive association between NDVIs and grain yield was observed in the V8/V9 (eight to nine leaves developed) stage of maize. Among various NDVIs, the greatest correlation was observed between yield and BNDVI (r = 0,408**) than for NDVI (r = 0,391**) and GNDVI (r = 0,366**). The significant, but lower positive association was also observed at the V4 (four leaves developed) growth stage. In respect to the association between different NDVI indices and grain yield, the greatest correlation was observed for BNDVI (r = 0,396**), GNDVI (r = 0,345**), and NDVI (r = 0,322**), Table 2.

A strong association that exists between NDVI and grain yield at the V-8 leaf development stage of maize suggested that this growth stage is a deciding factor in maize yield estimation. According to the Cabrera-Bosquet et al. (2011) it is related to the maximal biomass that maize acquire in this stage. Hybrid maize genotypes that gain higher aboveground biomass during the vegetative stage undoubtedly could produce more grain yield when growing conditions are appropriate. Maize crop in the intensive growth stage with abundant green biomass showed the highest values of each NDVI, while the greatest correlation in this stage indicated that the potential to produce high grain yields. These results are in accordance with previous findings reported by (Islam et al., 2011; Adebayo et al., 2014). A similar report was reported by Adebayo et al. (2014). In respect to various NDVI indices, BNDVI index were shown generally better than the other NDVI combinations in all observed growth stages. This index is a chlorophyll sensitive index that not uses the red channel and relies on visible blue. NDVI, based on NIR and the red band, showed a slightly lesser value than BNDVI since it is a good descriptor of photosynthetic activity because the more red lights that is absorbed by leaves, the higher the potential photosynthetic activity. According to Vina et al. (2004), BNDVI increases throughout the early growing season, peaked during flowering, and declined as senescence progressed. The accuracy of the data obtained using BNDVI was also shown in monitoring flowering time in maize crop (Wu et al., 2019). The main advantage of BNDVI is that the blue band could help reduce soil background effects, increasing the accuracy of vegetation assessments, especially in the initial development stages when maize does not completely cover the soil. It can provide more effective biomass estimations, especially in high canopy density where ordinary NDVI indices may saturate. In early growth stages, where maize is lacking, BNDVI can provide more accurate assessments of vegetation cover and overall plant condition than standard NDVI, which might not differentiate between soil and plant signals. The significant positive, but slightly lower association between grain yield and GNDVI at almost all observed stages can be explained by GNDVI being useful for evaluating photosynthetic rates and monitoring plant stress levels. GNDVI poses possibility to reduce the impact of soil reflectance, improving the accuracy of vegetation as-

Table 2. The correlation different NDVI indices and maize grain yield across the growing season

NDVIs	Growth stage of maize				
	V4	V7	V8/V9	VT/R1	R2
NDVI	0.322**	0.209	0.391**	-0.158	0.151
BNDVI	0.396**	0.370**	0.408**	0.137	0.175
NDVI	0.345**	0.136	0.366**	-0.063	0.165

***Correlation significant at the 0.01 level, *Correlation significant at the 0.05 level, *NDVI: The normalized difference vegetation index; *GNDVI: Green Normalized Difference Vegetation Index; *BNDVI: Blue Normalized Difference Vegetation Index, V4: four developed leaves, V7: seven developed leaves, V8/V9: eight to nine developed leaves, VT/VR1: tasseling and silking stage, R2: blister stage of maize development*

sessments in areas where crops are not yet fully developed. According to Yao et al. (2024), GNDVI possess sensitivity to green light reflection makes it particularly effective in detecting vegetation health and its estimation is valuable due to its direct correlation with chlorophyll content. Even though neither NDVI proved to have a notable advantage over the other, BNDVI based on the blue band appears to be more indicative than the other obtained NDVIs, displaying that a variety of NDVI combinations can be used to estimate grain yield. However, when combined with standard NDVI and Blue NDVI, Green NDVI can provide an improved understanding of crop health, enabling better management decisions. The results also revealed that leaf development and intensive grow period during the vegetative stage of maize are quite indicative stage for yield assessment. Although various NDVI indices should offer more precise data and a better understanding of data gathered, the findings presented here indicated the need for including additional studies for a better assessment of maize plant status and grain yield estimation.

CONCLUSIONS

The phenological state of the plants has been confirmed as a key factor in estimating final yield. Predicting maize grain yield prior to harvest is critical for monitoring maize productivity. By comparing the predicted yield to the expected values, one can draw conclusions about the plant status and vigour of the plants and make decisions accordingly. Based on the current findings, it can be stated that acceptable maize grain yield estimation is achieved by measuring between the V8/V9 and V4 growth stages, since the results demonstrated a significant positive relationship between reflectance in all NDVI combinations (NDVI, BNDVI and GNDVI). Although neither NDVI appeared to have a significant advantage over the other, BNDVI based on the blue band appears to be more indicative than the other NDVIs obtained, implying that various NDVI combinations can also be utilized to measure grain yield. The results also demonstrated that leaf development and intensive growth during the vegetative stages of maize are quite indicative stage for yield assessment. These findings can be used not only for grain estimation, but also for maize management decisions in production, to better understand the variability in spatial distribution of maize production. Since the optimal stages of NDVI measurement are additionally influenced by complex environmental conditions, more research in a variety of environments is required to test and assess multispectral POM sensor performance across all field situations.

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Conflicts of Interest: The authors declare no conflict of interest.

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