COMPARISON OF SPECTRAL INDICES DERIVED FROM ACTIVE CROP CANOPY SENSORS FOR ASSESSING NITROGEN AND WATER STATUS

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ABSTRACT

Much of the previous evaluation of active crop canopy sensors for in-season assessment of crop N status has occurred in environments without water stress. The impact of concurrent water and nitrogen stress on the use of canopy sensors for in-season N management is unknown. The objective of this study was to evaluate the performance of various spectral indices for sensing N status of corn, where spectral variability might be confounded by water-induced variations in crop reflectance. The study was conducted in 2009 with experimental treatments of irrigation level (100 and 70% ET), previous crop (corn or soybean) and pre-plant nitrogen fertilizer rate (0, 75, 150 and 225 kg N/ha). Crop canopy reflectance was measured from V11 to V15 using two active sensors – a two band (880 and 590nm) and a three band (760, 720 and 670 nm). Among the indices studied, the MTCI index was the least affected by water stress, with good ability to differentiate N rate with both crop rotations. The CI_{amber} and $NDVI_{red}$ indices showed more variation due to water supply, and had only moderate ability to differentiate N rates.

Keywords: active canopy sensors, site-specific nitrogen management, precision agriculture, water stress

INTRODUCTION

In-season nitrogen management for corn using active canopy sensors relies on the use of algorithms that can trigger on-the-go N fertilization in the field based on crop canopy reflectance. Optical sensing equipment that employs this approach is commercially available and all use some vegetation index as the basis for input with an algorithm that dictates the N rate application in the field according to crop reflectance (Shanahan et al., 2008; Eitel et al., 2008).

There are different approaches and vegetation indices used to determine N rate based on these sensors, but the majority of algorithms use the nitrogen sufficiency index (NSI) approach previously proposed for chlorophyll meter readings (Varvel et al., 1997). For example: when the vegetation index ratio between a region in the field and a well-fertilized reference in the same field reach a certain level, nitrogen fertilizer is needed according to a function that describes the relationship between yield and sufficiency index readings (Bausch and Duke, 1996). Some algorithms consider yield potential in the N rate recommendation, including in the calculation the indirect measurement of biomass dividing the Normalized Difference Vegetation Index (NDVI) by growing degree days at the time of sensing (Raun et al., 2002). Several vegetation indices have been used to calculate N rate for corn and wheat using active canopy sensors, e.g. Green Normalized Difference Vegetation Index (GNDVI) (Dellinger et al., 2008); Chlorophyll Index (CI_{amber}) (Solari et al., 2008) and NDVI (Raun et al., 2002).

Disregarding the approach to be used, an understanding is needed of how these indices may be influenced by water stress and previous crop. Previous work by Eitel et al (2008) investigated the impact on LAI (due to water availability) and nitrogen stress in wheat using a multispectral radiometer and a chlorophyll meter. They showed that the ratio of the modified chlorophyll absorption ratio index to the second modified triangular vegetation index (MCARI/MTVI2) are sensitive to N and less susceptible to LAI changing due to water stress. There are others examples of indices used specifically to detect water stress (Zygelbaum et al., 2009) and others to determine chlorophyll content and estimate gross primary productivity (LeMaire et al., 2004). All of these indices use radiometers or other passive sensors, so the use of active canopy sensors to calculate vegetation indices to be used for in-season N management, and their influences by water stress and previous crop in corn production is unknown. The objective of this study was to evaluate the performance of various spectral indices for measuring N status in corn, where spectral variability might be confounded by water-induced variations and previous crop influences on the reflectance spectra.

MATERIAL AND METHODS

Experimental Site Description and Statistical Design

The experimental site was a field at the University of Nebraska South Central Agricultural Laboratory near Clay Center, NE during the 2009 growing season, The study was conducted with experimental treatments of irrigation level (100 and 70% ET) using a linear-move sprinkler system, previous crop (corn after corn - CC or corn after soybean - CS) and pre-plant nitrogen fertilizer rate (0, 75, 150 and 225 kg N/ha).

The experimental design was a randomized complete block split plot, with irrigation level as the main plot, previous crop as the subplot, and fertilizer N rate as sub-subplots. The field was planted May 6, 2009 with Pioneer hybrid 33H29, using a plant population of 72610 plants/ha with a row spacing of 76.2 cm, and managed to supply all other nutrients required for high yield corn production.

Crop Canopy Sensing

Crop canopy reflectance was measured from V5 to R6 using two active canopy sensors – a two band sensor, Crop Circle 210 (880 and 590nm), and a three band sensor, Crop Circle 470 (760, 720 and 670 nm). The platform used for sensor data acquisition at several growth stages of corn was a bicycle modified to support two optical sensors, a Trimble GeoXT GPS receiver and laptop computer. This platform had the ability to maintain a distance of at least 60 cm between sensors and the top of the crop canopy throughout the growing season. Each plot (9.14 x 6.09 m) had 8 rows and the same rows (3 and 6) were sensed at each growth stage with about 30 sensor readings per plot for the plot average calculation.

Vegetation Indices

Five vegetation indices were evaluated for their potential to differentiate nitrogen rates with different irrigation levels and previous crop (Table 1). The criteria for index selection for N assessment was guided by the ranking proposed by Le Maire (2004) where the RMSE was minimized and the agreement with the PROSPECT Model was maximized for chlorophyll estimation and consequently nitrogen status of the crop, due to high correlation between these two variables. Some of the indices studied were included because of traditional use, e.g. (NDVI) and prior work using active canopy sensors, e.g. (CI_{amber}).

Table 1. Vegetation index formulas and wavebands used in this study.

Indices	Wavebands (nm)	Formula	Source
1.CI_{amber}	880, 590	$CI_{amber} = (R_{880}/R_{590}) - 1$	Gitelson et al, 2005
2.$CI_{red\ edge}$	760, 720	$CI_{red\ edge} = (R_{760}/R_{590}) - 1$	Gitelson et al, 2005
3.MTCI	760, 720, 670	$MTCI = (R_{760}-R_{708})/(R_{720}-R_{670})$	Dash & Curran, 2004
4.$NDVI_{red}$	760, 670	$NDVI_{red} = (R_{760}-R_{670})/(R_{760}+R_{670})$	Rouse et al, 1974
5.$NDVI_{red\ edge}$	760, 720	$NDVI_{red\ edge} = (R_{760}-R_{720})/(R_{760}+R_{720})$	Rouse et al, 1974

RESULTS AND DISCUSSION

Generally 2009 had good growing conditions at the beginning of the season in terms of ambient conditions such as temperature and rainfall. Irrigation commenced around the V10 growth stage, which is normal for this region (Figure 1). The level of water applied via irrigation illustrated in Figure 1 refers only to the 100% ET treatment.

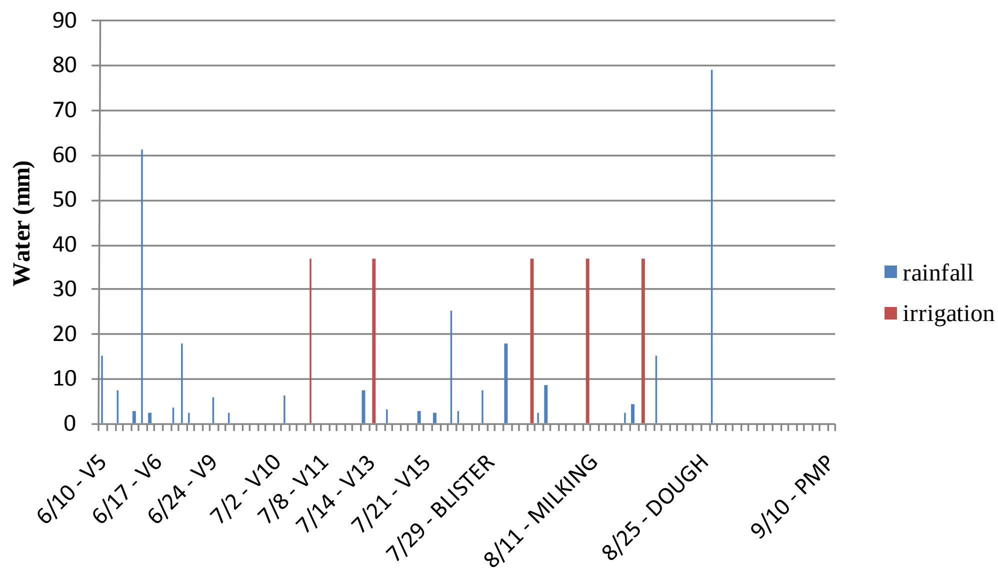

Figure 1. Daily rainfall and irrigation for the 2009 growing season, South Central Agricultural Laboratory. Dates shown are when canopy reflectance was collected.

Treatment Effects on Grain Yield

Average grain yield was high and optimized by irrigation. The N x rotation interaction was statistically significant, indicating that yield responses were different between the two crop rotations studied (Table 2 and Figure 2).

Table 2. Analysis of variance of corn yield over 70 and 100 % ET and different crop rotations (CC and CS).

Source of variation	df	F Value	Pr > F
N	3	51.93	<.0001
Rotation	1	162.33	<.0001
Water	1	6.53	0.0156
N*Rotation	3	8.26	0.0003
N*Water	3	0.13	0.9409
Rotation*Water	1	0.01	0.9346
N*Rotation*Water	3	0.64	0.5918

The yield difference between crop rotations were very high (2944 kg/ha) and significant averaging 70 and 100 % ET. At 70 % ET the yield differences between CC and CS were 2924 kg/ha (p>0.0001) and the yields were 10763 kg/ha and 13688 kg/ha respectively. For 100% ET the differences were similar (2963 kg/ha) but the yield levels higher, 11334 and 14294 kg/ha.

Analyzing water effects on grain yield, there were no interactions between water and N or rotation. Grouping water levels disregarding crop rotation scheme, the difference of 70 and 100 % ET was significant (p>0.013) with 12225 and 12816 kg/ha for 70 and 100 % ET respectively. On average the water levels were significant yielding 12816 kg/ha against 12225 kg/ha, 591kg/ha advantage for 100% ET when the two rotation schemes were analyzed together (p > 0.01). For CC rotation the yields were 11334 and 10763 kg/ha for 100 and 70% ET respectively with an increase of 571 kg/ha due to full water supply (p>0.09). For CS rotation the yields were 14297 and 13688 kg/ha for 100 and 70 % ET with a difference of 609 kg/ha (p>0.08). All N rates significantly increased corn yield in the CC rotation, although in the CS rotation yield using N rates of 150 and 225 kg N/ha were not different (Figure 2).

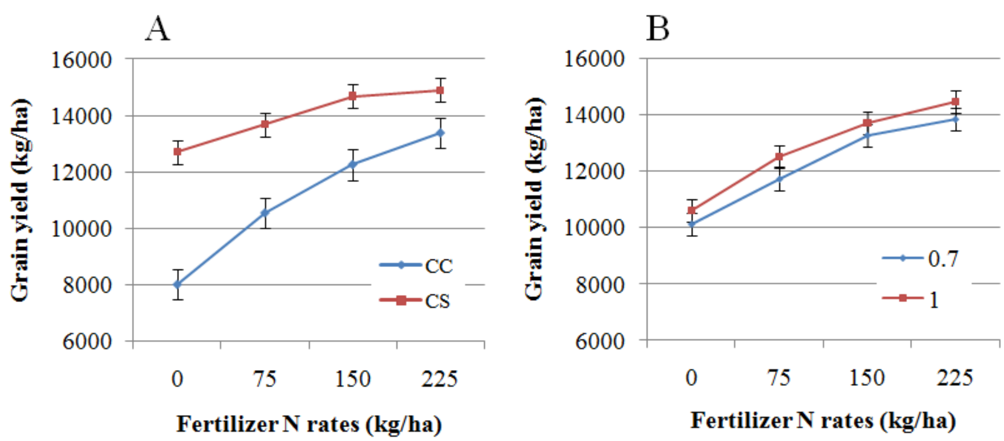

Figure 2. Grain yield at several nitrogen rates under different rotations (A) and water levels (B). Errors bars represent statistically significant differences according to Duncan's test (p > 0.1).

Treatment Effects on Vegetation Indices

In order to focus on growth stages in which active crop canopy sensors will be used to manage in-season N fertilization, only spectral reflectance data collected at the V11, V13 and V15 growth stages were included in this analysis. Earlier analysis has shown that N rate differences are difficult to detect prior to the V8 growth stage, and least for Nebraska conditions. The analysis of variance for vegetation indices (Table 3) indicated that during the period of V11 through V15 there were few incidences of statistically significant four and three-way interactions of treatment effects on vegetation indices. Of primary interest then are the significant two-way interactions involving growth stage, rotation and N rate. For example, the N*Rotation interaction was significant for all indices.

Table 3. Analysis of variance of five vegetation indices calculated from active canopy sensors at 70 and 100% ET and different crop rotations (CC and CS) during growth stages V11 – V15.

V11, 13, 15		CI_{amber}	$CI_{red\ edge}$	MTCI	$NDVI_{red}$	$NDVI_{red\ edge}$
Source of variation	**df**			**Pr > F**		
N	3	<.0001	<.0001	<.0001	<.0001	<.0001
Rotation	1	<.0001	<.0001	<.0001	<.0001	<.0001
N*Rotation	3	<.0001	<.0001	<.0001	<.0001	<.0001
Water	1	0.2875	0.5840	0.9307	0.4452	0.4189
N*Water	3	0.2585	0.6714	0.7841	0.7284	0.8349
Rotation*Water	1	0.7261	0.3621	0.6224	0.3900	0.6498
N*Rotation*Water	3	0.9675	0.8895	0.9705	0.9321	0.9600
Stage	2	<.0001	<.0001	<.0001	<.0001	<.0001
N*Stage	6	0.1651	<.0001	<.0001	0.0009	<.0001
Rotation*Stage	2	0.2545	0.0090	<.0001	0.3493	<.0001
N*Rotation*Stage	6	0.8775	0.2224	<.0001	0.6898	0.0273
Water*Stage	2	0.8702	0.8214	0.7684	0.8387	0.4371
N*Water*Stage	6	0.9421	0.9897	0.9553	0.9219	0.9985
Rotation*Water*Stage	2	0.8913	0.0586	0.8073	0.0837	0.4283
N*Rotation*Water*Stage	6	0.1956	0.3486	0.8810	0.5200	0.6872

Among the indices proposed for N assessment, only CI_{amber} did not have a significant N*Stage interaction, indicating that this index might require a specific growth stage within this window to be able to differentiate N rates. All other N management indices could be used for managing N without concern about growth stage during this important period for in-season N application. The $CI_{red\ edge}$ and $NDVI_{red\ edge}$ indices had similar responses, but $NDVI_{red\ edge}$ had a significant N*Rotation*Stage interaction, indicating $NDVI_{red\ edge}$ may vary in its ability to differentiate N rates at these growth stages (V11 – V15).

To illustrate responses for the indices tested considering different N rates at different water levels, the V11 growth stage was selected for all indices disregarding rotation. Index values were normalized (actual index value divided by the mean index value across N rates) to facilitate comparison among indices (Figure 3). The $NDVI_{red\ edge}$ index is not shown because it was very similar to $CI_{red\ edge}$, but it is important to point out that the slope of response for N rates are smaller as expected when NDVI is used to estimate chlorophyll content or biomass (Gitelson, et al, 1996).

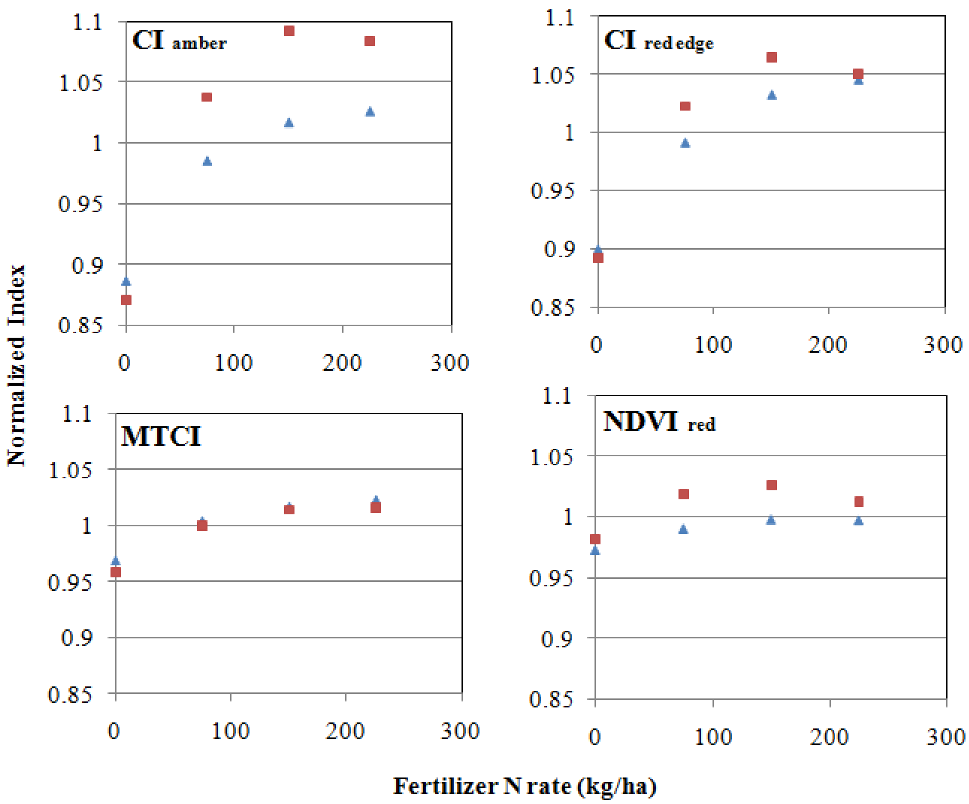

Figure 3. The response of vegetation indices at the V11 growth stage to N rate and water supply.

Among all indices tested the MTCI index was least influenced by water level. This may be particularly important in environments where water stress is likely in conjunction with N stress. In general, we observed in this experiment that corn plants under water stress (70% ET) had changes in leaf structure rather than LAI, but only in later stages (after VT). In corn production, impacts of water stress will vary with growth stage, but water stress at early growth stages will affect LAI the most (Çakir, 2004).

In terms of potential for N rate differentiation considering different crop rotations and disregarding water levels, the $CI_{red\ edge}$, MTCI and $NDVI_{red\ edge}$ indices could differentiate 0, 75 and 150 kg N/ha at CC rotation at all growth stages, while CI_{amber} index was able only to differentiate N rates at the V15 growth stage. The traditional $NDVI_{red}$ could differentiate only 0 kg N/ha from the other rates. Among all indices tested, the $CI_{red\ edge}$ and MTCI indices were found to have the best ability to differentiate N rates. For this reason, these indices are used to illustrate response to different rotations (Figure 4). The MTCI index was the only index that could differentiate 0, 75 and 150 kg N/ha with the CS rotation at the V15 growth stage (Figure 4).

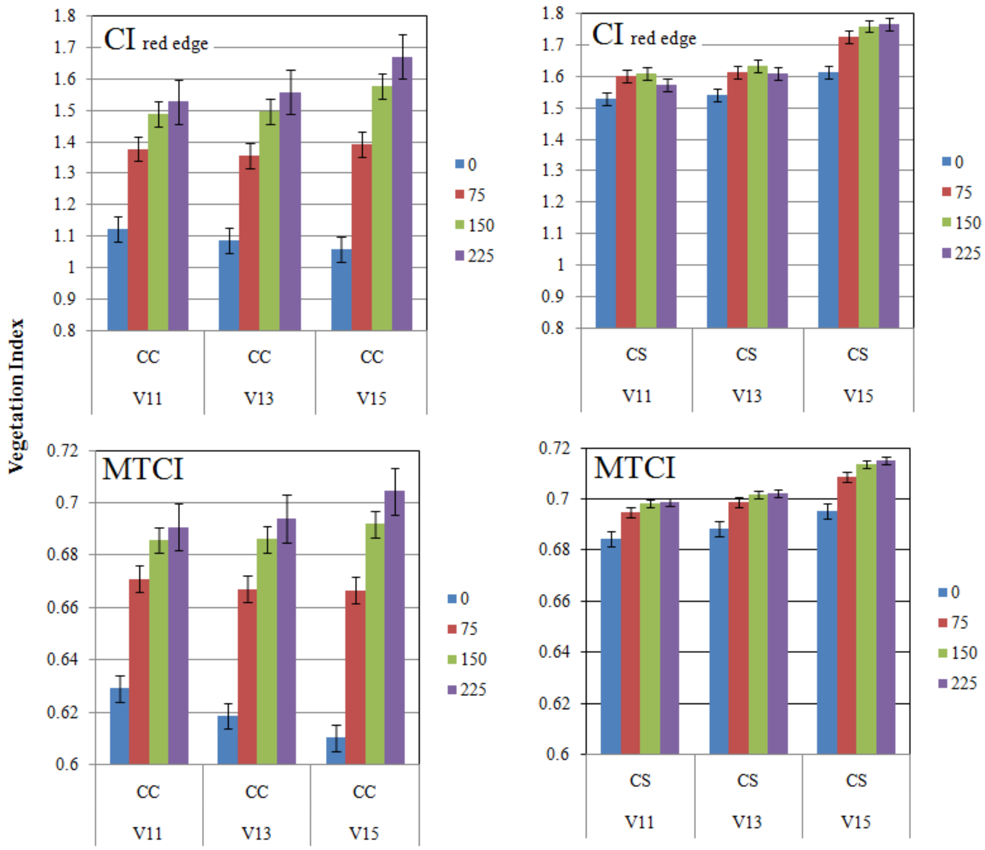

Figure 4. The effect of previous crop (CC and CS) and growth stage on crop reflectance using two vegetation indices, $CI_{red\ edge}$ and MTCI, averaged across water level. Errors bars represent statistically significant differences according to Duncan's Multiple Range Test ($p > 0.1$).

Association of Vegetation Indices and Grain Yield

At the growth stages evaluated (V11, 13 and 15), all vegetation indices showed high correlation with final grain yield (Figure 5). The $NDVI_{red\ edge}$, CI_{red_edge} and MTCI indices showed higher, and similar, correlations at all growth stages studied, even higher than the chlorophyll meter (SPAD) and CI_{amber}. The $NDVI_{red}$ indices had lower correlation with final grain yield at V11 and V13 growth stages compared to other indices. All correlations showed the same trend of increasing with growth stage.

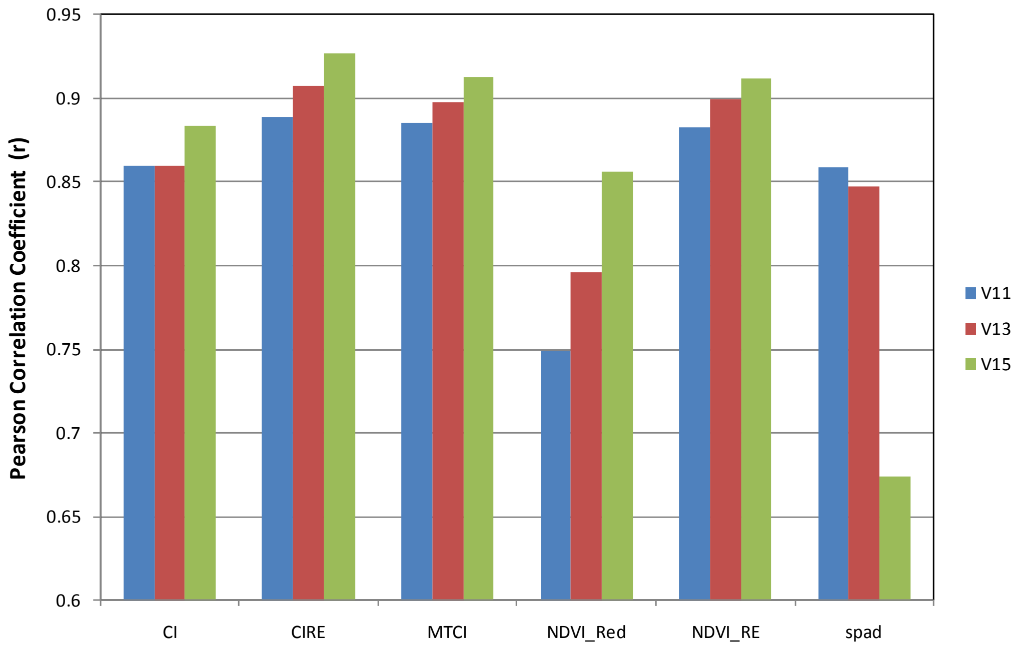

Figure 5. Pearson Correlation coefficient values for the association of absolute vegetation indices and final grain yield for three growth stages.

SUMMARY

The intent of this paper is to present how crop reflectance, measured by different vegetation indices, behaves under different levels of water supply, nitrogen rate and previous crop. We investigated the ability of these indices to differentiate N rate under these conditions, and the correlation of indices collected during vegetative growth stages with grain yield. Among the indices studied, the MTCI index was the least affected by water stress, with good ability to differentiate N rate with both crop rotations. The CI_{amber} and $NDVI_{red}$ index showed more variation due to water supply, and had only moderate ability to differentiate N rates. More research is needed to evaluate these indices under a wider range of water stress.

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