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IN-SEASON ASSESSMENT OF WHEAT CROP HEALTH USING VEGETATION INDICES BASED ON GROUND MEASURED HYPER SPECTRAL DATA

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ABSTRACT

An experiment on a 50 ha center pivot field was conducted to determine the Vegetation Indices (VI's) that were helpful in assessing the in-season performance of wheat crop treated with graded levels of irrigation water and fertilizers. The irrigation levels were at 100, 90, 80 and 70% Evapotranspiration (ETc); however, the fertilizer levels of N: P: K kg^{-1}ha included 300:150:200 (low); 400:250:300 (medium) and 500:300:300 (High). The crop was sown on January 1st and harvested on May 9th, 2012. Temporal data on biophysical parameters and reflectance of the crop in hyper spectral bands (350-2500 nm) were collected at booting and ripening growth stages (February 17th and April 5th, 2012). Results of the study revealed that many of the tested spectral indices showed significant response to irrigation levels. Out of those, only two spectral indices (Plant Senescence Reflectance Index 'PSRI' and Photochemical Reflectance Index 'PRI') also exhibited significant response to fertilizer levels. The Middle Infrared-Based Vegetation Index (MIVI) showed a significant response to the irrigation levels for both sampling dates. Among the tested spectral indices, Normalized Difference Infrared Index (NDII) and Normalized Difference Nitrogen Index (NDNI) exhibited the highest correlation to crop Leaf Area Index (LAI). Five indices showed the most response to wheat grain yield. These indices included Near Infrared band (NIR), Water Band Index (WBI), Normalized Water Index-1 (NWI-1), Normalized Water Index-3 (NWI-3) and Normalized Water Index-4 (NWI-4).

Keywords: Remote Sensing, Spectral Reflectance, Vegetation Indices, Wheat

1. INTRODUCTION

The use of remote sensing applications for crop growth monitoring is becoming an essential part of today's agriculture as it enhances the efficient management of agricultural resources. Because of the strong impact of deficiencies in the essential nutrients on crop growth and yield, assessment of biophysical parameters is necessary for monitoring crop performance and improving crop yield by site specific application of crop chemicals (Haboudane *et al*., 2007). According to the fact that crop phonological stages and growth period vary in different areas and cropping seasons and to the fact that crop phenology is affected by both weather variations and regional planting habits, determination of the important crop phonological stages is a key factor for modeling crop performance as well as improving the accuracy of crop type classification and yield estimation (Meng *et al*., 2009). The key factor for precision crop growth monitoring is the selection of the efficient devices and methods for the accurate measurements of crop growth parameters.

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Crop spectral reflectance measurements are being used efficiently for crop growth monitoring as they reflect wide range of biochemical and physiological measures. Thus, remote sensing applications based on the measurement and interpretation of the spectral reflectance of agricultural crops are considered as the most important tools for the assessment of crop growth and yield performance (Aparicio *et al*., 2000).

Hyper-spectral data provides significant information for discriminating land cover types, identifying small differences in green vegetation cover and crop moisture, in addition to the detection of plant stress. However, large volume of data poses a challenge for data processing and extracting crucial information. Therefore, the analysis of hyper-spectral data, to clearly interpret plant response to management practices, is crucial (Stellacci *et al*., 2012) Spectral vegetation indices, determined mathematically at various spectral bands, are considered as semi-analytical measures of vegetation activity and appropriate for the assessment of spatial variability in agricultural fields (Vina *et al*., 2011). These vegetation indices will enhance the interpretation process of the crop spectral reflectance measured at different growth stages and hence will help in understanding the response of agricultural crops to management practices. Therefore, remote sensing based on various vegetation indices (VI) is expected to provide important information that will help in the efficient assessment of within-field spatial variability of various agronomic parameters (Hatfield and Prueger, 2010).

Leaf Area Index (LAI), defined as the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows, is characterized as one of the most essential structural parameter of crop canopy (Lan *et al*., 2009). Also, LAI is considered as one of the most important biophysical parameters for the assessment of crop performance (vegetation health, biomass and photosynthesis) and for estimating crop yield. Monitoring the crop LAI during the cropping season will help in understanding the spatial variability in crop productivity. On the other hand, LAI can serve as indicator of stress in vegetation, crop growth performance and energy exchange (Duchemin *et al*., 2006; Zhang *et al*., 2012) According to problems associated with the in-situ measurement of Leaf Area Index (LAI), as it is considered to be time-consuming, expensive and sometimes unfeasible, developments in the field of hyper spectral remote sensing provide new ways for monitoring plant growth through the estimation of vegetation biophysical properties such as LAI (Darvishzadeh *et al*., 2006).

The main goal of the study was to provide an efficient means of performance evaluation of the wheat crop under different treatments. This was to be achieved through determining the Vegetation Indices (VI's) that could be used in assessing the in-season performance of wheat crop cultivated under different levels of irrigation water and fertilizer rates.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted on a 50 ha sandy loam soil field in Todhia farm located in the Eastern Province of Saudi Arabia within the latitudes of 24° 10' 22.7" and 24° 12' 37.2" N and longitudes of 47° 56' 14.6" and 48° 05' 08.56" E **Fig. 1**. The field was under center pivot irrigation system and has been under continuous wheat (*Triticum aestivum* L., cv. Yecora Rojo) cultivation.

2.2. Experimental Layout

The experiment was conducted on the study field which was cultivated with wheat crop (*Triticum aestivum* L., cv. Yecora Rojo) sown at 250 kg^{-1} on January 1th, 2012. Experimental treatments were laid out in split plot design with four irrigation levels as the main treatments and three fertilizer levels as the sub-treatments **Fig. 2**. The main treatments were I1 (irrigation at 100% ETc), I2 (Irrigation at 90% ETc), I3 (Irrigation at 80% ETc) and I4 (Irrigation at 70% ETc). The sub-treatments, however, includedF1 (300:200:200), F2 (400:250:250) and F3 (500:300:300) (N: P_2 O_5:K_2O kg^{-1}ha). Three samples were taken from each treatment to compose the data set for this study.

2.3. Spectral Reflectance Measurements

Wheat crop samples were collected on two different dates (February 17th and April 5th, 2012) that coincided with booting and early ripening growth stages. The crop spectral reflectance of the collected samples was measured in the Laboratory by a Spectroradiometer (Model-Field Spec 3 of ASD Inc. Colorado, USA) using the contact probe. The spectral reflectance was measured for wavelengths between 350 and 2500 nm, with an increment of 1 nm.

2.4. Calculation of Spectral Vegetation Indices

Vegetation Indices (VI's) which represented combinations of surface reflectance at two or more wavelengths designed to highlight a specific vegetation property (EXELES, 2009) were calculated using the measured wheat crop spectral reflectance values. The 22 vegetation indices investigated in this study and the formulas used to calculate them are presented in **Table 1**.

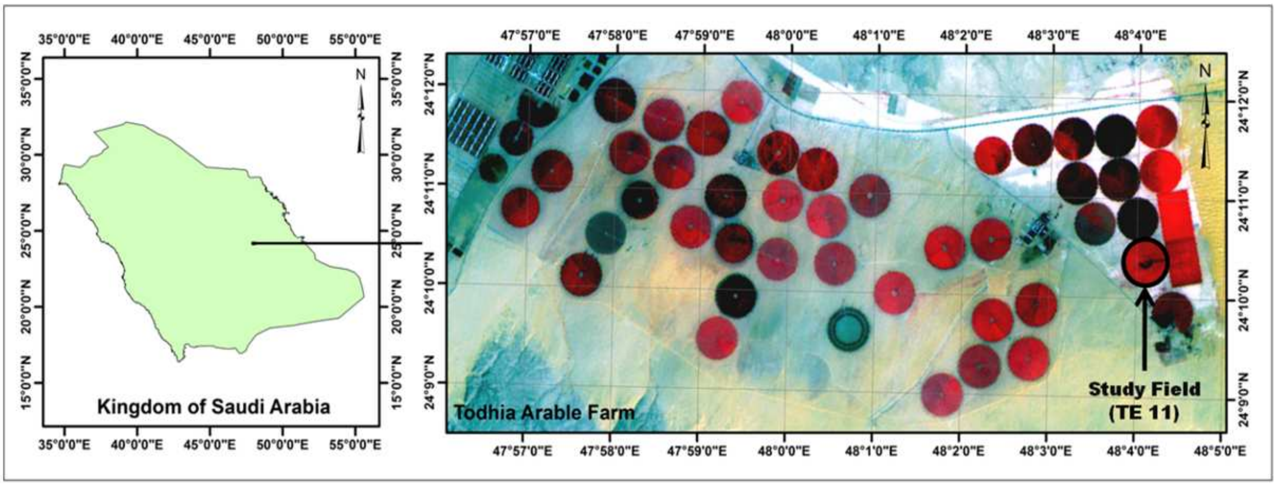

Fig. 1. Location of the study site

Table 1. The formulae for calculation of the Vegetation Indices

Spectral Index	Description	Formula	References
MIVI	Middle Infrared-Based Vegetation Index	(MIR1-RED)/(MIR1 + RED) Where MIR1 (TM5): 1550 to 1750 nm	Thenkabail *et al*. (2002) EXELES, 2013
$NDVI_{705}$	Red Edge Normalized Difference Vegetation Index	$(\rho_{750} - \rho_{705})/(\rho_{750} + \rho_{705})$*	
$mNDVI_{705}$	Modified Red Edge Normalized Difference Vegetation Index	$(\rho_{750} - \rho_{705})/(\rho_{750} + \rho_{705} - 2\rho_{445})$	
SIPI	Structure Independent Vegetation Index	$(\rho_{800} - \rho_{445})/(\rho_{800} + \rho_{445})$	
PSRI	Plant Senescence Reflectance Index	$(\rho_{680} - \rho_{500})/(\rho_{750})$	
NDWI	Normalized Water Difference Index	$(\rho_{857} - \rho_{1241})/(\rho_{857} + \rho_{1241})$	
MSI	Moisture Stress Index	$(\rho_{1599})/(\rho_{819})$	
NDVI	Normalized Difference Vegetation Index	$(\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + \rho_{RED})$	
PRI	Photochemical Reflectance Index	$(\rho_{531} - \rho_{570})/(\rho_{531} + \rho_{570})$	
WBI	Water Band Index	$(\rho_{900})/(\rho_{970})$	
mSR_{705}	Modified Red Edge Simple Ratio	$(\rho_{750} - \rho_{445})(\rho_{705} - \rho_{445})$	
VOG3	Vogelmann Red Edge Index 3	$(\rho_{734} - \rho_{747})/(\rho_{715} - \rho_{720})$	
NDNI	Normalized Difference Nitrogen Index	$[\log(1/\rho_{1510}) - \log(1/\rho_{1680})]/[\log(1/\rho_{1510}) + \log(1/\rho_{1680})]$	
NDLI	Normalized Difference Lignin Index	$[\log(1/\rho_{1754}) - \log(1/\rho_{1680})]/[\log(1/\rho_{1754}) + \log(1/\rho_{1680})]$	
NDII	Normalized Difference Infrared Index	$(\rho_{819} - \rho_{1649})/(\rho_{819} - \rho_{1649})$	
NWI-1	Normalized Water Index-1	$(R_{970} - R_{900})/(R_{970} + R_{900})$*	Gutierrez *et al*. (2010)
NWI-2	Normalized Water Index-2	$(R_{970} - R_{850})/(R_{970} + R_{850})$	
NWI-3	Normalized Water Index-3	$(R_{970} - R_{880})/(R_{970} + R_{880})$	
NWI-4	Normalized Water Index-4	$(R_{970} - R_{920})/(R_{970} + R_{920})$	
REIP	Red Edge Inflection Point	$700 + 40\{[(\rho_{667} + \rho_{782})/2] - \rho_{702}\}/(\rho_{738} - \rho_{702})$	Herrmann *et al*. (2010)

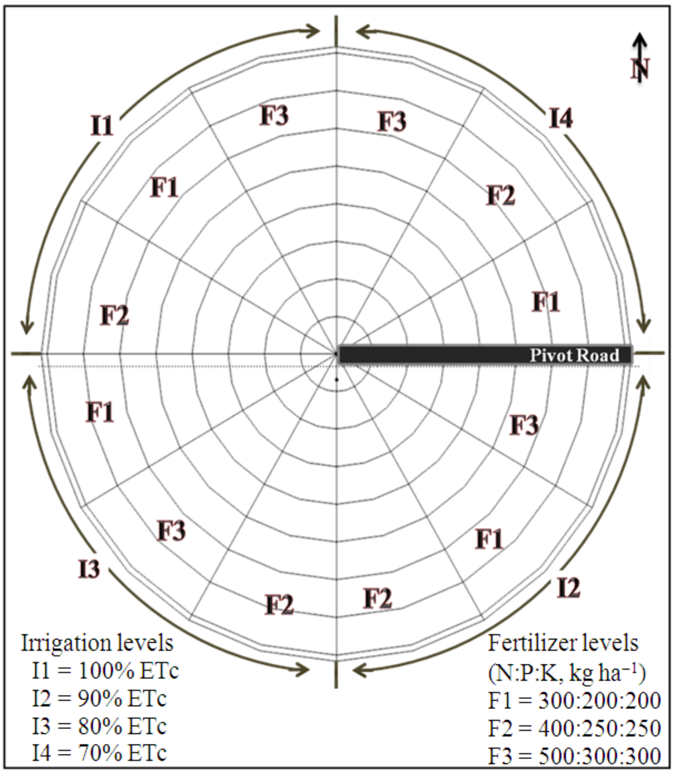

Fig. 2. Layout plan of the experiment

2.5. Leaf Area Index (LAI) Measurements

In-situ LAI measurements were made at the same locations and on the same dates of wheat crop sampling for spectral reflectance measurements (i.e., on February 17th and April 5th, 2012) using the Plant. Canopy Analyzer (Model: PCA-2200 of LI-COR Biosciences, USA). At each sampling point, one above canopy and five below canopy readings were recorded to determine a single LAI value.

2.6. Wheat Crop Yield Data Collection

Wheat grain yield (t/ha) data was collected on May 9th, 2012 by harvesting each experimental plot separately using a combine. For each plot, the collected wheat grain was weighed and recorded.

3. RESULTS

3.1. Assessment of the Calculated Spectral Vegetation Indices

Spectral vegetation indices were calculated from the measured spectral reflectance values of wheat crop samples representing four irrigation levels and three fertilizer levels on two sampling dates (February 17th and April 5th, 2012). To assess the response of the calculated spectral vegetation indices to the irrigation and fertilizer levels applied to wheat crop, the collected data values were subjected to ANOVA statistical analysis. Vegetation indices that showed significant response to irrigation and/or fertilizer treatments are presented in **Table 2**. It was observed that only 15 out of the 22 investigated spectral indices showed significant response to irrigation levels. Two of those (Plant Senescence Reflectance Index (PSRI) and the Photochemical Reflectance Index (PRI)) were also responsive to fertilizer levels. The results presented in **Table 2** revealed that the Middle Infrared-Based Vegetation Index (MIVI) and the Normalized Water Index-2 (NWI-2) were the only two indices that showed significant response to the implemented irrigation levels for both sampling dates. PSRI (for February 17th sampling date) and PRI (for April 5th sampling date) were observed to be significantly sensitive to both irrigation and fertilizer levels.

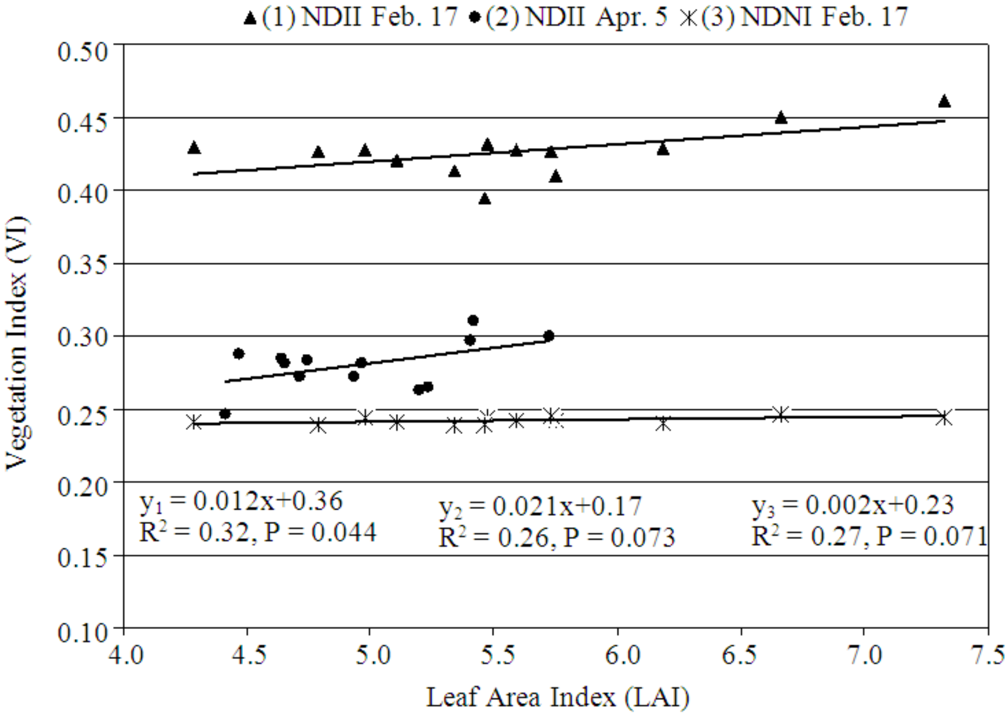

Fig. 3. Relationship of LAI with NDII and NDNI

3.2. Relationship between Vegetation Indices (VI's) and Leaf Area Index (LAI)

Leaf area index (LAI) was measured at the same locations and on the same dates of collecting wheat crop samples for spectral reflectance measurements (February 17th and April 5th, 2012). The relationship between the various spectral VI's and LAI is represented by the R-squared values shown in **Table 3**.

As shown in **Table 3**, the Normalized Difference Infrared Index (NDII) on both sampling dates (February 17th and April 5th, 2012) and the Normalized Difference Nitrogen Index (NDNI) on February 17th exhibited the strongest relationship with LAI considering the coefficient of correlation (R2) values. The relationship between LAI and both NDII and NDII is illustrated in **Fig. 3**.

NDII and NDNI exhibited direct linear proportional relationship with LAI **Fig. 3**. Statistical analysis results showed significant relationship ($P<0.05$) only between LAI and NDII for February 17th measurements (measurements taken at booting growth stage of wheat crop). Therefore, based on the results of the investigated vegetation indices in this study, the NDII can be used as an indicator of wheat crop LAI.

3.3. Relationship between Spectral Indices and Crop Yield

The vegetation indices, calculated from wheat crop spectral reflectance measurements taken on February 17th and April, 2012, were correlated with wheat grain yield **Table 4**. Results revealed that among the 22 investigated indices, only five (NIR, WBI, NWI-1, NWI-3 and NWI-4) showed the most response to wheat grain yield with the highest R2 values (in the range 0.3633 to 0.4894). Among those five indices, inverse relationship was observed between wheat grain yield and the Near Infrared band "NIR" (for February 17th measurement) and the Water Band Index "WBI" (for April 5th measurements) **Fig. 4**. A proportional relationship was observed, for April 5th measurements, between wheat grain yield and the Normalized Water Index-1 (NWI-1), the Normalized Water Index-3 (NWI-3) and the Normalized Water Index-4 (NWI-4) **Fig. 5**. The Near Infrared Index (NIR), calculated from February 17th measurements (at wheat crop booting growth stage), showed the most significant correlation with wheat grain yield ($R^2 = 0.49$, $P = 0.011$).

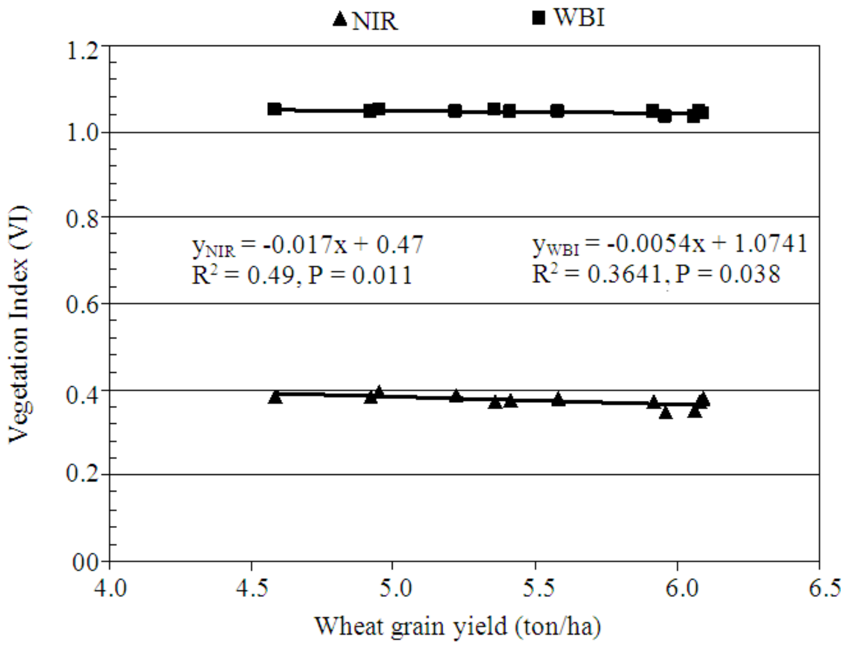

Fig. 4. Relationship of wheat grain yield with WBI and NIR

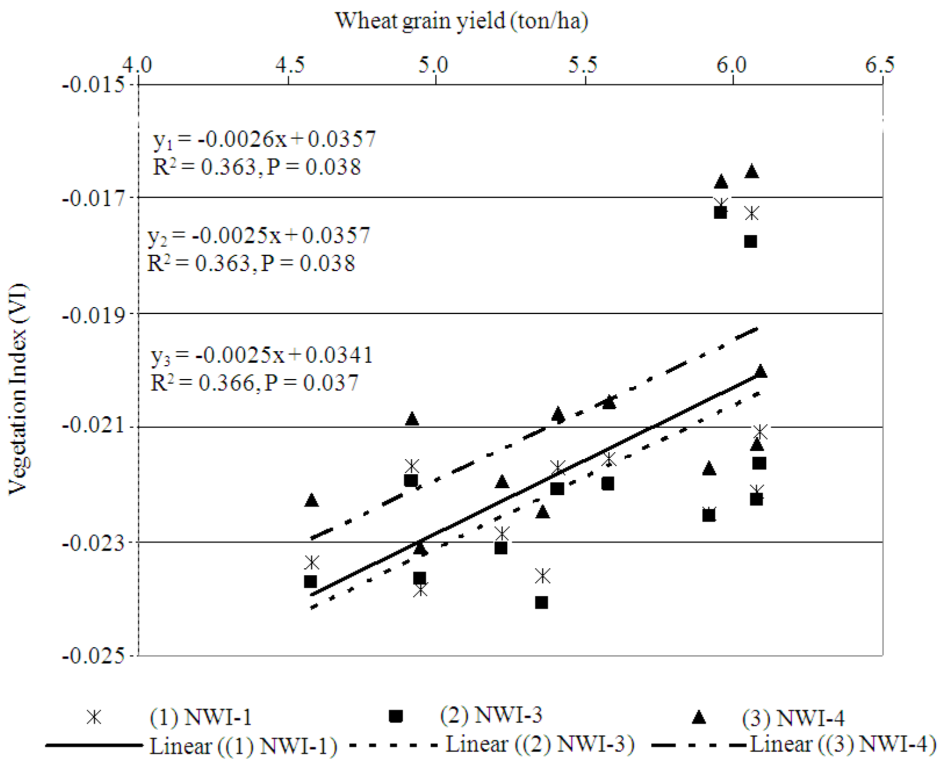

Fig. 5. Relationship of wheat grain yield with NWI-1, NWI-3 and NWI-4

Table 2. Response of vegetation indices to irrigation and fertilizer levels

Spectral Indices	Pr>F Irrigation levels Feb. 17th	Apr. 5th	Fertilizer levels Feb. 17th	Apr. 5th
RED	0.0026**	NS	NS	NS
NIR	0.0170*	NS	NS	NS
MIVI	0.0011**	0.0036**	NS	NS
$NDVI_{705}$	0.0250*	NS	NS	NS
SIPI	0.0019**	NS	NS	NS
PSRI	0.0001**	NS	0.0238*	NS
NDWI	0.0085**	NS	NS	NS
NDVI	0.0047*	NS	NS	NS
PRI	NS	0.0015**	NS	0.0261*
WBI	NS	0.0115*	NS	NS
NWI-1	NS	0.0117*	NS	NS
NWI-2	0.0081**	0.0095**	NS	NS
NWI-3	NS	0.0132*	NS	NS
NWI-4	NS	0.0100*	NS	NS
REIP	NS	0.0044**	NS	NS

Table 3. R^2 values between VI and LAI

Vegetation Indices	R^2 Feb. 17	Apr. 5	Vegetation indices	R^2 Feb. 17	Apr. 5
RED	0.001000	0.0391	NWI-1	0.1982	0.0352
NIR	0.024600	0.1556	NWI-2	0.1223	0.0774
MIVI	0.000002	0.0117	NWI-3	0.1654	0.0458
$NDVI_{705}$	0.022900	0.0672	NWI-4	0.2391	0.0292
SIPI	0.001900	0.0020	REIP	0.0094	0.0466
PSRI	0.018600	0.0077	mSR_{705}	0.0109	0.0629
NDWI	0.065200	0.0025	$mNDVI_{705}$	0.0161	0.1429
MSI	0.052900	0.0685	VOG3	0.0530	0.0098
NDVI	0.003300	0.0054	NDNI	0.2665	0.1004
PRI	0.022600	0.0109	NDLI	0.0131	0.0860
WBI	0.198800	0.0356	NDII	0.3193	0.2635

Table 4. Relationship between VI and wheat grain yield

Spectral Index	R^2 Feb. 17	Apr. 5	Spectral index	R^2 Feb. 17	Apr. 5
RED	0.3113	0.2205	NWI-1	0.0210	0.3633
NIR	0.4894	0.0755	NWI-2	0.0079	0.2818
MIVI	0.2480	0.2488	NWI-3	0.0162	0.3563
$NDVI_{705}$	0.2728	0.0642	NWI-4	0.0231	0.3655
SIPI	0.2668	0.1189	REIP	0.0217	0.2283
PSRI	0.2175	0.0460	mSR_{705}	0.0011	0.0480
NDWI	0.2150	0.1564	$mNDVI_{705}$	0.0089	0.0204
MSI	0.2922	0.0046	VOG3	0.1002	0.1383
NDVI	0.2771	0.1575	NDNI	0.0351	0.3050
PRI	0.0873	0.3329	NDLI	0.1315	0.1369
WBI	0.0214	0.3641	NDII	0.0843	0.1338

4. DISCUSSION

Results of the study showed that the best relationship was observed between the NDII and NDNI vegetation indices and wheat crop LAI. The relationship observed could be considered as a relatively weak relationship (R^2 values were in the range of 0.20 to 0.32). Similar results were reported by (Gupta *et al*., 2006) where lower R^2 values of 0.20 to 0.53 were obtained for the relationship between wheat crop LAI and spectral indices, such as Ratio Vegetation Index (RVI), Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI). In contrast, (Haboudane *et al*., 2004) reported higher R^2 values of 0.74 to 0.85 between LAI and VI's, such as Modified Chlorophyll Absorption Ratio Index 2 (MCARI2) and Modified Triangular Vegetation Index (MTVI2).

Statistically significant relationship between LAI and NDII only for February 17th measurements (at wheat crop booting growth stage) was revealed. Similar results were reported by (Zhang *et al*., 2012), where spectral modeling was thought to be an efficient means for predicting wheat crop LAI at the jointing and booting growth stage and, with less accuracy, at the tillering stage. They also observed that the spectrum measurements taken at the filling stage resulted in the weakest relation between the spectral predicted LAI and the measured LAI. This was attributed to the change in leaves structure at filling stage, where they turned yellow.

Among the 22 investigated indices, five exhibited a significant correlation with wheat grain yield. These five indices included NIR (R^2 = 0.49, P = 0.011), WBI (R^2 = 0.36, P = 0.038), NWI-1 (R^2 = 0.36, P = 0.038), NWI-3 (R^2 = 0.36, P = 0.040) and NWI-4 (R^2 = 0.37, P = 0.037). These results were in agreement with (Babar *et al*., 2006) where it was stated that the indices based on NIR (Water Index "WI", Normalized Water Index-1 "NWI-1" and Normalized Water Index-2 "NWI-2") showed the best correlation with wheat grain yield compared to other investigated spectral indices.

Although the most significant relationship between wheat grain yield and spectral indices was recorded for NIR calculated from February 17th measurements at the booting growth stage, the other four indices (WBI, NWI-1, NWI-3 and NWI-4) showing significant correlation with the grain yield were calculated from April 5th measurements at the ripening growth stage. Therefore, based on the results of this study, spectral indices could be significantly used for early wheat yield assessment at the booting growth stage. However, (Royo *et al*., 2003) reported that the milk-grain stage was the optimum growth stage for wheat yield assessment using spectral indices.

5. CONCLUSION

A field study was conducted to determine the vegetation indices that could be used as indicators of wheat crop performance treated with different levels of irrigation water and fertilizer rates. Fifteen out of the 22 investigated spectral indices showed significant response to irrigation levels. However, only two (Plant Senescence Reflectance Index-PSRI and the Photochemical Reflectance Index-PRI) of the fifteen indices also showed significant response to fertilizer levels. The Middle Infrared-Based Vegetation Index (MIVI) and the Normalized Water Index-2 (NWI-2) showed a significant response to the implemented irrigation levels for both sampling dates. The Plant Senescence Reflectance Index (PSRI) and the Photochemical Reflectance Index (PRI) were sensitive to both irrigation and fertilizer levels. Among the investigated spectral indices, only the Normalized Difference Infrared Index (NDII) showed a significant response ($P<0.05$) to LAI, hence, it can be used for the prediction of wheat crop LAI. Five indices (NIR, WBI, NWI-1 and NWI-3 and NWI-4) showed significant response to wheat grain yield, however, the NIR was found to produce the most significant correlation with wheat grain yield.

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