PRECISION FERTIGATION IN WHEAT FOR SUSTAINABLE AGRICULTURE IN SAUDI ARABIA

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ABSTRACT

Wheat is an important cereal crop of Saudi Arabia grown on an area of 250,000 ha with an annual production of 1,260,000 metric tons. The crop is cultivated on sandy soils using sprinkler irrigation under center pivots. The crop is sown in November and harvested in April. Efficient use of nutrients and irrigation water under such conditions would result in improving wheat yields and increasing profitability. Investigations are underway to understand the spatial variability in soil properties and determine the most optimum fertilizer dose and irrigation regime for obtaining higher grain yields of wheat. The research is being carried out in TE 11 pivot (50 ha area) of Todhia farm of H.H. Prince Sultan Bin Mohammed Bin Saud Al Kabeer. Management zones in the pivot were delineated based on different criteria such as laboratory analyzed soil EC (georeferenced), elevation from Aster product (AST 3A1) and historic composite NDVI from Landsat ETM+ . A field experiment was laid out in this pivot in Split Plot design with three replications to study the response of wheat to irrigation and fertilizer levels. Four irrigation treatments consisting of Irrigation at 100, 90, 80 and 70 % Evapotranspiration (ET) were randomly allocated to the main plots and three fertilizer treatments consisting of 300:150:200; 400:250:300 and 500:300:300 kg N: P_2O_5:K_2O per ha were randomly allocated to the sub-plots. The area covered by two spans formed each replication. The results of the study are presented in this paper.

Key words: Wheat, Precision fertigation, management zones, Saudi Arabia

INTRODUCTION

The Kingdom of Saudi Arabia lies in the tropical and sub-tropical desert region of the Middle East (FAO, 2008). Agriculture being an important sector in the economy of the Kingdom witnessed an impressive annual growth rate of 10.9 per cent as compared to GDP growth of 11.6 per cent between 1969 and 2004. The rapid progress witnessed in agriculture sector was at the cost of the fast dwindling non – renewable underground water resources. Thus, the country is now faced with a formidable challenge of adopting a sustainable agricultural policy to meet food requirements of a population of 27 million, growing at the rate of 2.9 per cent annually. This challenge necessitates striking a delicate balance between Food Security and Water Security. Hence, there is an urgent need to conserve the natural resources and to increase the input use efficiencies to achieve sustainability of agriculture in the kingdom. Wheat is one of the important crops of Saudi Arabia, cultivated on an area 250,000 ha producing 1,260,000 metric tons. Wheat yields of 4.5 tons per ha were obtained under irrigation with fertilizer productivity of 40 kg wheat per kg fertilizer nutrient (FAO, 2000).

Precision Fertigation (PF) is one of the most important components of Precision Agriculture (PA). Gebbers and Adamchuk (2010) have appropriately highlighted the relevance and importance of PA as a means of monitoring the food production chain and managing both the quantity and quality of agricultural produce. PA helps in increasing productivity and profitability by enabling efficient use of inputs in crop production. The success of PA depends on the accurate assessment, management and evaluation of spatio - temporal variability in crop production. Fertigation is a method of supplying nutrients along with irrigation water. Precision fertigation involves use of inputs such as water and fertilizers based on the basic principle of PA. It takes in to account the within field variability and accomplishes site-specific management of water and fertilizers. Investigations on precision fertigation in wheat were carried out on Todhia farm of H.H. Prince Sultan Bin Mohammed Bin Saud Al Kabeer. The objectives of the study were 1. To create management zones for optimizing use of inputs such as water and fertilizers. 2. To determine the optimum level of irrigation for wheat 3. To determine the optimum levels of nitrogen, phosphorus and potassium for wheat.

MATERIALS AND METHODS

The site is located between Al-Kharj and Haradh and lies within latitudes 24º10' 22.77" and 24º12' 37.25" N and within longitudes 47º56' 14.60" and 48º05' 08.56" E, covering an area of about 6967 ha. The precision fertigation research in wheat was initiated in one (TE 11) of the fifty center pivots on the Todhia farm of H.H. Prince Sultan Bin Mohammed Bin Saud Al Kabeer. Alfalfa crop was grown previously in this pivot. The alfalfa crop sown in the pivot in October 2010 was finally harvested in December 2011, just prior to the initiation of this study. Geo-referenced soil samples were collected from the center pivot that measured an area of 50 hectares in grids of 100m x 100m and were analyzed for physico-chemical properties.

Delineation of management zones

A management zone is a sub-region of a field which is a relatively homogenous zone. Cluster analysis procedures have been effectively used to identify regions of a field that are similar based on landscape attributes, or soil physical properties (Fraisse et al., 2001). In this study Management Zone Analysis (MZA) software (Fridgen, 2004) was used to determine the number as well as to delineate the management zones. Cloud free Landsat ETM+ satellite data of 7 Nov 2009, 25 Dec 2009, 11 Feb 2010, 18 Oct 2010, 3 Nov 2010, 12 Dec 2010, 21 Oct 2011 and 8 Dec 2011 were downloaded from Earth Explorer USGS website and NDVI images (Rouse et al. 1974) were prepared. All NDVI images were stacked together as multidate NDVI image (Sahoo et al., 2007) and subjected to extract mean values of NDVI to create a cluster image for MZA input. Geo-referenced data of lab analyzed soil EC, Aster image derived elevation and Landsat ETM+ derived Normalized Difference Vegetation Index (NDVI) were kriged, and then gridded to a common 10-m cell (Kitchen et al., 2003). Comma-delimited text file of these variables was imported to MZA. Descriptive statistics for the input variables were calculated; the Mahalanobis measure of similarity option was chosen for the delineation procedure. Other option settings were fuzziness component = 0.5, maximum number of iterations = 300, convergence criterion = 0.0001, minimum number of zones =2, and maximum number of zones =6. The output file was imported into a mapping programme of ARC GIS 2010 and maps were created for two-zone columns based on MZA graphical representation of FPI and NCE performance indices relative to cluster number as described by Fraisse et al., (2001).

Details of the field experiment

A field experiment was laid out in the center pivot to determine the optimum levels of irrigation and fertilizer nitrogen, phosphorus and potassium for obtaining higher grain yield of wheat. The experiment was laid out in split plot design with three replications. The area covered by two spans formed each of these replications. Two spans near the centre of the pivot and half over hung span at the outer end were treated as buffer zones. The plan of layout of the field experiment is depicted in Figure1.

The following four irrigation treatments (main treatments) were allocated randomly to the four quarters of the pivot: I1: Irrigating the crop at 100 % ET, I2: Irrigating the crop at 90% ET, I3: Irrigating the crop at 80% ET and I4: Irrigating the crop at 70% ET. The treatments consisting of three levels of nitrogen, phosphorus (P_2O_5) and potassium (K_2O) were allocated randomly to the sub plots. These were F1: 300:200:200 kg per ha ; F2: 400:250:250 kg per ha and F3: 500:300:300 kg per ha. All the phosphorus and potassium was band placed as basal as per the treatments. Sowing of wheat seed @ 250 kg per ha was done on January 1, 2012. Nitrogen was applied as foliar spray after an irrigation cycle in eleven splits starting from two weeks until ten weeks after sowing. At each time,

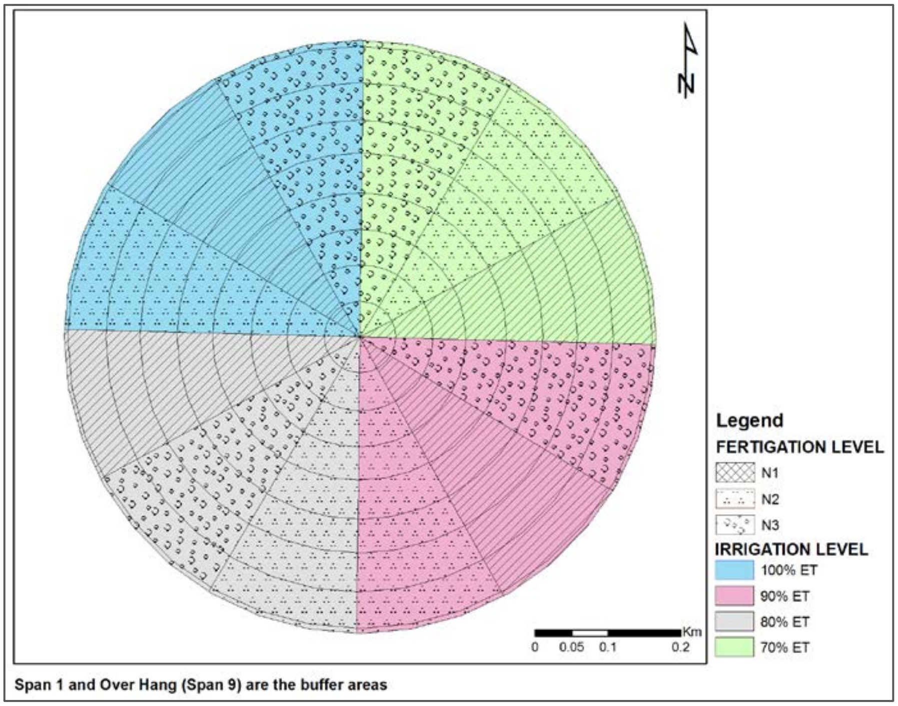


Fig.1: Layout plan of the field experiment (Pivot TE-11).

nitrogen was applied @ 20, 30 and 40 kg per ha in F1, F2 and F3, respectively. Frequency of irrigation varied from three to five days based on crop irrigation requirement that depended on ET values.

Irrigation requirement was worked out based on daily mean ET values (1995-2011) recorded on the farm, as per Allen et al., (1998). Irrigation treatments were imposed by adjusting the pivot speeds to deliver the required amounts of water in each treatment.

Observations

Periodic observations on NDVI using Crop Circle of Holland Scientific, USA and LAI using PCA 2200 of Licor Bio-Sciences, USA were recorded. The relationships between PCA-2200 measured LAI and ASTER satellite image based NDVI were examined.

Satellite data and Image Processing

A full scene of Aster imagery (17 Feb 2012 and 4 Mar 2012) was acquired. The data were time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients, and geolocation information. In addition, the data were corrected for parameters such as atmospheric effects and variations in emissivity. The remote sensing software package Erdas Imagine Version 2011 and its tools were used for the data processing. The NDVI was calculated using ASTER sensor bands 3 and 2 (Bawazir, 2009; Heiskanen, 2006). The reflectance was derived from the image to examine the relationship between LAI, and ASTER data. Correlation between reflectance of ASTER pixel and geo-referenced ground collected LAI (PCA-2200) data was examined using the following equation.

$$Y = 0.021\, x + 0.2665 \qquad (R^2 = 0.6014)$$

where Y is LAI, x is the NDVI of ASTER image.

RESULTS AND DISCUSSION

Delineation of management zones

The delineation of management zones was done based on soil EC, elevation and NDVI. The outputs from MZA analysis are depicted in Figures 2 and 3. The best classification occurs when membership sharing (FPI) and/or the amount of class disorganization (NCE) is at a minimum with the least number of classes used. Normally the FPI and NCE values should fall as the number of classes increases, and it is considered that the optimum number of clusters or zones is the number which is able to minimize the respective values of these two indices. In the present study the FPI and NCE were dissimilar. The minimum NCE was observed at two clusters while minimum FPI was found at six clusters. Since there was no agreement between the FPI and NCE indices as to the optimum number of clusters (Fig.3), one option was to choose the least number of classes as suggested by Lark and Stafford (1997), which in this case were two.

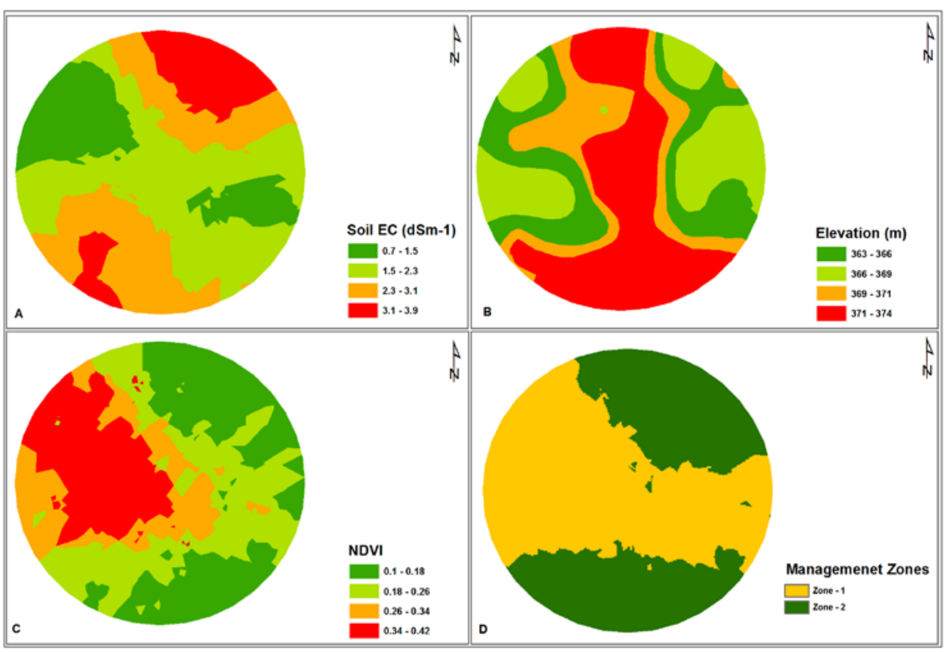


Fig.2: Clustering variables used as input for MZA and output of zone map; (A) Soil Electrical Conductivity - Soil EC, (B) Elevation, (C) NDVI and (D) Management zones by MZA clustering.

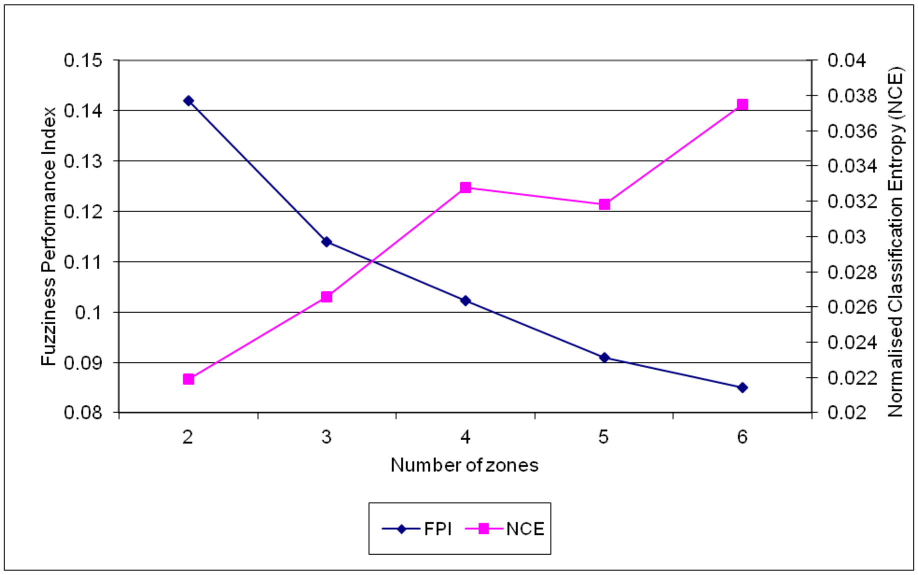


Fig.3: Fuzziness Performance Index (FPI) and Normalized Classification Entropy (NCE) as calculated by MZA for study area.

Therefore, minimum NCE found at cluster 2 was considered as the basis for dividing the pivot in to two management zones. Two management zones are convenient for subsequent application of variable rate inputs and field management. Of the total pivot area, 54.88 % is covered under zone – 1 and zone – 2 occupies 45.12% of area. Similar results were obtained by Boydell and McBratney (2002) in cotton, and Ping and Dobermann (2005) in corn, and Arno et.al., (2011) in grapes. The results also coincide with the recommendations of Taylor et al. (2003). A web-based decision support tool, zone mapping application for precision farming (Zone MAP, http://zonemap.umac.org), was developed to determine the optimal number of management zones and delineate them using satellite imagery and field data provided by users (Zhang et.al., 2010).

Response of wheat to irrigation regimes and fertility levels

Effect of irrigation regimes and fertility levels on LAI

The mean leaf area index (LAI) values of the crop increased from 3.731 at Zadok's scale 3.3 (50 days after sowing (DAS) (here after referred to as stage 1) to 5.592 at Zadok's scale 4.5 (65 DAS) (stage 2) and then declined to 4.960 at Zadok's scale 6.9 (95 DAS) (stage 3) (Table 1). The temporal changes in LAI were also evident in the Aster satellite image derived LAI maps for stages 1 and 2 depicted in Figure 4. Both irrigation regimes and fertilizer levels did not significantly influence the LAI at stages 1 and 3. However, at stage 2, irrigation at 80% ET was superior to irrigation at 90% ET. Higher fertilizer levels (F2 and F3) resulted in significantly higher LAI than at the lower level at stage 2. The highest LAI of 7.323 was recorded by irrigating at 80 % ET and F3 fertilizer level, which was significantly superior to the F1 at the same irrigation regime. Irrigating at 80 % ET maintained higher LAI values than in the other irrigation levels at F3 at the initial two stages. However, the trend was not sustainable at the third stage. A significant r^2 of 0.597 ($p \sim 0.05$) existed between the PCA 2200 measured LAI and ASTER Image predicted LAI (Fig. 5).

Table 1: Effect of irrigation regimes and fertilizer levels on Leaf Area Index

	Zadok's scale 3.3				**Zadok's scale 4.5**				**Zadok's scale 6.9**			
	F1	**F2**	**F3**	**Mean**	**F1**	**F2**	**F3**	**Mean**	**F1**	**F2**	**F3**	**Mean**
I1	4.32	3.10	3.37	3.59	5.11	5.75	5.48	5.45	5.19	5.39	4.72	5.10
I2	3.72	4.32	2.99	3.68	4.98	4.79	6.19	5.32	5.06	4.91	5.06	5.01
I3	3.37	4.46	4.32	4.05	4.29	6.66	7.32	6.09	4.94	5.04	4.65	4.88
I4	3.56	3.37	3.89	3.61	5.34	5.46	5.73	5.51	5.57	4.79	4.18	4.85
Mean	**3.74**	**3.81**	**3.64**	**3.74**	**4.93**	**5.67**	**6.18**	**5.59**	**5.19**	**5.04**	**4.65**	**4.96**
For Comparing Irrigation Level												
SE	0.2899				0.3118				0.2758			
$LSD_{0.05}$	NS				0.763				NS			
For Comparing Fertilizer Level												
SE	0.2642				0.2568				0.2424			
$LSD_{0.05}$	NS				0.5443				NS			
Comparison between two fertilizer level means at the same irrigation treatment												
SE	0.5285				1.0606				0.6545			
$LSD_{0.05}$	1.1204				2.5953				NS			
Comparison between two irrigation level means at the same or different fertilizer treatments												
SE	0.5199				1.0606				0.543			
$LSD_{0.05}$	1.1549				2.5953				NS			

Fig.4: Temporal changes in LAI of wheat crop at Zadok's scale A: 3.3 and B: 4.5 stages.

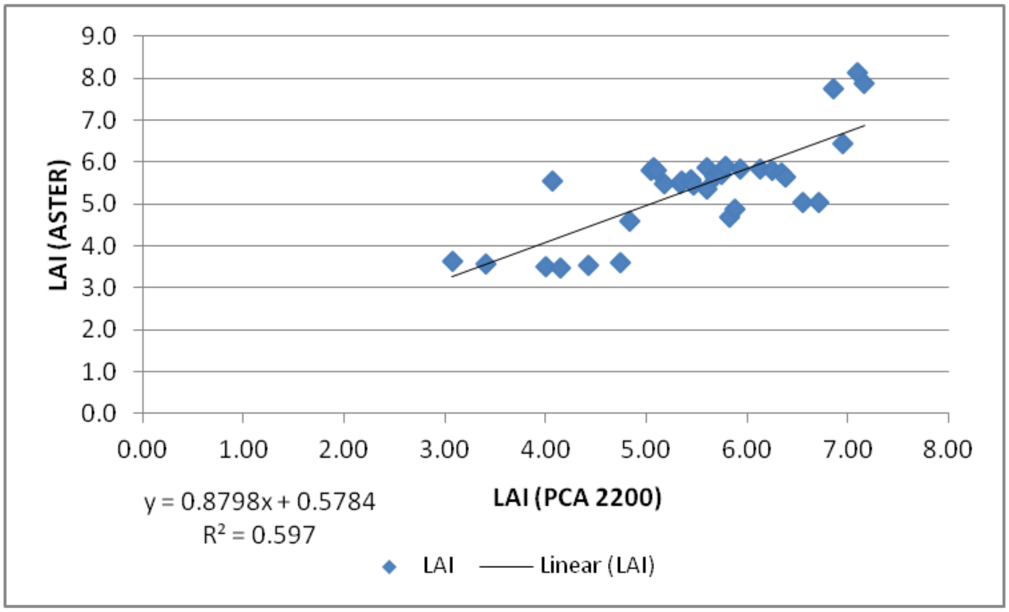
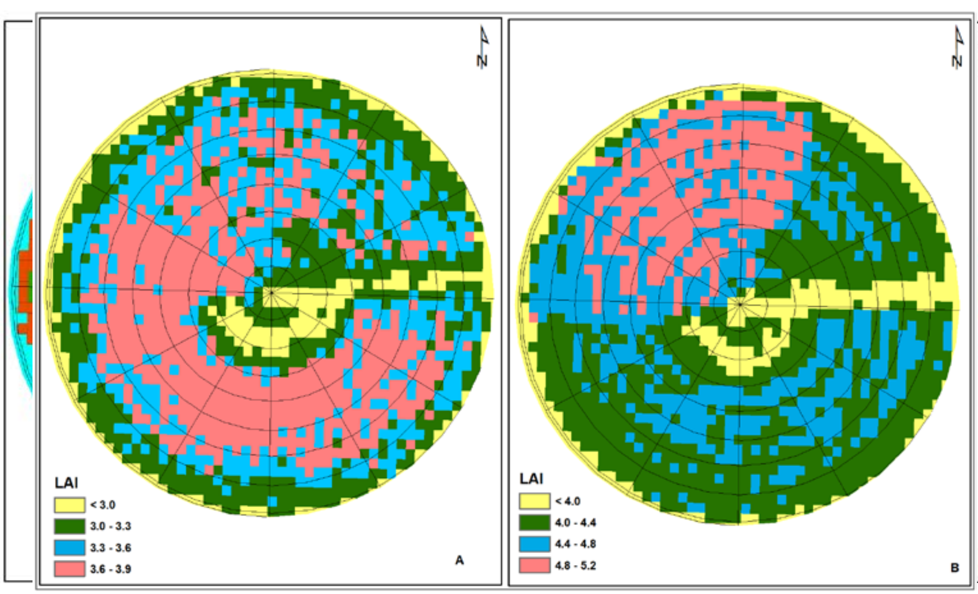


Fig.5: Scatter plot showing regression analysis between field measured LAI (PCA 2200) and ASTER image derived LAI.

Effect of irrigation regimes and fertilizer levels on NDVI

Temporal changes in the NDVI followed a similar trend as that of LAI. The mean NDVI increased slightly from 0.803 at stage 1 to 0.830 at stage 2 and then



declined to 0.692 at stage 3 (Table 2). The temporal changes in NDVI at stages 1 and 2 derived from ASTER satellite images are presented in Fig. 6.

Fig.6: Temporal changes in NDVI (ratio between band 3 and band 2 VNIR portion of ASTER image) of wheat crop at Zadok's scale 3.3 and 4.5 stages.

Table 2: Effect of irrigation regimes and fertilizer treatments on NDVI

	Zadoks Scale 3.3				Zadoks Scale 4.5				Zadoks Scale 6.9			
	F1	**F2**	**F3**	**M***	**F1**	**F2**	**F3**	**M***	**F1**	**F2**	**F3**	**M***
I1	0.800	0.823	0.863	0.828	0.848	0.835	0.878	0.854	0.713	0.713	0.729	0.718
I2	0.806	0.804	0.782	0.797	0.798	0.799	0.816	0.804	0.725	0.730	0.720	0.725
I3	0.805	0.805	0.825	0.812	0.801	0.866	0.814	0.827	0.718	0.680	0.625	0.674
I4	0.756	0.775	0.794	0.775	0.794	0.851	0.859	0.835	0.717	0.507	0.721	0.648
M*	0.792	0.802	0.816	0.803	0.810	0.838	0.842	0.830	0.718	0.658	0.699	0.692

	Zadoks Scale 3.3	Zadoks Scale 4.5	Zadoks Scale 6.9
For Comparing Irrigation Level			
SE	0.0224	0.0048	0.0387
LSD $_{0.05}$	NS	0.0117	NS
For Comparing Fertility Level			
SE	0.0107	0.0057	0.0394
LSD $_{0.05}$	0.0226	0.0121	NS
Comparison between two fertilizer level means at the same irrigation treatment			
SE	0.0213	0.0114	0.0789
LSD $_{0.05}$	0.0522	0.0279	NS
Comparison between two irrigation level means at the same or different fertilizer treatments			
SE	0.0339	0.0094	0.0712
LSD $_{0.05}$	0.0486	0.0171	NS

M* - Mean

The irrigation regimes, fertilizer levels and their interactions did not significantly affect the NDVI at stage 3. However, irrigation regimes at stage 2 and fertilizer levels at stages 1 and 2 significantly influenced the NDVI. At stage 2, irrigating at 100 % ET was found necessary to maintain a significantly higher NDVI (0.854) than in the other irrigation treatments. At stage 1, F3 recorded significantly higher NDVI than F1, but at stage 2, both the higher fertilizer levels were superior to F1. Irrigating at 80 % ET recorded highest NDVI with F3 level at stage 1 and with F2 level at stage 2. Scatter plot between ASTER generated NDVI and field measured (PCA 2200) LAI is depicted in Figure 7.

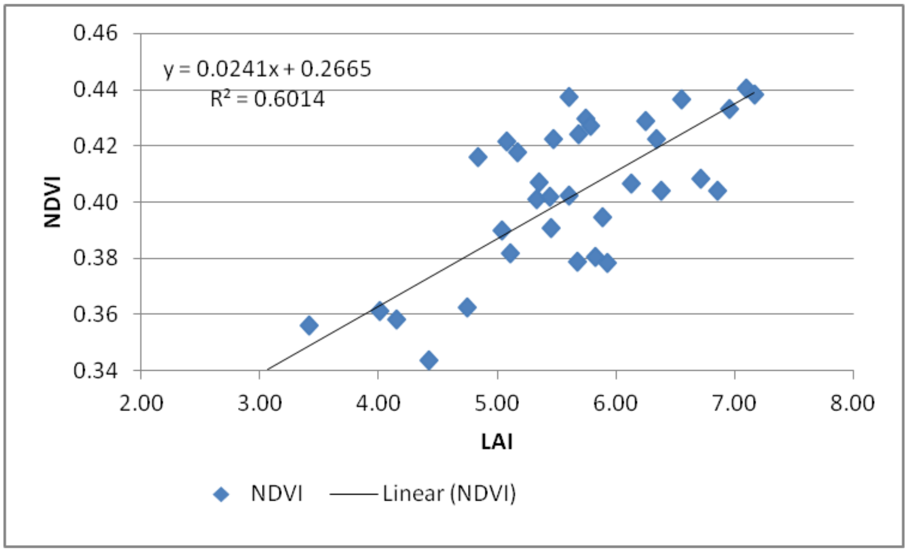


Fig 7: Correlation between LAI and ASTER image derived NDVI

Across crop growth stages, LAI values ranged from 3.0 to 7.2 with a mean of 4.9. Significantly positive correlation was observed between LAI and NDVI (p-value ~ 0.005; r^2=0.6014). As the LAI increased, a proportionate increase in NDVI was observed. Chen and Cihlar (1996) observed correlations between NDVI and LAI (r^2 ~ 0.52).

CONCLUSIONS

MZA software was used to delineate management zones based on laboratory analyzed soil EC, satellite image derived, elevation (Aster) and NDVI (Landsat ETM+). The pivot area of 50 ha was divided in to two convenient management zones based on minimum Normalized Classification Entropy (NCE) which is one of the performance indices of the unsupervised fuzzy classification. The wheat crop responded to irrigation regimes and fertilizer levels. Irrigating the crop at 80 % ET and application of 400 kg N, 300 kg P_2O_5 and 300 kg K_2O has resulted in higher LAI and NDVI. There was a good correlation between field measured LAI and NDVI with those derived from Aster satellite imagery.

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