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Full Length Article

Variable Rate Application Technology for Optimizing Alfalfa Production in Arid Climate

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Abstract

This study was to investigate the benefits of variable rate application technology for optimum production of alfalfa in arid climate. The study area was divided into two management zones by employing Fuzzy c-means cluster analysis. A field experiment was conducted in Split plot design. Irrigation treatments allocated to the main plots in January 2012 included: Irrigation at evapotranspiration (ET_c) of 100% (I1 ≈ 3130.54 mm/ha/annum), 90% (I2 ≈ 2817.49 mm/ha/annum), 80% (I3 ≈ 2504.41 mm/ha/annum), and 70% (I4 ≈ 2191.38 mm/ha/annum). The fertilizer levels ($N:P_2O_5:K_2O$ kg/ha/year) allocated to sub plots included: F1 – low (126:92:300), F2 – medium (234:138:400) and F3 – high (342:184:500). After retrofitting of variable rate irrigation (VRI) system on to the center pivot in May 2012, fertilizer levels formed main treatments and irrigation levels formed sub-treatments. The highest yield in both the harvests was obtained by irrigation at 80% ET_c. Across the two management zones and two harvests made in September and October 2012, medium fertilizer level (@ 234:138:400 kg/ha/year of $N: P_2O_5:K_2O$) resulted in higher alfalfa yield than the other two fertilizer levels. VRI showed benefits only in September 2012 harvest. In this harvest, adoption of VRI at 70% ET_c in MZ1 and 80% ET_c in MZ2 resulted in water saving of 30 and 20%, respectively. The following conclusions can be drawn from this study: 1. Variable rate application of irrigation water for the two management zones resulted in water saving of up to 30% in one out of two harvests. 2. Variable rate application of fertilizers was not effective and uniform rate application of fertilizers @ 234:138:400 kg/ha/year of $N: P_2O_5:K_2O$ resulted in higher alfalfa yield in both the management zones.

Keywords: Fertilizer levels; Irrigation regimes; Management zones; Yield mapping; Saudi Arabia

Introduction

With a mean annual average rainfall of around 100 mm (Hussain *et al*., 2010), agriculture in Saudi Arabia continues to use fast depleting ground water resources for irrigation to meet the ever increasing demand for food and fodder. Crops are irrigated through center/linear pivots using water pumped from deep aquifers. Under such circumstances, efficient use of scarce water resources assumes greater importance. This can be achieved by improving the water use efficiency of crops (Hussain *et al*., 2010). Forage production represents 23% of the total cropping area in Saudi Arabia, where alfalfa is viewed as the most important fodder crop cultivated (Zaharani *et al*., 2011; Abusuwar and Bakhashwain, 2012). Alfalfa consumes lot of water and its response to water application was reported to be linear (Bauder *et al*., 1978). The annual evapotranspiration of desert-grown alfalfa was estimated to be in excess of 1,900 mm/year (Phene, 2004). Studies in California (Donovan and Meek, 1983), Nevada, New Mexico, Nebraska and North Dakota (Sammis, 1981) revealed that 6-7 inches of water was required to produce a ton of alfalfa under non-limiting conditions. Water stress, especially under arid conditions, is considered as one of the key factors limiting its production (Hanson *et al*., 2008; Mushari, 2008). Saeed and El-Nadi (1997) reported that alfalfa grown under semi-arid conditions should be watered lightly and frequently to attain higher yield and water use efficiency (WUE). Proper irrigation system design adjustments combined with optimal fertigation practices resulted in water saving of 35% without loss in yield or quality of alfalfa irrigated by subsurface drip irrigation in California (Phene, 2004). Al-Noaim *et al.* (1978) investigated the production of alfalfa in Saudi Arabia, in a factorial experiment involving three irrigation rates (2730, 3850, and 5040 mm) and obtained 27.5, 31.4 and 31.9 tonnes of DM per hectare per year, respectively. Avila *et al.* (2003) recommended irrigation regime scheduled to replace 80% of ET for alfalfa in Mexico.

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Al-Lawati *et al.* (2010) assessed the performance of alfalfa in terms of productivity and WUE under different regimes of water salinity and irrigation levels in the Sultanate of Oman. They obtained higher WUE with 75 and 100% ET_c.

Achieving higher yields is important for profitable alfalfa production. But higher yielding alfalfa removes large quantities of nutrients from soil. Hence an adequate supply of nutrients is essential for obtaining profitable yields and to maintain high forage quality (Helalia *et al*., 1996; Bernardi *et al*., 2013). Alfalfa forage yield is enhanced significantly by phosphorus application (Berg *et al*., 2005). Addition of P and K fertilizer can increase alfalfa (*Medicago sativa* L.) yield and stand persistence (Berg *et al*., 2007). Macolino *et al.* (2013) conducted field experiments for three years to study the response of alfalfa to P and K fertilizers. They did not observe any benefit from P fertilizer application, but found positive response to application of 300 kg K_2O per ha.

Variable Rate Application (VRA) of inputs has been proposed as a new technology to improve input use efficiency and thus reduce input cost as well as agricultural pollution. Benefits of variable rate application (VRA) in agricultural production systems have been highlighted by numerous researchers. Benefits of VRA of agricultural inputs can be direct (e.g. economic benefits) as a result of increased yield, or indirect benefits, e.g. environmental and social benefits (Adhikari *et al*., 2009). As example, Hedley *et al*. (2009) assessed variable rate irrigation (VRI) against uniform rate irrigation (URI) on corn and pasture. Their study showed that VRI resulted in savings of 9-19% in water and energy (NZ$/ha of 35-149), and a reduction of 20-29% in drainage (i.e. reductions in nitrogen leaching, and improved water use efficiency). Also, Hu *et al*. (2007) reported that Site Specific Nitrogen Management (SSNM) maintained rice yields with significantly less fertilizer N (48 kg/ha) and no significant increase in total labor input, compared with Farmers' Fertilizer Practices (FFP). VRA of inputs requires management zones (MZ) to be delineated within the field with homogeneous crop requirements. Various techniques for delineating MZ were reported (Fridgen *et al*., 2004; Davatgar *et al*., 2012; Aggelopooulou *et al*., 2013). However, there are no reports from an arid environment of Saudi Arabia on delineation of management zones for variable rate application of inputs such as water and fertilizers to alfalfa. Therefore, the present investigation was carried out with the main goal of studying the response of alfalfa to variable rate application of irrigation and fertilizer levels. This study was conducted to delineate the study area into management zones and to investigate the effects of variable rate application of fertilizers and irrigation water on the growth and yield of alfalfa.

Materials and Methods

Experimental Site

The study was conducted on a 50 ha field of Todhia arable farm located between Al-Kharj and Haradh cities of Saudi Arabia within latitudes of 24º10' 22.77" and 24º12' 37.25" N, longitudes of 47º56' 14.60" and 48º05' 08.56" E, and elevation of 318-358 m (Fig. 1). The soil texture was sandy clay loam to clay loam in nature with 28.48%, 26% and 45.52% clay, silt and sand, respectively. Soil pH values ranged between 7.38 and 7.69. The soil EC ranged from 0.57 to 5.68 dS/m. The soil contained high amounts of $CaCO_3$ (21.68%). The nutrient composition of the soil varied from 25.73 to 55.60 mg/kg of nitrogen, 0.86 to 7.99 mg/kg of phosphorus and 11.90 to 84.91 mg/kg of potassium. The ground water used for irrigation had EC, pH and sodium absorption ratio (SAR) of 2.132 (dS/m), 7.2 and 3.67, respectively. The amount of anions and cations present in the irrigation water were: HCO^{-3} (3.30 meq/L); Cl^- (5.36 meq/L); and Na^+ (6.11 meq/L).

Delineation of Management Zones (MZ)

Geo-referenced EM 38 data of soil EC_a, elevation from ASTER DEM (AST3A01, orthorectified product of ASTER Image) and historic composite Normalized Difference Vegetation Index (NDVI) were subjected to fuzzy c-means clustering analysis and used as inputs to determine MZ using Management Zone Analyst (MZA) software (Fridgen *et al*., 2004). A total of eight cloud-free Landsat enhanced thematic mapper (ETM+) satellite images (November 7 and December 25, 2009; February 11, October 18, November 3 and December 12, 2010; October 21 and December 8, 2011) were downloaded from Earth Explorer USGS website to prepare NDVI images as per Rouse *et al*. (1973). The output file was imported into the mapping program of ARC GIS 2010 to create the management zone map of the field. The experimental field was delineated in two management zones based on MZA graphical representation of Fuzziness Performance Index (FPI) and Normalized Classification Entrophy (NCE) performance indices as described by Fraisse *et al*. (2001) and Lark and Stafford (1997).

Details of the Field Experiment

The field experiment was conducted on a 50 ha sandy clay loam field under center pivot irrigation system to determine the optimum levels of irrigation and fertilizer to optimize hay yield of alfalfa. Initially, the experiment was laid out in a split plot design with three replications (Fig. 2A). Four main treatments consisting of irrigation at 100% (I1 ≈ 3130.54 mm/ha/annum), 90% (I2 ≈ 2817.49 mm/ha/annum), 80% (I3 ≈ 2504.41 mm/ha/annum) and 70% (I4 ≈ 2191.38 mm/ha/annum) evapotranspiration (ET_c) were randomly allocated to the four quadrants of the field. Three fertilizer levels (kg/ha/year of N: P_2O_5: K_2O): F1 – low (126:92:300), F2 – medium (234:138:400), and F3 – high (342:184:500) were randomly allocated to the sub-plots. The treatments were superimposed in January 2012 on one year old alfalfa crop (variety: Greenmaster) sown in December 2nd, 2010, with a seeding rate of 20 kg/ha.

The area covered by two pivot spans formed one replication. Two spans near the centre of the pivot and half an over hung span at the outer end were treated as buffer zones. After in May 2012, retrofitting of the custom designed zone based Variable Rate Irrigation (VRI) system of Valley Irrigation, California, USA on to the center pivot irrigation system, the fertilizer levels formed the main plot treatments and four irrigation treatments (I1 to I4) formed the sub plot treatments in both of the management zones (Fig. 2B). Frequency of irrigation varied from three to five days. Irrigation requirement was worked out based on daily mean ET values for the period 1995 to 2011 (Table 1) recorded on the farm, as per the procedure described by Allen *et al.* (1998). Statistical Analysis System (SAS) Software Version 9.1.3 was used to apply the Analysis of Variance (ANOVA) model to analyze the collected data.

Ground Truth Data Collection

Data on field measured NDVI (NDVI $_{(G)}$) and Leaf Area Index (LAI$_{(G)}$) were collected on September 11th and October 7th, 2012. NDVI$_{(G)}$ was measured one meter above the crop canopy using the Crop Circle (Model: ACS-470) of Holland Scientific, USA. To determine the field data coordinates, an OmniSTAR GPS receiver (Model 9200-G2) was connected to the Crop Circle. LAI$_{(G)}$ measurements on the ground were made using the Plant Canopy Analyzer (Model: PCA – 2200) of LI-COR Biosciences, USA. At each measurement location, one above canopy and five below canopy readings were recorded to compute a single LAI value. Respective geo-locations were collected using a handheld Trimble GPS receiver (Model-Geo XH 600). Field measured LAI$_{(G)}$ was regressed against ASTER derived NDVI$_{(P)}$. The resulted regression equations were used to transform the satellite derived NDVI$_{(P)}$ to LAI$_{(P)}$ and construct the LAI$_{(P)}$ maps (Heiskanen, 2006; Zheng and Moskal, 2009).

Alfalfa Hay Yield Mapping

The hay yield monitor (Model 880) of Harvest Tec, USA was installed on a large square baler (Claas 3000) to record the harvested yields. Alfalfa yield of two cuts made on September 12th and October 14th, 2012 was recorded at the time of baling with constant pressure of 55 to 60 bars and the vehicle speed of about 15 – 20 km/h. Moisture content of 60 bales that were weighed was measured using a moisture probe (Delmhorst F-2000, Digital Hay Moisture Meter with 18 Inch Probe). The moisture content of the bales varied from 10.3 to 18.9%, and the majority bales showed a moisture content of about 13%. Hence the weight of 60 bales was recorded by normalizing to 13% moisture content. Yield monitor data was filtered using automated low pass filter of Erdas Imagine (Ver. 2010). The yield maps were prepared by interpolating the filtered point data to a 4 by 4 m grid using the ordinary kriging (Dobermann *et al*., 2003) tool of ESRI GIS (Ver. 2010).

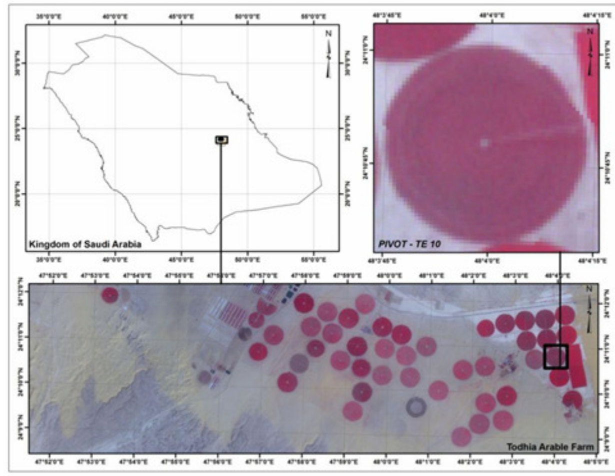

Fig. 1: Location of the experimental site – Todhia Arable Farm; located between Al-Kharj and Harad cities, Saudi Arabia

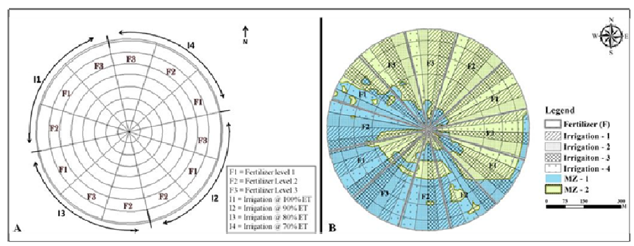

Fig. 2: Layout plans of the field experiment, (A) Before the deployment of Variable Rate Irrigation System (VRI) (i.e. January to May 2012) and (B) After installation of VRI (i.e. May to November 2012)

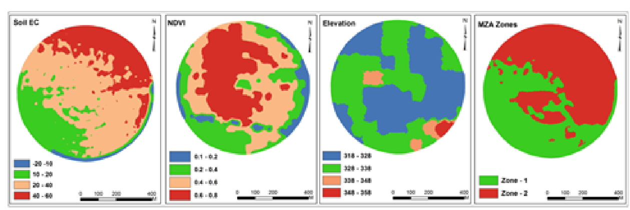

Fig. 3: EM-38 measured Soil EC$_a$, historic NDVI, ASTER DEM as elevation and the resulted Management Zones

During the preparation of yield maps, low or high yielding strips and points associated with significant turning and maneuvering of the baler were removed as described by Wiebold *et al*. (2003). Short segments which were affected by start or end-pass delays were also removed as described Simbahan *et al*. (2004).

Results

Management Zones (MZ)

In this study, site specific management zones were delineated using EM-38 measured Soil EC$_a$, historic NDVI and ASTER DEM (Fig. 3). Minimum NCE found at cluster two (Fig. 4) was used as the basis for dividing the pivot into two convenient MZ. Out of the total pivot area of 50 ha, 22.50 ha (44.75%) was covered under Management Zone – 1 (MZ1) and the remaining 27.77 ha (55.25%) was under Management Zone – 2 (MZ2).

Effects of VRA of Irrigation Water and Fertilizers on NDVI and LAI

Ground measured $NDVI_{(G)}$ and $LAI_{(G)}$ values (Tables 2-5) were found to differ significantly among the treatments for the measurements made in October 2012. Across MZ and in MZ2, higher $NDVI_{(G)}$ was observed at 70 and 80% ET_c than at 90 or 100% ET_c. Whereas, higher $LAI_{(G)}$ was recorded by irrigation at 70 and 80% ET_c than at 90% ET_c across the management zones. In MZ2, irrigation at 70% ET_c was superior to the other irrigation levels; while in MZ1, it was superior to only irrigation at 90% ET_c and on par with the other two levels of irrigation.

Alfalfa Hay Yield as Affected by Variable Rate Application of Irrigation Water and Fertilizers

Alfalfa hay yield maps developed for two harvests are presented in Fig. 5A (September) and Fig. 5B (October). Yield maps showed a distinct spatial variability in alfalfa hay productivity for the two harvests. The effects of irrigation and fertilizer levels on the alfalfa hay yield in the two management zones are depicted in Fig. 6 (September) and Fig. 7 (October). Treatment-wise alfalfa hay yield data are presented in Table 6 (September) and Table 7 (October). The irrigation and fertilizer treatments significantly influenced the hay yield of alfalfa in both the harvests.

Irrigation at 80% ET_c (≈ 2504.41 mm/ha/annum) resulted in the highest alfalfa hay yield with a mean of 3.50 t/ha for September harvest and 2.15 t/ha for October harvest. Variable Rate Irrigation (VRI) showed benefits only in September harvest. In this harvest, the highest hay yield of 3.27 t/ha was obtained in MZ1 with irrigation at 70% ET_c; however, it was on par with all the other irrigation levels. Whereas in MZ2, the highest yield of 3.63 t/ha was obtained with irrigation at 80% ET_c which was superior to all the other irrigation levels.

Alfalfa hay yield results revealed significant differences among the fertilizer levels. The medium fertilizer level - F2 (234:138:400 kg/ha/year of $N:P_2O_5:K_2O$) was superior to the other fertilizer levels and produced the highest alfalfa hay yield in both the management zones and for both September and October harvests.

Discussion

In this study, three years' Landsat ETM+ images and Fuzzy c-means cluster analysis were used for creation of

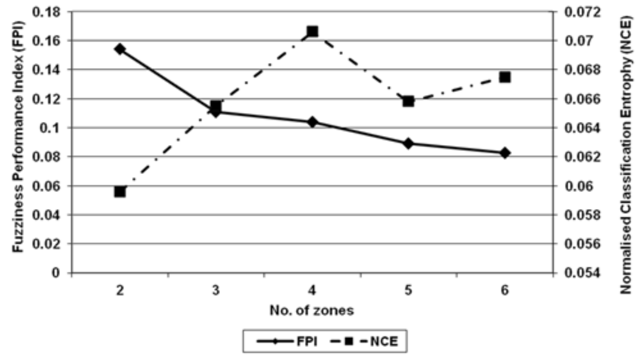

Fig. 4: Fuzziness Performance Index (FPI) and Normalized Classification Entropy (NCE) for the study area

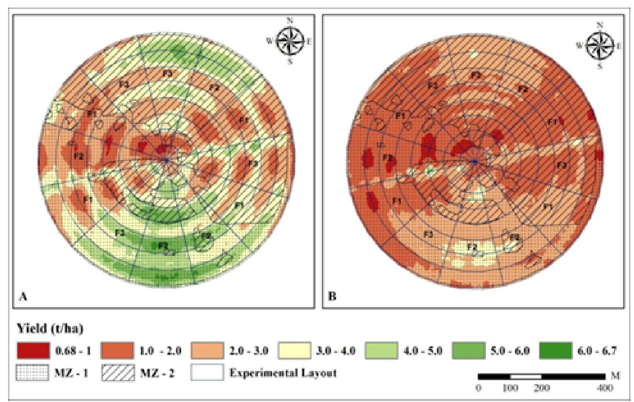

Fig. 5: Hay yield maps of alfalfa for September harvest (A) and October harvest (B)

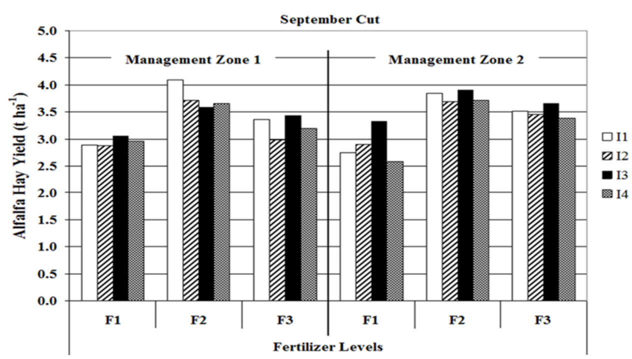

Fig. 6: Effects of irrigation (I) and fertilizer (F) levels on the alfalfa hay yield for September 2012

management zones of the experimental field. Previously, Boydell and McBratney (2002) used multi-year Landsat TM imagery for identifying potential within-field management zones and Arno *et al.* (2011) used fuzzy *c*-means algorithm for better identification of site-specific management zones. The number of zones was decided based on the least number of classes observed (two) in the Normalized Classification Entropy (NCE) index value.

Table 1: Average evapotranspiration (ET) values, mm, for the period 1995 to 2011

Date	Month											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	5.56	6.69	8.08	10.33	14.88	15.87	18.67	18.88	15.47	11.81	8.27	6.35
2	5.81	5.88	8.31	12.14	13.81	14.67	18.25	19.00	16.00	11.94	8.77	5.71
3	4.88	6.16	7.44	11.10	13.75	15.73	19.75	17.69	14.53	12.13	7.23	6.00
4	5.03	6.75	20.13	12.00	13.50	16.20	18.88	19.06	15.67	11.63	7.67	5.76
5	4.56	7.06	7.38	11.44	14.06	18.13	18.44	17.63	15.27	12.00	7.07	4.94
6	4.81	6.69	7.31	11.78	13.75	19.40	18.06	17.81	16.60	11.50	7.80	5.21
7	5.06	6.44	7.25	11.94	14.69	17.60	18.25	17.06	15.87	9.50	7.40	5.24
8	5.13	7.38	7.81	12.93	14.81	18.53	17.06	17.63	15.53	10.50	7.27	5.32
9	4.50	7.44	8.00	12.75	14.94	17.73	18.13	17.38	16.13	10.06	6.67	5.59
10	4.69	6.44	9.94	12.13	14.38	17.80	18.88	17.94	16.00	9.31	6.27	6.25
11	4.50	6.75	8.38	10.97	14.69	18.27	20.25	16.69	15.87	9.88	7.33	5.71
12	5.25	7.25	8.31	10.39	14.88	19.80	19.88	16.88	13.40	9.00	6.80	4.53
13	4.56	6.81	9.00	11.31	14.56	18.93	19.88	16.63	14.00	9.31	6.87	5.35
14	5.03	7.00	9.31	11.97	14.41	18.93	21.31	17.63	14.87	9.81	6.73	4.94
15	5.50	7.37	9.88	11.86	14.38	17.60	20.75	16.69	13.87	10.38	6.47	4.47
16	5.00	7.06	8.87	11.94	14.50	18.67	19.25	17.69	13.13	9.81	6.13	4.00
17	4.44	6.31	8.81	14.11	13.94	18.13	20.00	16.75	14.07	9.31	6.80	5.25
18	17.25	6.50	9.88	12.33	14.56	18.20	19.50	15.81	12.13	9.94	6.53	5.12
19	3.81	8.00	10.00	12.94	16.00	17.73	17.88	16.00	12.67	9.94	6.39	4.18
20	4.69	8.13	11.00	14.00	15.13	17.33	19.56	15.50	13.07	9.19	5.33	4.65
21	5.06	8.25	10.31	13.33	15.38	19.73	17.88	16.50	13.20	8.88	5.67	4.41
22	4.23	7.56	9.94	12.89	16.31	20.33	17.63	16.38	13.00	8.81	6.07	5.24
23	4.69	7.19	11.31	13.17	14.63	19.80	16.81	15.75	12.33	8.44	5.47	4.88
24	5.25	6.69	9.38	13.78	15.25	19.93	17.38	16.06	11.40	8.31	5.93	4.94
25	4.81	7.94	10.81	15.39	15.19	18.87	17.06	14.38	12.27	8.33	5.60	4.56
26	6.19	8.94	11.56	14.56	14.94	18.47	16.81	16.00	11.60	8.81	5.80	4.31
27	6.44	7.56	10.09	13.89	15.50	18.33	18.25	16.88	11.27	8.13	5.93	4.75
28	5.56	8.03	10.00	14.33	15.47	18.53	18.31	16.06	11.67	7.69	6.10	4.56
29	6.25	7.50	8.69	15.47	15.75	20.00	17.69	14.81	11.60	8.63	5.47	4.38
30	5.38	--	9.50	17.39	16.56	19.27	17.75	16.06	12.00	8.50	6.03	5.63
31	6.00	--	10.50	--	15.87	--	17.50	16.75	--	8.20	--	5.49
Average	5.48	7.16	9.59	12.82	14.85	18.28	18.57	16.84	13.82	9.67	6.60	5.13

Table 2: Effects of irrigation and fertilizer levels on $NDVI_{(G)}$ (September 11, 2012)

Irrigation Level	Management Zone – 1				Management Zone – 2				Overall Mean
	F1	F2	F3	Mean	F1	F2	F3	Mean	
I1	0.74	0.67	0.66	0.69	0.66	0.68	0.58	0.64	0.66
I2	0.76	0.61	0.60	0.66	0.61	0.51	0.60	0.57	0.62
I3	0.59	0.65	0.56	0.60	0.47	0.32	0.67	0.49	0.54
I4	0.55	0.66	0.67	0.63	0.66	0.65	0.69	0.66	0.64
Mean	0.66	0.65	0.62	0.64	0.60	0.54	0.64	0.59	0.62
ANOVA								SE	$LSD_{(0.05)}$
(1) Management Zones (MZ)								0.0236	NS
(2) Irrigation Levels (I)								0.0619	NS
(3) Fertilizer levels (F)								0.0410	NS
(4) MZ Vs. I								0.0875	NS
(5) MZ Vs. F								0.0580	NS
(6) I Vs. F								0.0820	NS
(7) MZ * I * Z								0.1290	NS

The experimental field was delineated into two convenient management zones based on NCE index, because the least number of zones based on FPI index was 6 (Fig. 4) which is more difficult to manage compared to two zones. The results were similar to those of Lark and Stafford (1997) and Patil *et al*. (2013), who decided the number of management zones based on the least number of classes of NCE.

Based on the fact that NDVI saturates beyond a threshold value and that ground measurement of both NDVI and LAI is a time consuming task, two models of $NDVI_{(P)}$-$LAI_{(G)}$ were generated for the measurements made in September and October 2012 (Fig. 8 and 9). The results showed linear relationship for both dates, with higher correlation between $LAI_{(G)}$ and $NDVI_{(P)}$ for September 2012 (R^2 = 0.65) than for October 2012 (R^2 = 0.52) mainly due to saturation of $NDVI_{(P)}$ at higher LAI values in October 2012. The results are in agreement with those of Baret and Guyot (1991) and Hall *et al*. (1995) who reported that NDVI saturates when the LAI values reach a threshold ranging from 2 to 6 depending on the vegetation type.

Table 3: Effects of irrigation and fertilizer levels on $NDVI_{(G)}$ (October 7, 2012)

Irrigation Level	Management Zone – 1				Management Zone – 2				Overall Mean
	F1	F2	F3	Mean	F1	F2	F3	Mean	
I1	0.68	0.62	0.65	0.65	0.57	0.58	0.63	0.59	0.62
I2	0.65	0.52	0.55	0.57	0.61	0.60	0.59	0.60	0.59
I3	0.60	0.58	0.61	0.60	0.69	0.70	0.67	0.68	0.64
I4	0.58	0.63	0.66	0.62	0.66	0.68	0.66	0.67	0.65
Mean	0.63	0.59	0.62	0.61	0.63	0.64	0.64	0.64	0.62
ANOVA								SE	$LSD_{(0.05)}$
(1) Management Zones (MZ)								0.0026	0.0111
(2) Irrigation Levels (I)								0.0128	0.0296
(3) Fertilizer levels (F)								0.0144	NS
(4) MZ Vs. I								0.0181	0.0418
(5) MZ Vs. F								0.0204	NS
(6) I Vs. F								0.0289	NS
(7) MZ * I * Z								0.0379	NS

Table 4: Effects of irrigation and fertilizer levels on $LAI_{(G)}$ (September 11, 2012)

Irrigation Level	Management Zone – 1				Management Zone – 2				Overall Mean
	F1	F2	F3	Mean	F1	F2	F3	Mean	
I1	5.59	5.22	5.22	5.35	5.34	5.44	4.84	5.21	5.28
I2	5.70	4.98	4.88	5.19	5.00	4.34	5.04	4.79	4.99
I3	5.66	5.15	4.56	5.13	3.84	3.45	5.41	4.23	4.68
I4	4.67	4.97	5.36	5.00	5.33	5.28	5.51	5.38	5.19
Mean	5.41	5.08	5.01	5.17	4.88	4.63	5.20	4.90	5.03
ANOVA								SE	$LSD_{(0.05)}$
(1) Management Zones (MZ)								0.1076	NS
(2) Irrigation Levels (I)								0.3255	NS
(3) Fertilizer levels (F)								0.2039	NS
(4) MZ Vs. I								0.4603	NS
(5) MZ Vs. F								0.2883	NS
(6) I Vs. F								0.4078	NS
(7) MZ * I * Z								0.6585	NS

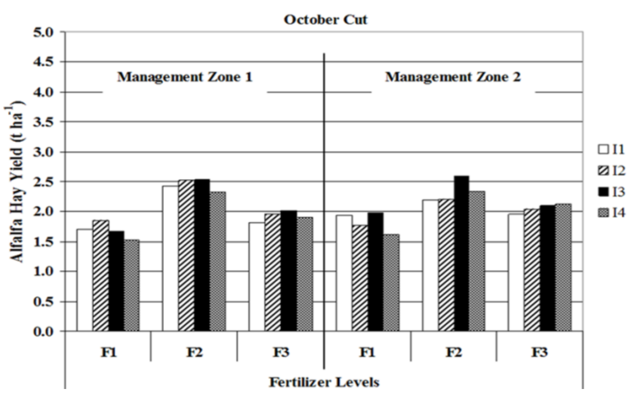

Fig. 7: Effects of irrigation (I) and fertilizer (F) levels on the alfalfa hay yield for October 2012

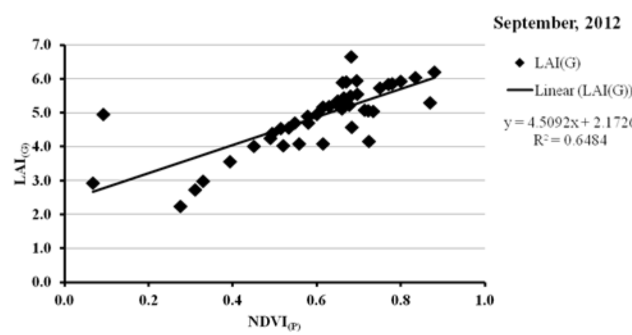

Fig. 8: Correlation between $NDVI_{(P)}$ and $LAI_{(G)}$ for September 2012

The threshold LAI values of alfalfa were 4.5 – 5.5 and 2.4 – 3.2 for data collected in this study, in September and October 2012, respectively. Since the threshold LAI values were within the range of 2-6 as reported earlier, the generated NDVI-LAI empirical relationship could be used efficiently for the retrieval of $LAI_{(P)}$ from remotely sensed $NDVI_{(P)}$ data, as LAI is considered as one of the most important indices that is highly related to crop growth processes. Fig. 10 shows an example of LAI prediction using $NDVI_{(P)}$ data for September and October 2012. This relationship can be very useful to couple modeling and remote sensing approaches through forcing, calibration or assimilation procedures.

In this study, irrigation with 2504 mm/ha/annum of water (80% ET_c) resulted in the highest alfalfa hay yield in two harvests. In a previous study (Al-Noaim *et al*., 1978) carried out in Saudi Arabia, much higher quantity of water (3850 mm/ha/annum) was applied to obtain higher yield. However, the results of this study are in close agreement with those of Al-Lawati *et al.* (2010) who recorded higher WUE by irrigation at 75% ET_c. Further, it was found that by adopting VRI at 70% ET_c in MZ1 and 80% ET_c in MZ2,

Table 5: Effects of irrigation and fertilizer levels on $LAI_{(G)}$ (October 7, 2012)

Irrigation Level	Management Zone – 1				Management Zone – 2				Overall Mean
	F1	F2	F3	Mean	F1	F2	F3	Mean	
I1	3.11	2.86	2.97	2.98	2.57	2.65	2.87	2.70	2.84
I2	3.00	2.27	2.45	2.57	2.80	2.70	2.65	2.72	2.65
I3	2.76	2.64	2.78	2.73	3.09	3.12	3.09	3.10	2.92
I4	2.59	2.87	3.04	2.83	3.04	3.13	3.04	3.07	2.95
Mean	2.87	2.66	2.81	2.78	2.88	2.90	2.91	2.90	2.84
ANOVA								SE	$LSD_{(0.05)}$
(1) Management Zones (MZ)								0.0094	0.0405
(2) Irrigation Levels (I)								0.0592	0.1365
(3) Fertilizer levels (F)								0.0764	NS
(4) MZ Vs. I								0.0837	0.1931
(5) MZ Vs. F								0.1081	NS
(6) I Vs. F								0.1529	NS
(7) MZ * I * Z								0.1954	NS

Table 6: Effect of irrigation and fertilizer levels on alfalfa hay yield (t/ha) for September 2012 harvest

Irrigation Level	Management Zone – 1				Management Zone – 2				Overall Mean
	F1	F2	F3	Mean	F1	F2	F3	Mean	
I1	2.89	4.09	3.36	3.45	2.75	3.85	3.51	3.37	3.41
I2	2.88	3.71	2.98	3.19	2.90	3.69	3.46	3.35	3.27
I3	3.05	3.59	3.43	3.36	3.32	3.90	3.66	3.63	3.50
I4	2.96	3.66	3.20	3.27	2.58	3.71	3.38	3.22	3.25
Mean	2.95	3.76	3.24	3.32	2.89	3.79	3.50	3.39	3.36
ANOVA								SE	$LSD_{(0.05)}$
(1) Management Zones (MZ)								0.0722	NS
(2) Irrigation Levels (I)								0.0681	0.1381
(3) Fertilizer levels (F)								0.1071	0.2469
(4) MZ Vs. I								0.0963	0.1953
(5) MZ Vs. F								0.1514	NS
(6) I Vs. F								0.1180	0.2392
(7) MZ * I * Z								0.1357	NS

Table 7: Effect of irrigation and fertilizer levels on alfalfa hay yield (t/ha) for October 2012 harvest

Irrigation Level	Management Zone – 1				Management Zone – 2				Overall Mean
	F1	F2	F3	Mean	F1	F2	F3	Mean	
I1	1.70	2.43	1.82	1.98	1.93	2.19	1.96	2.03	2.01
I2	1.85	2.52	1.96	2.11	1.77	2.21	2.04	2.01	2.06
I3	1.68	2.53	2.02	2.08	1.98	2.59	2.10	2.22	2.15
I4	1.52	2.32	1.90	1.91	1.61	2.34	2.12	2.02	1.97
Mean	1.69	2.45	1.93	2.02	1.82	2.33	2.06	2.07	2.05
ANOVA								SE	$LSD_{(0.05)}$
(1) Management Zones (MZ)								0.0113	NS
(2) Irrigation Levels (I)								0.0583	0.1182
(3) Fertilizer levels (F)								0.0617	0.1422
(4) MZ Vs. I								0.0824	NS
(5) MZ Vs. F								0.0872	0.2011
(6) I Vs. F								0.1009	NS
(7) MZ * I * Z								0.0943	NS

water saving of 20 to 30% could be attained. The results of the effects of fertilizer levels on alfalfa yield are in agreement with previous studies that emphasized the need for supply of adequate nutrients to alfalfa (Bernardi *et al*., 2013) including phosphorus (Berg *et al*., 2005), potassium (Macolino *et al*., 2013) and combination of phosphorus and potassium (Berg *et al*., 2007).

There was good correlation between alfalfa hay yield and $NDVI_{(G)}$, $NDVI_{(P)}$, and $LAI_{(G)}$ and $LAI_{(P)}$ as indicated by reasonably higher R^2 values (Fig. 11). The results are in tune with the earlier reports of good correlation between NDVI and yield of crops such as wheat (Groten, 1993; Doraiswamy and Cook, 1995; Doraiswamy *et al*., 1996; Patil *et al*., 2013) and between LAI and yield of crops (Maas, 1998; Patil *et al*., 2013). The alfalfa hay yield could also be predicted with reasonable accuracy, based on October 2012 $NDVI_{(G)}$, $NDVI_{(P)}$, and $LAI_{(G)}$ and $LAI_{(P)}$ using the algorithms given in Table 8.

Table 8: Regression algorithms for alfalfa hay yield prediction

Harvest Reference	Algorithm	R^2
October 2012	$Yield = ((347.27*NDVI_{(G)}^3)-(630.79*NDVI_{(G)}^2)+(385.1*NDVI_{(G)})-77.053)$	0.6348
	$Yield = ((-1527.1*NDVI_{(P)}^3)+(2434.2*NDVI_{(P)}^2)-(1282.8*NDVI_{(P)})+225.29)$	0.5447
	$Yield = ((2.1661*LAI_{(G)}^3)-(18.728*LAI_{(G)}^2)+(54.159*LAI_{(G)})-50.298)$	0.4690
	$Yield = ((-15.776*LAI_{(P)}^3)+(113.11*LAI_{(P)}^2)-(267.858*LAI_{(P)})+211.2)$	0.6344

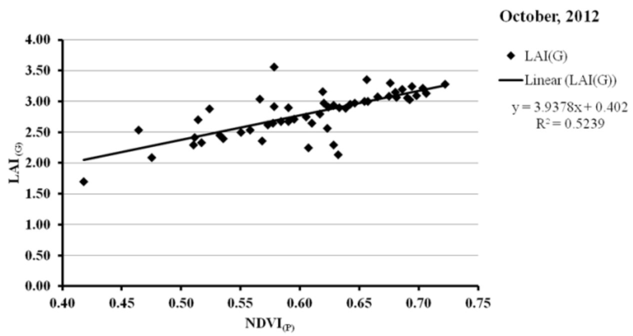

Fig. 9: Correlation between $NDVI_{(P)}$ and $LAI_{(G)}$ for October 2012

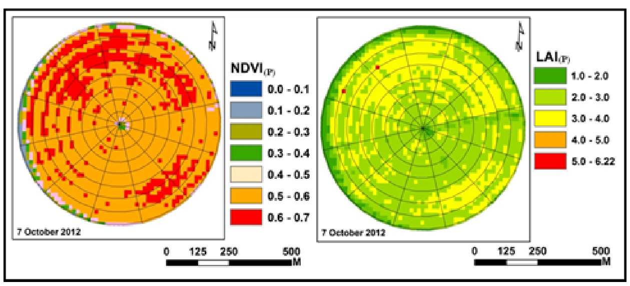

Fig. 10: LAI maps predicted from remotely sensed NDVI data

Conclusion

In this study, three years' Landsat ETM+ images, geo-referenced EC_a and elevation from ASTER DEM were used as parameters for delineation of management zones. Fuzzy c-means cluster analysis was employed for creation of two convenient management zones based on the least number of classes observed in the Normalized Classification Entropy (NCE) index value. Irrigation with 2504 mm of water (80%ET_c) resulted in the highest alfalfa hay yield in two harvests. Water saving of 20 to 30% could be attained by adopting VRI at 70%ET_c in MZ1 and 80%ET_c in MZ2. The medium fertilizer level - F2 (234:138:400 kg/ha/year of N: P_2O_5: K_2O) was superior to the other fertilizer levels and produced the highest alfalfa hay yield in both the management zones and for both September and October 2012 harvests. The study demonstrated the benefit of variable rate application of irrigation water that resulted in water saving of up to 30% in one out of two harvests. However, the benefit of variable rate application of fertilizers was not evident.

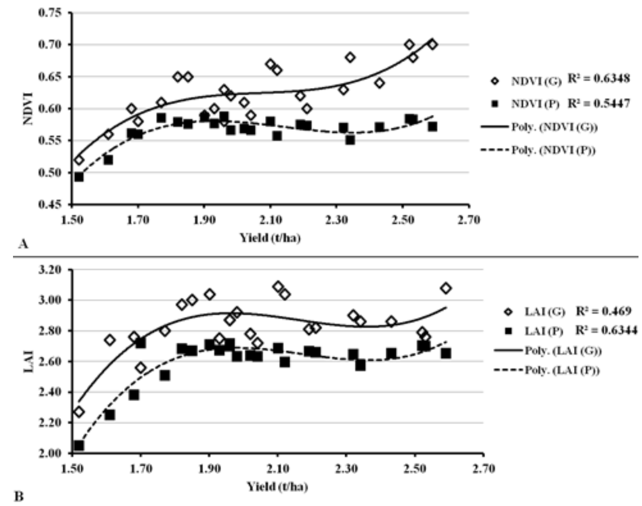

Fig. 11: Regression between alfalfa hay yield vs NDVI and LAI for October 2012

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