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Sustainable Agriculture in the Arid Desert West of the Nile Delta: A Crop Suitability and Water Requirements Perspective

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ABSTRACT
In this study, the selection of suitable crops and the water management were considered as the main pillars of sustainable agriculture in dry deserts. The main objective is to use remote sensing and GIS for setting a suitable cropping pattern and estimate the crop water requirements in arid desert area. A newly reclaimed area located to the west of the Nile Delta was selected for this work. A Landsat ETM+ and a Shuttle Radar Topography Mission data were processed using ENVI 4.7 software for landforms mapping. The recognized landforms comprised; old deltaic plain, aeolian plain and depression with alluvial deposits. The mapped units were represented by 24 soil profiles and 36 observation points. The soil profiles were morphologically described, sampled and analyzed. A GIS soils database was established using the landform map and the results of the land surveying and soil analysis. Based on land characteristics (i.e., soils, water and climate) the suitable crops for each landform were proposed. The land surface temperature (LST) and Crop evapotranspiration (ET) are estimated from Landsat ETM+ thermal band by using the Surface Energy Balance Algorithm for Land (SEBAL). The water requirements of the proposed crops were calculated and the irrigation management is discussed with respect to the soil properties. Results indicated that partial land uses could be achieved the agricultural sustainability in such area.

Key words: Soils database, landforms, crop ET, remote sensing, West delta, Egypt

INTRODUCTION
The scarceness of fertile soils and water resources in cultivated dry deserts imposes considerable attention in both cropping pattern and water requirements. In Egypt, most of the newly developed lands were situated along the western fringes of the Nile Delta. The cost of reclamation of such regions for canals, pumping stations, main roads, electricity transmission facilities, utilities and related buildings is rather high (MALR, 1994). Therefore, the land suitability for crops in this area is an essential action in order to maintain the sustainable development of investment as well as the sustainable usage of the soils. Land evaluation is a vital link in the chain leading to sustainable management of land resources. It is assigned the indispensable task of translating the data on land resources into terms and categories, which can be understood and used by all those concerned with land improvement and land use planning (FAO, 1991, 2007). In arid regions, water resources are naturally limited and the challenge to produce more food under water shortage is real (Bouman, 2007). The accurate estimation of Crop Water Requirements (CWR) in such areas is a must. Traditional methods of estimating the CWR are based on the crop coefficient (Kc) approach that requires the determination of reference Evapotranspiration (ETo) and Kc. Potential

evapotranspiration is then determined as a product of the ETo and Kc (FAO, 1998). Values of Kc from a reference table assume homogeneity over a respective area and may contribute to an error in estimating crop water requirements due to their empirical nature (Ray and Dadhwal, 2001). In the view of this limitation, new techniques for estimating actual evaporation and transpiration is being developed using spatial and temporal information. The quantification of CWR using satellite data is the optimum way to independently and regularly measure of water requirements on a field-by-field basis over large land areas. In the area under investigation, typical field sizes of newly reclaimed lands range between 10 and 30 acres (GARPAD, 1997). These sizes require high resolution images (e.g., Landsat ETM+) to extract spatial information. Soil properties and landforms are most significant factors controlling the Irrigation Water Management (IWM). Moreover, soil information database can improve the estimation of the current and the future land potential productivity and can help identifying land and water use limitations (FAO/IIASA, 2008). This study aims to use remote sensing data and GIS to create a soil database, propose suitable crops and estimate their water requirements for the newly reclaimed arid desert located to the west of the Nile Delta.

MATERIALS AND METHODS

Study area: The area under investigation is located to the west of the Nile Delta and extended between 30° 31′ 30″ and 30° 46′ 04″ E longitudes and 30° 19′ 45″ and 30° 31′ 15″ N latitudes, (Fig. 1). It covers an area of 113.49 km^2. This area has always been confined as a possible area for reclamation and utilization due to its location and the presence of ground water that is suitable for irrigation (El-Maghraby, 1990). It is considered as an extremely arid region where, the mean annual rainfall is 41.4 mm, mean annual evaporation is 1715.6 mm, mean temperature is 21°C, wind speed average is 3.4 m sec^{-1} and the mean relative humidity is 48%. (Egyptian Meteorological Authority, 1996). The main landforms exhibit the west Nile Delta region are, river terraces, levees, flood plain, old deltaic plain and windborne deposits (Sadek, 1984). The Pleistocene formations which are composed of sand and gravel in this area are of assorted sizes bordering the cultivated areas where they form a series of various elevation terraces (Hermina and Klitzsch, 1989).

Establishing soils database: The Landsat Enhanced Thematic Mapper Plus (ETM+) records 7 spectral bands in the visible, infrared and thermal portions of the electromagnetic spectrum. The

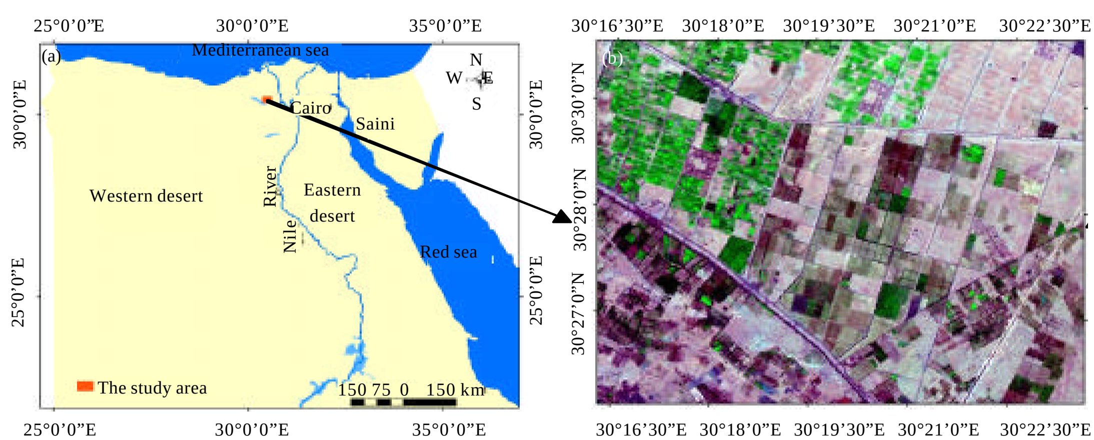

Fig. 1(a-b): (a) Location of the study area on Egypt map and (b) Landsat ETM+ (bands 7, 4, 2) of the study area spatial resolution of this sensor is 30 m (except thermal band-6 of 60 m resolution). The Scan Line Corrector (SLC) of the Landsat 7 was failed in May 31, 2003, creating a scanning pattern of wedge-shaped gaps. The Landsat 7 still to gain data with the SLC-off, generating images of about 22% missed data (Storey *et al*., 2005). To recover the capability of the image, the SLC-off data is exchanged with calculated values from the histogram-matched scenes using ENVI 4.7 software. Landsat ETM+ image acquired during the year 2010 (pass 177/row 39) was used, the image was enhanced by using ENVI 4.7 software. To improve the contrast and enhancing the edges, the image was stretched using linear 2%, smoothly filtered and their histograms were matched according to Lillesand and Kiefer (2007). The atmospheric correction was done to reduce the noise effect using FLAASH module. Image was radiometrically and geometrically corrected to accurate the irregular sensor response over the image and to correct the geometric distortion due to Earth's rotation (ITT, 2009). The Digital Elevation Model (DEM) of the study area (Fig. 2) was extracted from the Shuttle Radar Topography Mission (SRTM). The SRTM is a respected space data of land surface that obtained by accurate positioned radar scanning earth at 1-arc seconds intervals. This data could be combined with multispectral images to realize better view of the landscape. The Landsat ETM+ image and SRTM data were processed in ENVI 4.7 software to identify the different landforms and establish the soil database (Dobos *et al*., 2002; Zinck and Valenzuela, 1990). A semi detailed survey was carried out throughout the investigated area in order to gain an appreciation on soil patterns, land forms and the landscape characteristics. A total of 60 ground truth sites were studied in the field from which twenty four soil profiles and thirty six observation points were collected to represent the different preliminary mapping units. The morphological description of the profiles was carried out according to the guidelines outlined by FAO (2006) and the soil color is defined according to Munsell Color Charts (SSS, 1975). Sum of 67 disturbed soil samples was collected and prepared for laboratory analyses. A total of 9 water samples were collected from the irrigation sources (artesian wells) in the study area, where each landform was represented by one water sample. Representative soil and water samples were collected and analyzed according to USDA (2004) and Klute (1986). The obtained data from land survey and laboratory analyses were recorded in the attribute table of the landform map using Arc-GIS 9.2 software. The standard deviation of soil properties in each landform was computed using SPSS.13 software.

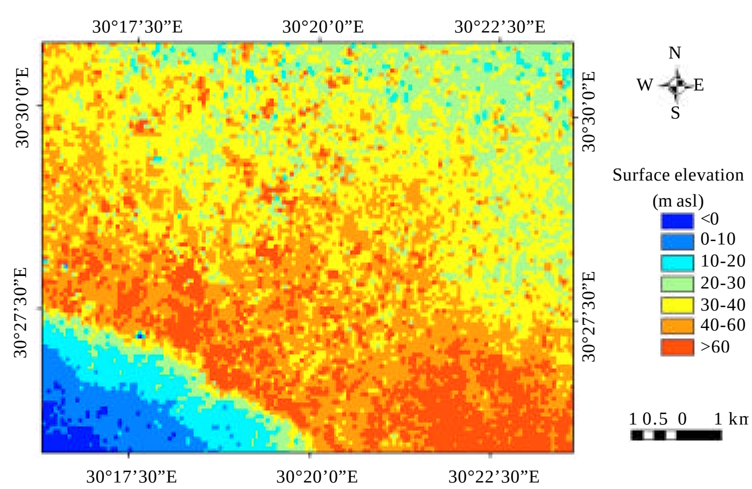

Fig. 2: Surface elevation derived from SRTM image (30 m resolution)

Land suitability for crops: The land suitability classification for crops was carried out according to FAO (1985, 2007) methodology using the following data:

- **Soil properties:** Soil depth, texture, structure, available water percent, pH value, $CaCO_3$ percent, Organic Matter (OM%), electrical conductivity (EC as dS/m), Exchangeable Sodium Percentage (ESP) and surface slope %
- **Water quality:** pH value, electrical conductivity EC (dS m^{-1}), Na (meq L^{-1}), Cl (meq L^{-1}), Mg (meq L^{-1}), HCO_3 (meq L^{-1}) and B (ppm)
- **Climatic data:** Wind speed (m sec^{-1}), relative humidity%, temperature (°C) and rainfall (mm $year^{-1}$)

Satellite based estimations

Land surface temperature (LST): The thermal bands of Landsat ETM+ (band 6) manifests the amount of infrared radiant flux (heat) emitted from different surfaces. The long infrared waves are radiations that are detected as heat energy; therefore, the thermal IR band well correlate with the temperature of the surfaces it scans (EOSC, 1994). For the current study, six available Landsat ETM+ images band 6, of path 177 and row 39, acquired during the period 3/7/2008 and 19/05/2009 are employed. Satellite detectors acquire thermal data and store it as Digital Numbers (DN) with a range of 0-255. The DN values were transformed to temperature degrees in Celsius as follows:

Converting the DNs to radiance values as:

$$CVR = G \times (CVDN)+B \tag{1}$$

where, CVR is the cell value as radiance, CVDN is the cell digital number, G and B are the gain and the bias obtained from the image header file (NASA, 2002).

Converting the radiance to degrees in Celsius as:

$$T = [K2/\ln (K1/CVR+1)]-273 \tag{2}$$

where, T = Temperature in Celsius, K1 = 666.09 and K2 = 1282.71, (NASA, 2002).

Normalized difference vegetation index (NDVI): NDVI show patterns of vegetative growth by indicating the quantity of actively photosynthesizing biomass on a landscape (Burgan *et al.*, 1996). The NDVI can be assessed as follows:

$$NDVI = (NIR-RED)/(NIR+RED) \text{ unit-less ratio} \tag{3}$$

where, NIR is the near infrared band (DN values) and RED is the red band (DN values).

The obtained NDVI values are located in the range (-1 to 1), the negative values point to non vegetated surfaces, while the positive values indicate vegetated surfaces (Burgan and Hartford, 1993).

Crop evapotranspiration (ET): The estimation of the crop ET by Surface Energy Balance Algorithm for Land (SEBAL) requires several data input i.e., NDVI, emissivity, broadband surface albedo and LST, these inputs are obtained from digital image processing (Bastiaanssen *et al*., 1998). The broadband albedo is estimated from the weighting factors of the multispectral bands, while the surface emissivity is calculated from NDVI, (Liang *et al*., 1999). Calculation of the net incoming radiation and soil heat flux is done by using Bastiaanssen (1995) procedure, while the sensible heat flux is determined after Tasumi *et al*. (2000). The difference between air and soil temperature for the "hot" pixel is calculated and the air density is obtained consuming meteorological data of relative humidity. Maximum air temperature is obtained from the El Tahrir climatic station at the time of the satellite overpass. The ET was calculated using SEBAL from the instantaneous evaporative fraction (Λ) and the daily averaged net radiation, Rn24 according to Hafeez (2003) as follows:

$$\Lambda = \lambda E/Rn\text{-}G_{\circ} = \lambda E/\lambda + H_{\circ} \text{ unit-less ratio} \tag{4}$$

$$ET_{24}\ (\text{mm d}^{-1}) = \Lambda/R_{n24}\ ((2.501\text{-}0.002361\times LST)\times 10^{6})] \tag{5}$$

where, λE is the latent heat flux, Rn is the net radiation absorbed or emitted from the earth's surface, G_o is the soil heat flux, H_o is the sensible heat flux (W m^{-2}), ET_{24} = daily ET (mm day^{-1}); Rn24 is the average daily net radiation (W m^{-2}) and LST is the land surface temperature as °C.

The difference between (Λ) and the evaporative fraction resulting from the 24 h integrated energy balance is marginal and may be neglected (Brutsaert and Sugita, 1992; Crago, 1996; Farah, 2001). For 24 h or longer, G_o can be ignored, so, the net available energy (Rn-G_o) can be reduced to net radiation (Rn). The use of remote sensing data accurately provides the spatial distribution of the calculated $ET_{24.}$ However, this calculation can not be used directly where the ET_{24} is commonly affected by the local climatic conditions and moisture content in the field, which fluctuate hourly. Therefore, simulating daily records is required to obtain accurate results of seasonal ET. Missing values of ET_{24} could be obtained by calculation of daily ETo using the modified Penman-Monteith method (Tasumi *et al*., 2000). The crop ETc (mm d^{-1}) could be calculated as:

$$ETc = Kc\times ET_{24} \tag{6}$$

where, Kc is the crop coefficient obtained after FAO (1998).

RESULTS

Landforms: Digital Elevation Model (DEM) is a 3D electronic model of the land's surface (Brough, 1986). It provides better functionalities than the topographic maps. A DEM can be employed to offer varieties of data that can assist in mapping of landforms and soil types. Information derived from a DEM, i.e., surface elevation, slope % and slope direction, could be used with the satellite images to increase their capabilities for soil mapping (Lee *et al*., 1988). The landforms of the study area were delineated by using the digital elevation model, Landsat ETM+ and ground truth data. The produced map was imported into a Geo-database as a base map (Fig. 3), the following landforms were recognized:

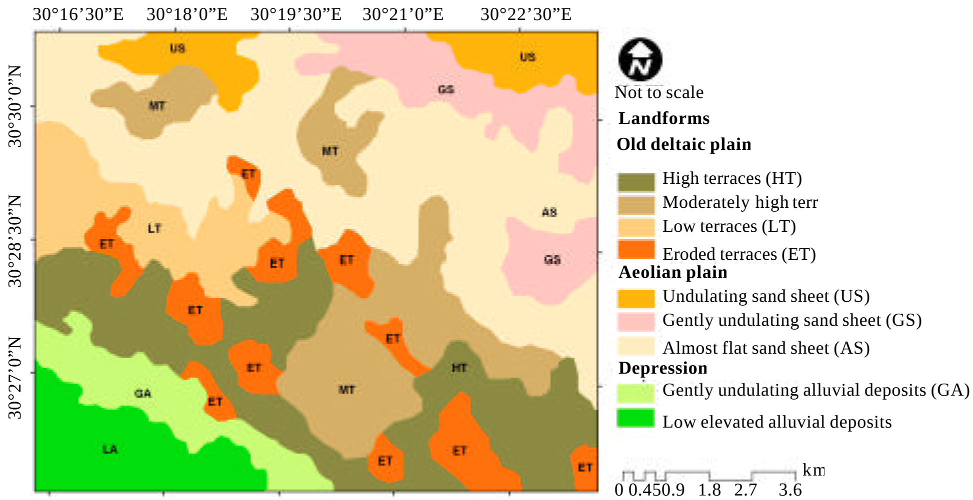

Fig. 3: The main landforms in the study area

- **Old deltaic plain:** This landscape covers an area of 53.56 km^2 representing 47.20% of the total area. The main landforms in this landscape are high terraces HT, (18.98 km^2), moderately high terraces MT, (16.38 km^2), low terraces LT, (8.30 km^2) and eroded terraces (9.90 km^2)
- **Aeolian plain:** This landscape covers an area of 46.30 km^2, i.e., 40.80% of the total area. It includes the landforms of almost flat sand sheet AS, (30.71 km^2), gently undulating sand sheet GS, (9.42 km^2) and undulating sand sheet US, (6.17 km^2)
- **Depression:** This unit covers an area of 13.63 km^2, representing 12.00% of the total area. It is subdivided into gently undulating alluvial deposits GA, (6.14 km^2) and low elevated alluvial LA, (7.49 km^2)

Soils: The morphological description and some physical and chemical analyses of the investigated soils are shown in Table 1-3. Standard Deviation (SD) of soil properties (Table 4) represents the high homogeneity of soils within each landform. The obtained data show that the soils of the study area are, in general, characterized by very pale brown (10 YR 7/3) to pale brown (10 YR 6/3). The soil texture is sandy in the aeolian plain landforms, while it differs from loamy sand to gravely sand in the old deltaic plain. Surface gravel is few in the aeolian plain landforms, while it differs from few to many on the surfaces of old deltaic plain. Soil structure is single grained, except for the soils of low and moderately high terraces, which have a weak sub-angular blocky structure. These types of soil structure indicate initial stage of soil development that may be related mainly to an increase in sand percentage and a decrease in Organic Matter (OM) content. Soil stickiness and plasticity are none to slight as they coincide with the soil texture. The particle size distribution shows that the medium and fine sand is dominated in the soils. The soil profiles in the different landforms are deep as the soil depth differs from 110 to 160 cm. The hydraulic conductivity of the soils changes from rapid (23.7 cm h^{-1}) to moderate (15.9 cm h^{-1}), which is mainly due to the sandy texture, single grain texture and low OM content. Field capacity and wilting point ranged between 13.5 to 15.3% and 4.5 to 7.4%, respectively. The percent of OM is very low in the different landforms of the

Table 1: Morphological description of the soils in the different landforms

				Soil color								
Landform	P	S	Slope %	Dry	Moist	Te	Sug	Str	Sti	Pla	Ce	Ca
High terraces (HT)	3	11	G	10YR7/3	10YR6/3	GS	Ma	Sg	NST	NPL	W	ST
Moderately high terraces (MT)	3	10	A	10YR7/6	10YR6/6	LS	C	WSB	SST	SPL	M	ST
Low terraces (LT)	3	9	A	10YR7/4	10YR6/4	LS	F	WSB	SST	SPL	M	ST
Eroded terraces (ET)	2	7	U	10YR7/4	10YR6/4	GS	Ma	Sg	NST	NPL	M	ST
Almost flat sand sheet (AS)	3	6	A	10YR7/4	10YR7/3	S	F	Sg	NST	NPL	W	MO
Gently undulating sand sheet (GS)	3	6	G	10YR7/3	10YR6/3	S	F	Sg	NST	NPL	W	MO
Undulating sand sheet (US)	3	6	U	10YR7/4	10YR6/4	S	F	Sg	NST	NPL	W	MO
Gently undulating alluvial (GA)	2	6	U	10YR7/6	10YR6/6	S	C	Sg	NST	NPL	W	ST
Low elevated alluvial (LA)	2	6	A	10YR7/4	10YR7/3	LS	C	WSB	SST	SPL	M	ST

P: Sum of representative soil profiles for each land form (total 24), S: Sum of soil samples for each landform (total 67), G: Gently undulatiug, A: Almost flat, U: Undulating, Te: Texture, Sug: Surface gravel, Str: Structure, Sti: Stickiness, Pla: Plasticity, Ce: Cementation, Ca: Carbonates, GS: Ggravelly sand, LS: Loamy sand, S: Sandy, C: Common, F: Few, Ma: Many, Sg: Single grains, WSB: Weak sub-angular blocky, NST: Non sticky, SST: Slightly sticky, NPL: Non plastic, SPL: Slightly plastic, W: Weak, M: Moderate, ST: Strong effervescence with HCl, MO: Moderate effervescence with HCl

Table 2: Some physical properties of the investigated soils

		Particle size distribution (mm) (%)							Volume basis (%)		
Landform	Soil depth (cm)	2-1	-0.5	-0.25	-0.125	-0.063	<0.063	HC (cm h^{-1})	FC	WP	AW
High terraces	150	16.0	23.7	35.4	24.1	0.5	0.3	19.5	15.2	7.6	7.6
Moderately high terraces	160	3.6	12.4	47.2	23.3	2.9	10.7	18.6	14.2	4.9	9.3
Low terraces	150	10.4	25.2	42.5	9.4	0.4	12.2	16.7	14.3	4.5	9.8
Eroded terraces	110	18.5	16.6	30.1	27.1	5.6	2.1	16.3	15.3	7.5	7.8
Almost flat sand sheet	170	0.6	7.9	39.2	48.6	3.2	0.4	22.3	13.5	5.8	7.7
Gently undulating sand sheet	120	0.4	10.1	35.7	50.3	3.2	0.4	19.8	14.3	6.6	7.7
Undulating sand sheet	130	2.0	21.6	37.4	33.7	5.2	0.1	23.7	14.1	6.2	7.9
Gently undulating alluvial	140	1.6	18.4	35.5	41.6	2.2	0.6	19.4	15.2	6.3	8.9
Low elevated alluvial	110	4.3	15.4	43.3	23.5	2.4	11.3	16.4	14.3	4.7	9.6

HC: Hydraulic conductivity, FC: Field capacity, WP: Wilting point, AW: Available water, ESP: Exchangeable sodium percent

Table 3: Some chemical properties of the investigated soil

	Soil properties								
							N	P	K
Landform	pH	OM (%)	$CaCO_3$ (%)	EC (dS m^{-1})	CEC (meq/100 g soil)	ESP	(ppm)		
High terraces	7.9	0.66	6.2	5.8	8.8	12.3	6.2	1.4	19.6
Moderately high terraces	8.1	0.52	5.4	4.5	10.5	14.5	6.1	1.9	18.4
Low terraces	7.8	0.81	4.6	3.5	12.9	11.5	7.3	2.1	22.4
Eroded terraces	8.2	0.61	12.4	8.5	5.6	15.5	7.4	1.2	20.5
Almost flat sand sheet	7.8	0.53	8.4	1.8	4.6	11.2	5.6	0.8	23.6
Gently undulating sand sheet	7.9	0.43	4.6	3.6	6.2	9.5	4.6	1.4	21.3
Undulating sand sheet	7.9	0.63	3.5	3.2	7.9	11.4	3.6	1.8	24.8
Gently undulating alluvial	7.8	0.72	4.4	4.2	12.3	12.6	7.8	1.6	30.2
Low elevated alluvial	8.1	0.63	6.8	4.5	18.5	14.5	8.5	2.3	35.2

OM: Organic matter, EC: Electrical conductivity, CEC: Cation exchange capacity, ESP: Exchangeable sodium percent

Table 4: Standard deviation (%) of soil properties in each landform

	Soil properties												
Landforms	pH	OM	$CaCO_3$	EC	CEC	ESP	N	P	K	HC	FC	WP	AW
HT	0.12	1.38	2.13	0.56	0.85	0.72	1.13	3.14	1.38	2.31	1.61	1.22	2.34
MT	0.16	2.44	1.26	0.89	2.11	1.21	1.68	1.27	3.41	1.53	0.84	0.93	1.55
LT	0.54	1.08	0.98	1.28	1.87	0.97	0.97	1.34	1.11	2.41	1.35	1.48	1.32
ET	0.48	1.12	1.74	1.39	2.34	2.32	0.84	3.67	2.16	1.97	2.34	2.33	1.09
AS	0.13	0.95	2.08	2.62	0.68	0.94	1.02	1.67	3.18	0.96	1.05	1.44	1.36
GS	0.23	0.86	1.62	1.84	1.19	1.42	1.36	2.13	1.84	0.87	1.64	1.73	2.51
US	0.82	1.33	1.27	2.11	1.88	1.03	1.27	1.12	2.14	1.23	2.43	2.11	1.12
GA	1.2	1.08	1.95	1.64	3.58	2.62	1.27	1.35	2.55	2.13	2.31	1.85	3.22
LA	0.98	1.14	2.16	2.34	2.13	1.85	0.98	2.65	1.25-	1.62	1.98	3.41	2.57

HT: High terraces, MT: Moderately high terraces, LT: Low terraces, ET: Eroded terraces, AS: Almost flat sand sheet, GS: Gently undulating sand sheet, US: Undulating sand sheet, GA: Gently undulating alluvial, LA: Low elevated alluvial, HC: Hydraulic conductivity, FC: Field capacity, WP: Wilting point, AW: Available water, ESP: Exchangeable sodium percent

study area as it not exceeds 0.81%. Calcium carbonate changes from 12.4% in the soils of eroded terraces to 3.5% in the undulating sand sheet landform. The Electrical Conductivity (EC) values ranged from 1.8 to 8.5 dS m^{-1}, the high values characterized the soils of the old deltaic plain which could be ascribed to its high $CaCO_3$ content. The Exchangeable Sodium Percent (ESP) varies from 9.5 to 15.5, representing a high positive correlation with EC (0.895**), $CaCO_3$ (0.761**) and fraction <0.125 mm (0.588*).

Irrigation water: Table 5, shows some chemical properties of the irrigation water in the study area. The data reveal that it is characterized by low salinity as the electrical conductivity ranges between 0.8 and 1.2 dS m^{-1}. The concentrations of soluble Na, Mg, Cl and HCO_3 are located in the ranges of (6.3-8.9), (0.2-1.9), (7.2-8.9) and (0.5 and 0.9) meq L^{-1}, respectively. The pH values differ from 7.3 to 7.5 and boron (B) concentration varies from 0.7 to 1.2 ppm. According to Ayers and Westcot (1994) the irrigation water was classified as high quality in the different landforms except for MT, LT, US and LA units which have a moderate limitation of Cl, Mg and B concentrations.

Table 5: Some analyses of irrigation water

Landform	pH	EC (dS m^{-1})	Na (meq L^{-1})	Mg (meq L^{-1})	Cl (meq L^{-1})	HCO_3 (meq L^{-1})	B (ppm)
High terraces (HT)	7.4	0.9	7.4	0.4	8.4	0.5	0.8
Moderately high terraces (MT)	7.5	1.2	6.8	0.6	7.2	0.6	1.2
Low terraces (LT)	7.3	0.8	8.2	0.4	8.9	0.8	1.2
Eroded terraces (ET)	7.4	1.2	8.9	0.6	8.8	0.9	0.7
Almost flat sand sheet (AS)	7.4	0.9	7.6	0.2	8.3	0.8	0.9
Gently undulating sand sheet (GS)	7.5	0.9	8.1	1.3	8.6	0.7	0.9
Undulating sand sheet (US)	7.3	0.8	8.4	1.9	8.7	0.9	1.2
Gently undulating alluvial (GA)	7.3	0.9	6.5	1.4	7.6	0.6	0.7
Low elevated alluvial (LA)	7.4	1.1	6.3	1.2	7.4	0.8	1.2

Land suitability for crops: One of the most important factors affect the agricultural sustainability is the classification of land according to its suitability for crops. In this study the land suitability was obtained for the following land uses:

- **Field crops:** Barley, maize, peanut, soya bean, sugar beet, sunflower and wheat

- **Vegetables and forage crops:** Alfalfa, cabbage, onion, pea, potato, sorghum, tomato and watermelon
- **Fruits:** Apple, banana, citrus, date palm, fig, grape, olive and pear

The land suitability classes for the above mentioned land uses were obtained from matching crop requirements and land characteristics i.e., soil, water and climate. The results indicated that the most suitable land uses (S1 and S2) in the area are, peanut, sunflower, maize, soya bean, pea, potato, sorghum, tomato, watermelon, apple, date palm, citrus, fig, grape and olive. Crops sensitive to the high values of both relative humidity and the atmospheric temperature i.e., Onion, Cabbage and Pear (Sys *et al.*, 1993; FAO, 1985) were classified as marginally or not suitable (S4 and N). Citrus is very sensitive to Boron (Maas, 1984) and so it was classified as marginally or not suitable except for ET and GA landforms. Boron concentration in irrigation sources in these two units is less than 0.75 ppm. The land uses of barley, maize, peanut, soya bean, sugar beet, sunflower, wheat, alfalfa, pea, potato, sorghum, tomato, watermelon and olive are mainly affected by the soil factors i.e., texture, salinity and sodicity (Abd El-Kawy *et al.*, 2010; Aldabaa *et al.*, 2010; Ali *et al.*, 2007). Consequently, their suitability classes were differed from site to another. The landforms of old deltaic and aeolian plains (i.e., HT, MT, LT, ET, GS and US) have several limitations related to the soil, so few suitable land uses are obtained. Table 6 represents the most suitable crops for each landform in the study area.

Table 6: Land snitability classification for crops

	Land snitability for crops				
Landform	S1	S2	S3	S4	N
High terraces (HT)	-	Date palm, fig, grape, peanut	Potato	Citrus, olive, apple, pear, tomato, sunflower, sugar beet, barley, wheat, sorghum, maize, alfalfa, watermelon	Banana, cabbage, onion, pea, soya bean
Moderately high terraces (MT)	Date palm	Potato	-	Fig, grape, citrus, olive, apple, pear, tomato, peanut, sugar beet, maize sorghum, alfalfa, watermelon,	Banana, cabbage, onion, pea, soya bean, barley, wheat, sunflower
Low terraces (LT)	Date palm	Tomato, peanut	Fig, citrus	Grape, olive, apple, pear, tomato, sugar beet, alfalfa, watermelon, sunflower, sorghum, barley, wheat, pea, maize, soya bean	Banana, cabbage, onion
Eroded terraces (ET)	-	Date palm, olive, tomato, sorghum, sunflower, potato watermelon	Maize	Fig, grape, cabbage, sugar beet, alfalfa, barley, wheat, pea	Peanut, soya bean, apple, citrus, pear, banana, onion
Almost flat sand sheet (AS)	Date palm	Fig, grape, olive, apple, tomato, peanut, potato, sunflower, watermelon, pea, sorghum, maize, soya bean	-	Cabbage, citrus, sugar beet, alfalfa, barley, wheat, pear	Banana, onion

Table 6: Continue

Landform	Land snitability for crops				
	S1	S2	S3	S4	N
Gently undulating sand sheet (GS)	Date palm	Fig, grape, peanut, potato	-	Citrus, olive, apple, pear, tomato, sunflower, sugar beet, barley, wheat, pea, sorghum, maize, alfalfa, watermelon	Banana, cabbage, onion
Undulating sand sheet (US)	Date palm	Fig, grape, peanut, potato	-	Citrus, olive, apple, pear, tomato, sunflower, sugar beet, barley, wheat, pea, sorghum, maize, alfalfa, watermelon	Banana, cabbage, onion
Gently undulating alluvial (GA)	Date palm, fig, tomato, grape	Potato, pea, watermelon, sorghum, citrus, apple, maize, olive sunflower, peanut,	Soya bean	Cabbage, sugar beet, barley, wheat, alfalfa, pear,	Banana, onion
Low elevated alluvial (LA)	Date palm, tomato	Sunflower, olive, fig, potato, watermelon, grape, sorghum, peanut, pea, maize, apple, soya bean	-	Cabbage, citrus, sugar beet, barley, wheat, alfalfa, pear	Banana, onion

S1: Highly suitable with no yield reduction, S2: Snitable, with 20% yield reduction, S3: Moderately snitable, with 40% yield reduction, S4: Marginally suitable, with 60% yield reduction, N: Not suitable

Crop water requirements: The common problem of the predictable methods for ETc estimations is that they can only provide accurate ET estimations for a homogeneous region around a meteorological station. However, this problem is solved from a technical point of view by remote sensing (Tsouni *et al*., 2008). The SEBAL model was used for estimating ET and mapping its spatial distribution and seasonal variation over the area. A sum of 6 Landsat (ETM+) satellite images (dated to 03 July, 05 Sep. and 26 Dec./2008 and 27 Jan, 16 Mars and 19 May/2009) were processed to generate ET maps for winter and summer seasons. Land Surface Temperature (LST) was derived for all acquired images, averages of LST in winter and summer seasons are shown in Figure 4 and 5. The obtained data indicate that the calculated averages of LST during the winter 2009 differ from 15.6 to 23.3°C, while it differs from 26.3 to 33.2°C in the summer 2008. It is noticed that the gently undulating alluvium, almost flat alluvium, high terraces and eroded terraces have the highest values of surface temperature in both winter and summer. Daily reference evapotranspiration (ET_{24}) was computed, the spatial distribution and seasonal variation are represented in Fig. 6 and 7. The obtained data refers that the winter values of ET24 differ from 2.5 to 3.72 mm/day while the computed summer values vary from 4.21 to 5.32 mm/day. These results were matched with soil and crop data to estimate the water requirements for the most suitable crops by using the CROPWAT 8.0 software produced by FAO (1992). The Leaching Requirement (LR) in the different landforms was calculated considering the salinity of irrigation water and the soils using the model developed by Rhoades and Merrill (1976). Table 7 represents the estimated CWR and LR for the most suitable land uses (S1 and S2).

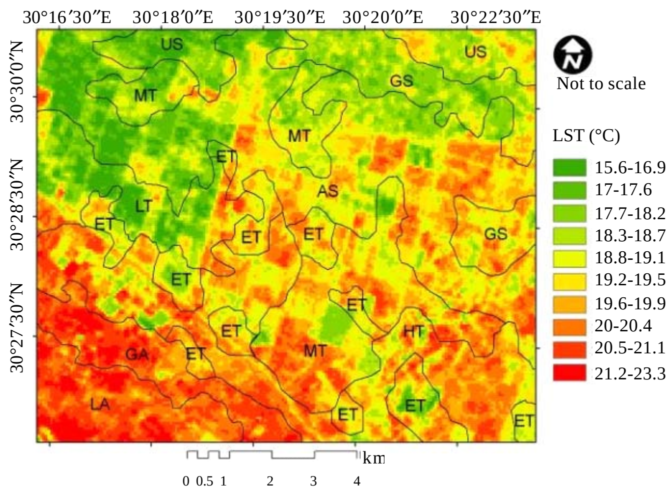

Fig. 4: Average of land surface temperature (winter 2009)

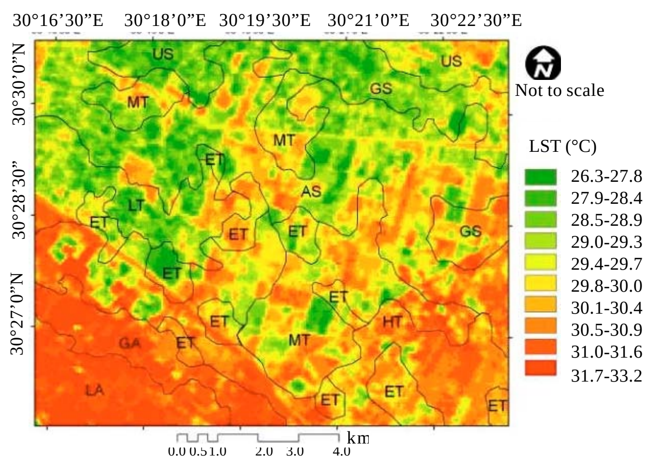

Fig. 5: Average of land surface temperature (summer 2008)

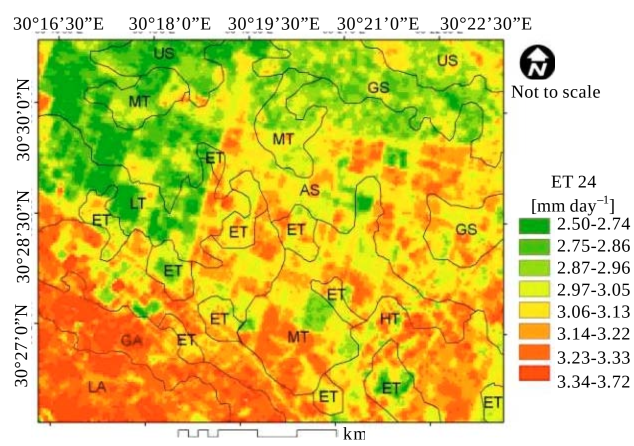

Fig. 6: Spatial distribution of daily ET (winter 2009)

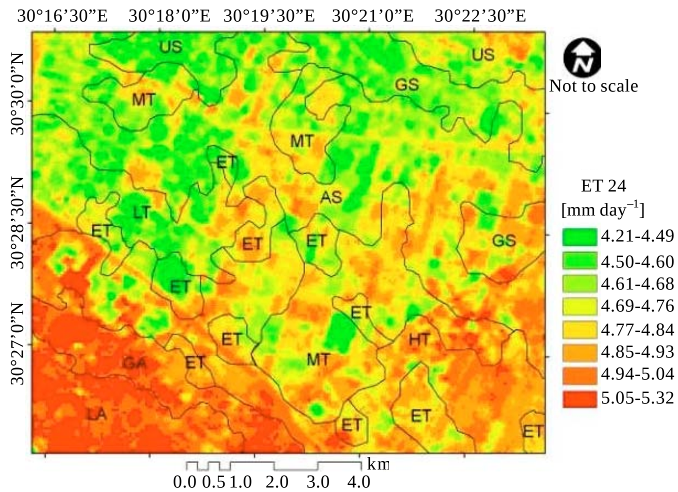

Fig. 7: Spatial distribution of daily ET (summer 2008)

Table 7: The CWR and leaching requirements (m^3/acre per season) in the studied landforms

		Leaching requirements (LR)								
Crop	CWR	HT	MT	LT	ET	AS	GS	US	GA	LA
Peanut	757.0	nr	nr	656.4	nr	0.0	632.6	280	632.6	nr
Sunflower	720.8	nr	0.0	0.0	307.0	0.0	0.0	0.0	0.0	0.0
Maize	681.8	nr	nr	975.8	nr	1042.5	913.2	476.9	913.2	1042.5
Soya bean	769.7	nr	nr	nr	nr	1225.2	1225.2	nr	nr	nr
Pea	215.7	nr	nr	nr	nr	905.6	905.6	nr	nr	nr
Potato	499.4	nr	nr	900.8	nr	842.9	842.9	440.2	842.9	962.3
Sorghum	632.4	nr	0.0	nr	213.9	0.0	0.0	0.0	0.0	0.0
Tomato	855.7	nr	373.1	605.8	nr	0.0	587.3	272.8	578.4	634.4
Watermelon	612.8	nr	nr	750.6	nr	702.4	702.4	366.8	702.5	801.9
Apple	1289.1	nr	nr	1276.1	nr	1194.1	1194.1	623.6	1194.1	nr
Date palm	1609.3	326.6	365.7	710.9	365.7	0.0	0.0	0.0	689.9	732.6
Citrus	1186.1	nr	nr	1576.4	nr	1475.1	1475.1	770.3	1475.2	nr
Figs	1569.8	265.2	289.2	0.0	289.2	0.0	0.0	0.0	0.0	0.0
Grapes	1079.4	871.1	1072.1	1393.6	nr	1293.1	1293.1	697.4	1293.1	1501.7
Olives	1171.6	265.2	289.2	0.0	289.2	0.0	0.0	0.0	0.0	0.0

nr: The LR is excessively large and the production of that crop is not recommended in relevant landform, HT: High terraces, MT: Moderately high terraces, LT: Low terraces, ET: Eroded terraces, AS: Almost flat sand sheet, GS: Gently undulating sand sheet, US: Undulating sand sheet, GA: Gently undulating alluvial, LA: Low elevated alluvial

DISCUSSION

Soils are well-known as the essential part of the landscape and their features are mainly controlled by the landforms on which they are formed. In the area under investigation, the soils represent a high correlation with associated landforms. Accordingly, results of crop suitability and water management were discussed considering the landform level. It was found that the soil water constants in the study area are mostly controlled by the particle size distribution. Thus, the lowest values of Wilting Point (WP) were observed at Low Terraces (LT) and low elevated alluvium units

(LA). As consequently the highest values of the Available Water (AW) were expected. While high and eroded terraces (HT and ET) have the highest values of WP and FC, hence, low values of available water were found. This result may be due to high content of sand (2-1, 1-0.5 and till 0.250 mm) which reflects the dominant coarse pores (Huang *et al.*, 2006) regardless the high amount of $CaCO_3$. This means that $CaCO_3$ does not have any role as cement material in these landforms, where they have a single grain structure. Increasing HC value was recognized in these landforms, whereas, the improvement of hydro-physical properties through increasing organic matter content is necessary (Hudson, 1994). Under these conditions, irrigation intervals should be very short in LT and LA than any other landforms to set up low discharge emitters avoiding water loss through evaporation and deep percolation. Short intervals will take place in case of the high and eroded terraces according to the slope aspect (gently undulating and undulating topography) saving system pressure and fulfill high uniformity of water distribution. According to the high EC and ESP values specially in the soils of eroded terraces, leaching requirements must be added to the irrigation water to drive salts away active root zone. In some cases the excessive amount of leaching water should be applied before cultivation until salts reach a suitable level for crops. In most homogeneous aeolian plain values of the soil water constant (FC, WP and AW) range between 13.5 to 15.4, 5.8 to 6.6 and 7.6 to 7.9% on the volume basis. The HC reach its highest values in the aeolian plain, where it ranges between 19.8 and 23.7 cm h^{-1}. These could be ascribed to their own characteristics e.g., sandy texture, single grain structure and weak cementation. The clear homogeneity in all the studied features of these landforms except slope gradient means that the application of a small amount of irrigation water is needed to eliminate water loss by the ways mentioned above. So, lateral length and emitters discharge, relative to soil HC, are the most important parameters in irrigation system design. The depression landscape contains two landforms i.e., gently undulating alluvium (GA) and low elevated alluvium (LA). In the LA values of HC, FC and WP decrease by about 15.5, 5.9 and 25.4%, while the AW, $CaCO_3$, EC and ESP values were increased behave the contrary situation. Accordingly, irrigation intervals would be shortened in gently undulating alluvial rather than almost flat landform. In scheduling irrigation, it is important to identify the critical periods in which plant water stress has the most pronounced effect on growth and yield of crops. Since, this is also directly related to the nutrient requirements by the crop. Analyses of soil, water and climatic factors indicated that the soil texture and boron concentration in irrigation water limited the suitability of wheat, barely and onion (Maas, 1984). The suitability of maize, soya bean, peanut and sorghum was limited by the coarse soil texture, high salinity and ESP (FAO, 1985). The cultivation of apple and banana is limited by soil salinity (Maas, 1986), atmospheric temperature and relative humidity, while olive and date palm trees were moderately limited by the soil texture and salinity. In old deltaic plain (i.e., HT, MT, LT and ET) cropping system was limited by cultivation of 10 crops i.e., Date palm, fig, grape, peanut, olive, tomato, sorghum, sunflower, watermelon, potato. Constrains of this unit are soil texture, soil salinity and exchangeable sodium percentage. In the aeolian plain (i.e., AS, GS, US) the crop suitability is only limited by the coarse soil texture and thus more crops (14 crops of S1 and S2) were recommended. In the landforms of Gently Undulating (GU) and low elevated alluvial (LA) moderate limitation of soil salinity and sodicity affect the suitability of the salt sensitivity crops. In view of that, sustainable agriculture in the study area faces several limitations and requires considerable attention related to the choice of appropriate crop and water management.

CONCLUSION

Analysis of the results of this study can be conclude that numerous constrains related to soil properties, climatic conditions and water quality face the agricultural sustainability in the dry desert. To overcome these constrains; crop type and water management must be compatible with the land resources. Remote sensing and GIS techniques facilitate the selection of the suitable crops and improve the estimations of irrigation water requirements. The application of these techniques in the study area indicate that the most suitable crops are peanut, sunflower, maize, soya bean, pea, potato, sorghum, tomato, watermelon, apple, date palm, citrus, fig, grape and olive. The crop suitability in the investigated area is limited by coarse soil texture, soil salinity, relative humidity and boron concentration in irrigation water. The seasonal land surface temperature and evapotranspiration over the study area were estimated by using SEBAL model, the result offer an accurate data to estimate the water requirements for the recommended crops. The quantities of irrigation water required for one crop differ widely from landform to another due to the soil salinity variations that affect the leaching requirements. In some cases (e.g., soils of old deltaic plain), salts must be leached from soil profiles to ensure that a subsequent crop's salt tolerance will not be exceeded. Achieving agricultural sustainability in this area requires significant efforts related to farm management, which should be in line with available land resources.

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