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MAXIMIZING LAND AND WATER PRODUCTIVITY OF SUDAN-GRASS UNDER SPRINKLER IRRIGATION IN SANDY SOIL

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ABSTRACT

A field experiment was conducted at Ismailia Research Station (30° 35' N latitude, 30° 26' E longitude, 20.0m above mean sea level), Egypt during the 2016 and 2017 growing seasons to study the effect of three irrigation treatments (125, 100 and 75%ETo) on forage yield and its attributes of Sudan-grass crop. The effects of irrigation levels on the amounts of applied irrigation water, water consumptive use, water productivity on forage yield and its components, as well as its yield quality were studied. Results indicated that distribution uniformity values were 76 and 78% in 1st and 2nd seasons, respectively. Average amounts of applied irrigation water under 125, 100, and 75% ETo irrigation levels treatment were 4450, 3710 and 2980 m^3 ha^{-1}, respectively. While the average water consumption were 3675, 2879 and 2140 m^3 ha^{-1}, respectively. The percentages of saved water were 20 and 50% for the 100 and 75 ETo, respectively as compared with the 125% ETo treatment. Average water use efficiency under 125, 100, and 75% ETo irrigation levels treatment values were 8.48, 7.76 and 7.62 and water productivity values were 7.0, 6.02 and 5.48 respectively. Moreover, there was a significant effect of the tested irrigation levels on forage yield and quality, plant height, number of tillers plant^{-1}, number of leaves plant^{-1}, dry leave stem ratio and green yield, as well as yield quality (dry yield, protein, ash and fiber). The results also revealed that there was a highly significant positive correlation between green forage yield and each of leaves number, dry leaf stem ratio, plant height, tillers number and protein. Thus, in case of water shortage, irrigating Sudan-grass in sandy soils with 100% ETo will save 20% of applied irrigation water used for irrigation, gives the water use efficiency of 7.76 green yield/m^3 water consumed and water productivity of 6.02 kg green yield/m^3 under sprinkler irrigation system and fertigation practice.

(Key words : Sudan-grass, BIS model, sprinkler system, sandy soil, water use efficiency and water productivity)

INTRODUCTION

Water is considered a scare resource in many areas of the world, especially in arid and semiarid regions as Egypt.Egypt is facing shortage in water resources, and demand for water is increasing due to growing population, competition between different water consuming sectors and the expansion in irrigated agriculture, as well. Hence, attempts are required to increase water use efficiency of different crops. Management of water demand in on-farm irrigation level should be a focus point to reduce the increasing demand of water to match the future supplies, thereby reducing the effect of water deficit that the country will face. Egypt depends on irrigated agriculture for more than 95% of agriculture area (AbouZeid, 2002). Water availability to the agricultural sector is becoming a major constraint to agricultural production, where it is the largest consumer of the Egyptian water resources. Egypt's water policy mainly depends on the expansion of modern irrigation techniques in the newly reclaimed soils of desert and irrigation practices improvement in old lands of the Nile Delta and Valley. The application of modern irrigation techniques, such as drip, bubbler and sprinkler to increase irrigation efficiency is one of the measures utilized for competent use of water (Anonymous, 2002). Irrigation water is not sufficient for both irrigation and reclamation purposes in Egypt due to limited water resource coming from the fixed share of the Nile River. Effective irrigation water management is good agricultural practice to maximize water productivity under this situation. One of the most important methods of

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water conservation is used modern irrigation systems (sprinkler and drip), and irrigation scheduling under sandy soils. Under clay soils conditions, increasing irrigation intervals or decreasing irrigation depths are the saving methods.

The current challenge in agriculture is to produce more yields by utilizing less water, especially in regions with limited land and water resources (Fereres and Soriano, 2007 and Zhang *et al.*, 2012). Efficient irrigation systems require the selection of an appropriate method of irrigation for crop growth, adequate monitoring of the irrigation system and of water delivery and appropriate application rates depending on the growth stage of the crop. Irrigation requirements differ depending on the locations, soil types and cultural practices (Bilalis *et al.*, 2009).Furthermore, maximum crop production requires complete capture of incident solar radiation and can only be achieved with supporting sufficient levels of water and nutrients (Loomis and Connor, 2002). Plants irrigated with low water depletion of the total available soil water produced greater leaf area than plants irrigated with high levels of water depletion and therefore had greater intercepted photosynthetically active radiation (Langeroodi *et al.*, 2014, Adeboye *et al.*, 2016).

In Egypt, a need has arisen to investigate the sustainable use of irrigation water, in addition to water saving techniques and its effects on crop productivity.The nature of the soils in the newly reclaimed lands is mainly sandy with low water storage capacity and low fertility and organic matter content, as well (Page *et al.*, 1982).Under such conditions, the choice of an irrigation method, which accomplish efficient water use, higher crop yield and quality, save energy and enhance farm profits, is the most important issue.Drip and sprinkler irrigation systems are considered highly efficient methods of delivering water and fertilizer uniformly to crops (Abu Zeid, 1999). In addition, an advantage in using drip irrigation is that small amounts of water can be used even for saline water (Hanson and May, 2011).

Sudan-grass (*Sorghum sudanense*(Piper) Stapf.) is a warm-zone cereal crop grown as forage for livestock in regions where high temperature and low rainfall prevailed during late summer and early autumn. Green forage yield of Sudan-grass is an important forage crop in tropical, semi-tropical and even warm-temperate regions (Bahrani and Ghenateghestani).The forage is readily consumed by livestock when used at vegetative stages (Newman *et al.*, 2010). The shortage of green forage in summer season is considered to be one of main problem in feeding animals in Egypt from May until November. Sudan grass is among the best suitable forage crops for areas with hot weathering conditions, limited water resources and light-texture soil (sandy soil) in Egypt. Both crops can provide two to three cuts to meet the green fodder requirement of milk animals in summer season under Egyptian suitable climatic conditions.

Breeding decisions based only on correlation coefficients may not always be effective since they provide only one-dimensional information neglecting important and complex interrelationships among plant traits (Kang, 1994).There is a little information available on the consumption of irrigation water, water required and fertigation practice of sorghum and Sudan-grass as important summer forage crops in Egypt. Using irrigation scheduling and fertigation practices in sandy soil are considered useful practices to increase maximizing unit productivity land, water and fertilizer unit productivity (Taha, 2012). The energy required to pump irrigation water for crop production is measured in terms of fuel or electric power use to pump each unit of water(Anonymous, 2017). Additionally, the amount of irrigation water pumped depends on several irrigation system factors, namely specific system design factors (potential irrigation system efficiency), the system design uniformity, the relative area of coverage, crop factors (type of crop, size of plants, plant density), and other production system (Smajstrla *et al.*, 1998). Climate factors include solar radiation, temperature, humidity and wind speed have an effect on the pumped irrigation water (E1-Qousy *et al.*, 2006).

Thus, the objectives of this study were to evaluate the effect of different ETo-dependent irrigation levels on amounts of applied irrigation water, water consumptive use, water use efficiency, water productivity, yield and its components, and green forge quality.

MATERIALS AND METHODS

Experimental site description

A field experiment was conducted at Ismailia Experimental Research station (30^o 35' N latitude, 30^o 26' E longitude, 20.0 m above mean sea level), Ismailia Governorate, Egypt, during 2016 and 2017 summer growing seasons. The experimental site represents the newly reclaimed sandy soil of East of the Nile Delta. The climate is cool in winter with a mean air temperature of about 13.0°C. Summer is hot with no rain, and with mean air temperatures that varies from 28.0 to 30.55°C during June, July, and August, as well as mean wind speed of 2.93 m h^{-1} during the daytime for these months. Average monthly weather data at the experimental site during the growing seasons for the period from 2011 to 2015 are presented in table (1).

Table 1. Mean monthly values of solar radiation (Srad), maximum temperature (Tmax), minimum temperature (Tmin), wind speed (Ws), dew point (Td), and reference evapotranspiration (ETo) at the experimental site from 2011 to 2015

Month	Srad (MJ m^{-2} day^{-1}	Tmax (^{0}C)	Tmin (^{0}C)	Ws (ms^{-1})	Td (0C)	ETo (mm day^{-1})
May	27.73	33.50	17.84	3.06	20.53	6.48
June	28.05	36.31	20.19	3.08	21.91	7.15
July	28.89	38.03	21.90	2.89	22.92	7.29
August	25.10	38.14	22.95	2.79	22.25	6.67
September	23.03	34.84	21.17	2.82	20.47	5.25

The data in table 1 were used to calculate monthly reference evapotranspiration (ETo)values in the experimental site according to the Basic Irrigation Scheduling model (BISm) as described by Snyder *et al.* (2004).

Samples from the upper 60 cm soil surface were collected at 15 cm interval to determine the main soil physical, chemical properties, and soil-moisture constants. The obtained values are presented in table 2. The available macronutrient values of N, P and K were 16.50, 5.20, and 62.20 mg kg^{-1}, respectively. Accordingly, the soil was characterized by low fertility and insufficient available water for plant growth. The electrical conductivity (EC) of irrigation water was 0.52 dS m^{-1}, and pH value was 7.55. Chemical and physical soil analyses were conducted by the standard methods as described by Tan (1996).

Table 2.Some physical and chemical properties of the soil at the experimental site

Soil properties	**Soil depth (cm)**			
Particle size distribution	0-15	15-30	30-45	45- 60
Coarse sand, %	68.55	73.55	74.10	77.15
Fine sand, %	25.78	22.15	22.20	18.95
Silt, %	3.67	2.90	2.80	3.10
Clay, %	2.00	1.40	0.90	0.80
Texture class	Sandy	sandy	Sandy	sandy
Bulk density, Mg m^{-3}	1.64	1.76	1.74	1.70
Field capacity, % w/w	12.70	11.15	6.90	7.85
Permanent wilting point, % w/w	3.65	2.90	2.15	2.10
Available water, %	9.05	8.25	4.75	5.75
pH (1:2.5)	7.64	7.58	7.60	7.41
ECe, soil past extract, dS m^{-1}	0.56	0.54	0.50	0.48
Soluble cations, meq l^{-1}				
Ca^{2+}	1.24	1.20	1.24	1.26
Mg^{2+}	0.55	0.53	0.50	0.48
Na^{+}	1.55	1.57	1.60	1.62
K^{+}	0.16	0.18	0.14	0.16
Soluble anions, meq l^{-1}				
CO_3^{2-}	-	-	-	-
HCO_3^{-}	1.05	1.15	1.06	1.08
Cl^{-}	1.72	1.74	1.73	1.75
SO_4^{2-}	0.66	0.68	0.68	0.70

Experimental design and tested treatments

The field experiment was implemented in complete block design (BD), with four replicates. The horizontal plots were devoted to the irrigation treatments (plot size was 576 m^2).

The tested treatments were as follows

Irrigation treatments (I)

I_1: Irrigation with amounts of water equal to 125%ETo

I_2: Irrigation with amounts of water equal to 100%ETo

I_3: Irrigation with amounts of water equal to 75%ETo

Cultural practices

Sudan-grass (Giza 2 var.) seeds were cultivated on the 6th and 8thof May 2016 and 2017seasons. The seed rate was 48 kg ha^{-1}. Fertilizers were applied through irrigation water (fertigation) in 80% of irrigation time. Sudan-grass was cultivated under sprinkler system in a total area (main plot) of 576 m^2 (48 × 12 m) and an irrigation interval of three days. A solid-set sprinkler irrigation system with rotary RC 160 sprinklers of 0.94 to 1.30 m^{3}hr^{-1} discharge rate at 2.80 bars nozzle pressure was used to irrigate the crops. The sprinkler system consists of main PVC pipe line (160 mm diameter), sub main PVC pipe lines (110 mm diameter), and PVC lateral lines (50 mm diameter). The laterals were spaced at 12 X 12 meters apart. Application of the irrigation water treatments started from the tenth irrigation after planting date. According to the findings of Taha (2012),all major fertilizers were added in equal doses (3 doses week^{-1}). The fertigation started after 8 days after planting in both growing seasons. Nitrogen fertilizer (ammonium nitrate, 33.5% N) was added at the rate of 286 kg N ha^{-1}, potassium sulfate was added at the rate of 119 kg K_2O ha^{-1}, and 52 kg P_2O_5 ha^{-1} of phosphoric acid (60%) were added. All fertilizers were added through irrigation water (fertigation) using the differential pressure tank. Fertigation was done in 80% of irrigation time.

Furthermore, cutting of Sudan-grass plants was done three times, namely the first cutting was 55 days after sowing, second cutting was 45 days from first cutting and third cutting was 35 days from the second cutting in both growing seasons.

Measurements of agronomic traits and yield

1-Plant height (cm): It was measured from soil surface up to the highest leaf tip of the plant for ten guarded plants were randomly chosen from each plot before each cut.

2- Number of leaves plant $^{-1}$

3- Number of tillers m^{-2}

4- Dry leaves/stem ratio

5- Fresh forage yield (kg plot^{-1}): plants of the plot were hand clipped and weighed in kg plot^{-1} and it was converted to ton ha^{-1} (Fertilizer in kg ha^{-1} and yield in kg ha^{-1}). Total fresh yield was calculated by sum of cuts yield.

6-Dry forage yield (kg plot^{-1}): Samples of 100 gm were dried at 105^0 Cto constant weight and dry matter percentages (DM%) was estimated. The dry forage yield (ton ha^{-1}) was calculated by multiplying fresh forage yield (ton ha^{-1}) by dry matter percentage.

Chemical analysis

The forage nutritive values were estimated on dry matter basis (%) at the three cuts in both seasons to determine crude protein percentage (CP%), crude fiber (CF%) and ash content. The sub sample (10g) dry matter was highly grounded and passed through 0.5 mm sieve then was preserved for chemical analysis. The dry matter and ash contents were determined according to Official Agriculture chemists Anonymous (1999)**.** Ash contents were calculated by incineration the highly grounded samples at 550 ^{o}C for three hours. For crude protein, the nitrogen content of feed sample was determined by Kjeldahl (Anonymous, 1999) and value recorded for nitrogen was then multiplied by 6.25 (Jones, 1931) to determine CP of the sample. The crude fiber contents were recorded as recommended by Van Soest *et al.* (1991). Total carbohydrates percentage was determined in plants using colrimatric method described by Herbert *et al.*(1971).

Irrigation-water measurements and crop-water relations

Distribution uniformity (DU):

The water distribution uniformity (DU) of the sprinkler system was measured in the field. The DU values were calculated by the equation developed by Merrim and Keller (1978) as follows:

$$DU = \frac{Diq}{D} \times 100$$

where:

DU = distribution uniformity (%).

Diq = average depth of water collected by cans from sprinklers at the low quarter of the field (cm).

D = average depth of water collected by cans from all sprinklers (cm).

Water consumptive use (WCU)

Crop water use was estimated by the method of soil moisture depletion according to Majumdar (2002) as follows:

$$WCU = \sum_{i=1}^{i-4} \frac{\theta 2 - \theta 1}{100} \times Bdxd$$

where:

WCU = water consumptive use or actual evapotranspiration, ETa (mm).

i = number of soil layer.

¸2 = soil moisture content after irrigation, (%, by mass).

¸1 = soil moisture content just before irrigation, (%, by mass).

Bd = soil bulk density, (g/cm^3)

d = depth of soil layer, (mm).

Applied irrigation water

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

$$AIW = \frac{ETo \times I}{Ea\ (1 - LR)}$$

where:

AIW= depth of applied irrigation water (mm)

ETo = reference evapotranspiration (mm d^{-1}). ETo values calculated using BISm.

I = irrigation intervals (days)

Ea= irrigation application efficiency of the sprinkler irrigation system (Ea = 77% first seasons and 80% second season for sprinkler system).

LR= leaching requirements (was not considered in this experiment due to its indirect effect on the amount of water applied for water stress treatment, 0.8 ETo)

Water use efficiency is calculated according to Stanhill (1986) as:

$$WUE = \frac{Forage\ sudan\ grasses\ \ yield, Y\ \left(\frac{kg}{\square a}\right)}{Consumed\ Irrigation\ Water,\ WCU\left(\frac{m3}{\square a}\right)}$$

Y =Forage Sudan grasses yield (kg ha^{-1}).

WCU =Water consumed by the crop during entire growing season (m^3 ha^{-1}).

Crop water productivity (WP):

Crop water productivity is calculated according to Zhang (2003) as follows:

$$\mathbf{WP, kg\ m - 3} = \frac{\mathbf{Forage\ sudan\ grass\ yield\ Y,} \left(\frac{\mathbf{kg}}{\mathbf{ha}}\right)}{\mathbf{Applied\ \ Irrigation\ \ Water}\left(\frac{m3}{ha}\right)}$$

Statistical analysis

Data were statistically analyzed according to Steel and Torrie 1980), and treatment means were compared by least significant difference test (LSD) at 0.05 level of significance. Bartlett's test was done to test the homogeneity of error variance. The test was not significant for all assessed traits, so, the two seasons' data were combined. Correlation coefficientsas referred by Steel andTorrie (1980)were estimated, as follows:

1- Simple correlation: a matrix of simple correlation coefficients between the yield and its components were computed as applied by Steel and Torrie (1980).

2- Stepwise multiple linear regression: this model was used according to Draper and Smith (1981) to determine the variables that accounted for the majority of the total yield variability.

3- To avoid the lack of fit of stepwise multiple linear regression as a result of multicollinearity phenomenon (the strong association among the yield components), the level of multicollinearity was estimated using Variance Inflated Factor (VIF) as suggested by Hair *et al.* (1992). Large VIF values (above 10) reported high collinearity causing rejection of the model (Hair *et al.*, 1992).

Sudan-grass chemical composition

Results in table 4 indicated significant effects of the adopted irrigation treatments on dry yield, protein, ash and fiber (%) in the two growing seasons. The highest values of dry yield, protein, ash and fiber of three cuts were produced from the irrigation with 125% ETo treatment, compared to the other treatments. Meanwhile, the lowest values of these traits were recorded under the 75% ETo

RESULTS AND DISCUSSION

Sudan-grass yield and its component

Results in table 3 indicated significant effects of the adopted irrigation treatments on plant height (cm), number of tillers plant^{-1}**,** number of leaves plant^{-1}, dry leave to stem ratio and green yield (ton ha^{-1}) in the two growing seasons. Under application of 125% ETo, the crop was able to develop sufficient biomass and root system leading to higher plant length, number of tillers plant^{-1} and number of leaves plant^{-1}. The highest value of plant height and number of tillers per plant was found after the second cut from irrigation with 125% ETo treatment, compared to the other treatments. These results attributed to availably water, fertilizer and more distribution in the field. Meanwhile, the lowest values of these two traits were recorded for the 75% ETo treatment, which attributed to increasing water stress under irrigation treatment 0.75 of ETo. Furthermore, increasing the amount of irrigation water increased number and length of internodes as well as number of leaves plant^{-1} due to the promoting role of water in cell division, expansion and enlargement (Nezami *et al.*, 2008). These results are similar to the results found by Ismail *et al.* (2017), who stated that decreasing water application decreased yield attributes under sprinkler irrigation.

Plant height, number of tillers plant^{-1}, number of leaves plant^{-1}, dry leave to stem ratio and green yield increased slightly in 2nd season as compared to the 1st season under all irrigation treatments. It is attributed to higher distribution uniformity of the sprinkler irrigation system in the 2nd season with more efficient water and fertilizer distribution and availability to the plants. These results homogeneous and was close to that obtained by (Zahid *et al.*, 2002) and Afzal, *et al.* (2013), who found that green forage yield was increased linearly with by increasing irrigation water and nitrogen fertilization rates.

Water distribution uniformity

The distribution uniformity values of irrigation water for the both growing seasons were 76 and 78 % for the two tests conducted at the beginning of each growing season, respectively. The obtained results showed a little increase in DU values in the second season as compared to the first season, namely 80 and 78%, respectively under sprinkler irrigation in sandy soils. This trend of results was similar to that obtained by Taha (2012 and 2013) and El-Mehy *et al.* (2018), who reported that the values of distribution uniformity of irrigation water for the second season increased compared to the first season.

Applied irrigation water, saved water, and water consumption

The data regarding effect of tested treatments on the depths of applied irrigation water and saved water during the 2016 and 2017 seasons are presented in table 5. Results indicated that the depths of applied water were 451, 376 and 303 mm during 2016 season and were 439, 366 and 393 mm during 2017 season for the 125, 100 and 75 ETo treatments, respectively. The percentages of saved water were 20 and 50% for the 100 and 75 ETo, respectively, as compared with the 125% ETo treatment. The results indicated, in general, that increasing water availability to the plants increased water consumption. The highest values of seasonal water consumptive use were 3790 and 3560 m^3 ha^{-1} under irrigation with 125% ETo treatment in the first and second growing seasons, respectively. Whereas, the lowest values of seasonal water consumptive use were 2930 and 2160 m^3 ha^{-1} obtained under irrigation with 75% ETo in the first and second seasons, respectively. These results were close to that obtained by El-Mehy, *et al.* (2018),who found that the sprinkler irrigation method saved 19.94 % and 48.84% water, under 100% and 80% ETo compared to 120% ETo water application respectively.

Moreover, this results similar to what obtained by El-Mehy *et al.* (2018),who found that the sprinkler irrigation method saved 19.94 % and 48.84% water, under 100% and 80 % ETo compared to 120 % ETo water application respectively.

Water use efficiency and water productivity

Results in table 6 indicated an increase in water use efficiency (WUE) values by increasing water irrigation with 125% ETo treatment compared, to the other treatments of both the seasons. Also, WUE values tended to increase in the second growing season compared to the first growing seasons a result of increasing water distribution uniformity. This result could be due to the increase in the distribution uniformity of the sprinkler system in the second growing season with direct effect on more efficient water and fertilizer distribution in the field. The results in table 6 showed that the highest water use efficiency values were 8.08 and 8.88 kgm^{-3} obtained from irrigating with 125%ETo in 1stand 2nd seasons, respectively. The lowest water use efficiency values (7.45 and 7.77 kgm^{-3}) were obtained from the 75% ETo. This result attributed to decreased availability of water and fertilizer distribution in the field under 75% ETo. These results are in harmony with the results obtained by Ismail *et al.* (2017), who found that decreasing water application increased irrigation water use efficiency of Sudan- grass under sprinkler irrigation.

The results in table (6) also showed that water productivity (WP) tended to increase with the increasing in the irrigation water applied from 125 to 75%ETo. Also, values tended to increase in the second growing season compared to the first growing seasons as a result of increasing water distribution uniformity. This result could be due to the increase in the distribution uniformity of the sprinkler system in the second growing season with direct effect on more efficient water and fertilizer distribution in the field.The results in table (6) showed that the highest water productivity, i.e. 6.79 and 7.20 kg/m^{-3} were obtained from irrigating with 125% ETo in 1stand 2nd seasons, respectively. The lowest water use efficiency values (7.46 and 7.77 kg m^{-3} of consumed water) were obtained from the 75% ETo.

Simple correlation matrix

Correlation coefficients between the studied traits and each of dry and green yields under the studied irrigation treatments are shown in table 7. The results revealed that there was a highly significant positive correlation between dry and green yields and each of leaves number (0.954**), dry leaf to stem ratio (0.944**), plant height (0.780**), tillers number (0.832*) and protein (0.571*) with both dry and green yield under 125 and 100%ETo. These results could be explained by the tendency of the plant to increase the number of tillers and stem height due to the availably water, fertilizer and their better distribution in the field. Meanwhile, under irrigation with 75% ETo there was insignificant positive relationship between leaves number, and dry leaf to stem ratio, and significant positive correlation between plant height and tillers number with dry and green forage yield. However, insignificant associations were observed between green forage yield and carbohydrate (0.337) and ash (0.253), and insignificant negative correlation with fibers (-0.315).These results are quite homogeneous identical with Amir Bibi, *et al.* (2016), who found that water stress predominately affects green fodder yield also had negative impacts on its quality parameters.Forage quality components showed different correlation coefficients under water stress and normal conditions. Green forage yield had positive correlation with all quality components so increase in the forage yield may improve the quality of forage. Under water stress, the indirect selection of traits like sugar content crude protein and total ash will had negative effect on green forage.

Table 3.Effect of irrigation treatments on vegetative of Sudan-grass in two growing seasons (2016 and 2017)

Season	**2016**			**2017**		
Cuts	1st cut	cut2nd	3rd cut	1st cut	2nd cut	3rd cut
Irrigation	**1- Plant height (cm)**					
125 % ETo	122.333 a	130.667 a	98.333 a	126.000 a	134.333 a	100.667 a
100% ETo	111.667 b	118.000 b	85.667 b	115.000 b	121.667 b	89.667 b
75% ETo	67.667 c	76.667 c	60.000 c	68.333 c	80.000 c	65.000 c
LSD 0.05	6.1468	6.7665	6.6393	4.2129	6.6393	4.2810
	2-Number of Tillers					
125 % ETo	95.667 a	104.667 a	62.333 a	97.667 a	107.000 a	65.667 a
100% ETo	81.333 b	87.667 b	52.333 b	83.333 b	90.000 b	55.667 b
75% ETo	53.667 c	66.333 c	43.667 c	56.000 c	68.667 c	46.667 c
LSD 0.05	3.4683	6.0061	5.0754	4.4762	5.6111	4.7259
	3- Number of Leaves					
125 % ETo	9.500 a	8.230 a	7.170 a	9.700 a	8.433 a	7.320 a
100% ETo	8.133 b	7.293 b	6.187 b	8.467 b	7.433 b	6.303 b
75% ETo	6.600 c	6.183 c	4.930 c	6.967 c	6.320 c	5.120 c
LSD 0.05	0.6465	0.2728	0.2449	0.5350	0.2210	0.2256
	4- Dry leave to stem ratio					
125 % ETo	34.220 a	28.577 a	24.223 a	34.503 a	28.757 a	24.497 a
100% ETo	30.320 b	25.827 b	21.243 b	30.483 b	26.033 b	21.483 b
75% ETo	25.050 c	20.560 c	14.210 c	25.207 c	20.770 c	14.417 c
LSD 0.05	1.8220	1.4577	1.1318	1.7410	1.4489	1.0703
	5- Green yield ($t\ ha^{-1}$)					
	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
125 % ETo	12.16 a	10.70 a	7.78 a	12.57 a	10.95 a	8.09 a
100% ETo	8.58 b	7.05 b	6.00 b	9.00 b	7.62 b	6.40 b
75% ETo	6.47 c	5.02 c	4.32 c	6.85 c	5.43 c	4.51 c
LSD 0.05	0.1973	0.4006	0.2363	0.1549	0.4907	0.2833

1stcut =55 days after sowing &2nd cut = 45 days from first &3rd cut = 35 days from second cut.

Table 4. The effect of irrigation treatments on forage yield and quality (dry yield, protein, ash and fiber)of Sudan grass in two growing seasons (2016 and 2017)

Season	**2016**			**2017**		
Cuts	1st cut	cut2nd	3rd cut	1st cut	2nd cut	3rd cut
Irrigation	**1- Dry yield**					
125 % ETo	1.227 a	0.976 a	0.826 a	1.395 a	0.985 a	0.852 a
100% ETo	0.911 b	0.811 b	0.582 b	0.941 b	0.835 b	0.594 b
75% ETo	0.716 c	0.568 c	0.366 c	0.744 c	0.602 c	0.377 c
LSD 0.05	0.1203	0.0327	0.0330	0.1504	0.0505	0.0363
	2- Protein					
125 % ETo	9.033 a	9.357 a	8.110 a	9.100 a	9.427 a	8.150 a
100% ETo	8.023 b	8.630 b	7.333 ab	8.083 b	8.697 b	7.387 ab
75% ETo	7.353 c	7.927 c	6.643 b	7.713 c	7.987 c	6.680 b
LSD 0.05	0.7359	0.3080	1.2834	0.1220	0.3988	1.2543
	3- Ash.					
125 % ETo	6.560 a	7.317 a	6.460 a	6.587 a	7.340 a	6.483 a
100% ETo	6.490 a	7.033 b	6.273 b	6.527 a	7.060 b	6.300 b
75% ETo	6.143 b	6.327 c	5.933 c	6.183 b	6.350 c	6.023 c
LSD 0.05	0.2950	1.4910	0.1054	0.2939	0.1589	0.0702
	4- Fiber					
125 % ETo	31.530 a	30.747 a	32.567 a	31.560 a	30.777 a	32.607 a
100% ETo	31.343 a	29.680 a	32.390 b	31.370 b	29.707 a	32.423 b
75% ETo	30.920 b	28.527 b	31.420 c	30.940 c	28.557 b	31.460 c
LSD 0.05	0.2139	1.2250	0.1901	0.2068	1.2232	0.1838

1stcut =55 days after sowing &2nd cut = 45 days from first cutting &3rd cut = 35 days from second cutting.

Table 5. Effect of tested treatments on the depths (mm) and amounts (m^3/ha) of applied irrigation water, saved water, and water consumption by Sudan-grass during 2015 and 2016 growing seasons

Irrigation treatments	2016			2017		
	Applied water (mm) &(m^3 ha-^{1})	% (mm) &(m^3 ha-^{1})	Water consumption (m^3 ha^{-1})	Applied water (mm) & (m^3 ha^{-1})	% saved	Water consumption (m^3 ha^{-1})
125 % ETo	451 (4510)	—	3790	439 (4390)	—	3560
100% ETo	376 (3760)	20	2880	366 (3660)	20	2878
75% ETo	303 (3030)	49	2120	293 (2930)	51	2160

Table 6. Water use efficiency for of sudan grass under different irrigation treatments in both growing seasons

Irrigation treatments	Water use efficiency (kg /m^3)		Water productivity (kg /m^3)	
	2016	2017	2016	2017
125 % ETo	8.08	8.88	6.79	7.20
100% ETo	7.51	8.00	5.75	6.29
75% ETo	7.46	7.77	5.22	5.73

Table 7. Simple correlation coefficients matrix among Sudan-grass green and dry forage yield and its components under 125, 100 and 75 ETo irrigation treatments over 2016 and 2017 seasons

Irrigation treatments	125%ETo		100%ETo		75%ETo	
Traits	**GY**	**DY**	**GFY**	**DFY**	**GFY**	**DFY**
Plant height (Ph)	0.780**	0.533*	0.691**	0.860**	0.209	0.415
Tillers No. (TNo.)	0.832*	0.545*	0.767**	0.909**	0.285	0.525*
Leaves No. (LNo.)	0.954**	0.924**	0.947**	0.971**	0.885**	0.973**
Dry leaf stem ratio (DLSR)	0.944**	0.908**	0.947**	0.962**	0.933**	0.994**
Protein (Pro)	0.571*	0.429	0.401	0.645**	0.475*	0.698**
Carbohydrates (Car)	0.337	-0.095	0.144	0.424	0.273	0.517*
Ash (Ash)	0.253	-0.102	0.230	0.478*	0.376	0.596**
Fibers (Fib)	-0.315	0.056	-0.302	-0.574*	-0.313	-0.604**
Green forage yield (GFY)	1	0.850**	1	0.932**	1	0.933**
Dry forage yield (DFY)		1		1		1

*** and ** significant at 0.05 and 0.01 probability levels, respectively**

Stepwise linear regression analysis

This method was used to determine the more effective traits that mostly explained the variation of forage yield. Table 8 shows the partial regression coefficients under ETo 125% irrigation treatment as well as their significance for the accepted limiting two variables that significantly contributing to variation of green forage yield. These variables were tillers number and ash. According to the results 97.2 % (expressed as R^2) of the total variation in green forage yield could be attributed to these aforementioned two traits. The other seven traits were not included in the model due to their very low relative contribution. On the other hand, the validity of the proposed model was established where the values of Variance Inflation Factor (VIF) for the accepted variables were less than 10 indicating no effect of multicollinearty.The obtained results were similar to those reported by Amir Bibi *et al.* (2016), who found that all forage yield components had positive correlation with green forage yield under both conditions so the indirect selection of forage yield components may prove to be helpful in increasing the green forage yield of the crop.

Table 8. Regression parameters of the accepted variables according to stepwise multiple linear regression at 125%ETo irrigation treatment for sudan-grass green forage yield

Reg. Parameters Characterstics	Regression coefficient (b)	Standard Error (SE)	Probability level (P-Value)	Varience Inflation Factor (VIF)
Tillers No. (TNo.)	1.405 **	0.003	000	2.173
Ash (Ash)	-0.779	0.129	000	2.173
Intercept	9.536			
Model sig.	000			
R^2 (%)	97.2			
R^2_{Adjusted}	96.8			

The prediction equation for sudan-grass yield formula was as follows:

$$GFY = 9.536 + 1.405\,(TNo.) - 0.779\,(Ash)$$

Data presented in table 9 shows the partial regression coefficients under ETo 100% irrigation treatment as well as their significance for the accepted limiting one variable that significantly contributing to variation of green forage yield. This variable was leaves number. According to the results 89.6% and 89.0 (expressed as R^2 and R^2 adjusted, respectively) of the total variation in green forage yield could be attributed to this aforementioned leaves number trait. The other six traits were not included in the model due to their very low relative contribution.

Table 9. Regression parameters of the accepted variables according to stepwise multiple linear regression at 100%ETo irrigation treatment for Sudan-grass green forage yield

Reg. Parameters Characterstics	Regression coefficient (b)	Standard Error (SE)	Probability level (P-Value)	Varience Inflation Factor (VIF)
Leaves No. (LNo.)	0.947 **	0.043	000	1.0
Intercept	-0.590			
Model sig.	000			
R^2 (%)	89.6			
R^2_{Adjusted}	89.0			

The prediction equation for sudan-grass yield formula was as follows:

$$GFY = -0.59 + 0.947\ (LNo.)$$

Data presented in table 10 shows the partial regression coefficients under ETo 75% irrigation treatment as well as their significance for the accepted limiting one variable that significantly contributing to variation of green forage yield. These variables were leaves number and protein. According to the results 89.8% and 88.4% (expressed as R^2 and R^2 adjusted, respectively) of the total variation in green forage yield could be attributed to this aforementioned two traits. The other five traits were not included in the model due to their very low relative contribution. As mentioned before, the leaves number and protein were the most important variables according to stepwise analysis under 75% ETo irrigation treatments. Therefore, these two traits have to be ranked the first in any breeding program for improving green forage yield in Sudan-grass. These results Seyed zavar *et al.* (2014), who found that the stepwise regression analysis in the average stress condition showed that the number of rows ear^{-1}, 300-seed weight, number of kernels row^{-1}, number of leaves ear^{-1} explained totally 83% of kernel yield variation.

Table 10. Regression parameters of the accepted variables according to stepwise multiple linear regression under 75% ETo irrigation treatment for sudan-grass green forage yield

Reg. Parameters Characterstics	Regression coefficient (b)	Standard Error (SE)	Probability level (P-Value)	Varience Inflation Factor (VIF)
Leaves No. (LNo.)	1.305 **	0.003	000	2.534
Protein (Pro)	-0.540	0.129	000	2.534
Intercept	0.871			
Model sig.	000			
R^2 (%)	89.8			
R^2_{Adjusted}	88.4			

The prediction equation for Sudan-grass yield formula was as follows:

$$GFY = 0.871 + 1.305\ (LNo.) - 0.54\ (Pro)$$

Data presented in table 11 shows the partial regression coefficients under ETo 125% irrigation treatment as well as their significance for the accepted limiting three variables that significantly contributing to variation of dry forage yield. These variables were leaves number, protein and carbohydrates. According to the results 91.0% and 89.1% (expressed as R^2 and R^2 adjusted, respectively) of the total variation in dry forage yield could be attributed to these aforementioned traits. The other five traits were not included in the model due to their very low relative contribution.

The prediction equation for Sudan-grass yield formula was as follows:

$$DFY = 0.892 + 0.892\ (LNo.) - 0.136\ (Pro) - 0.293\ (Carb)$$

The current results of stepwise multiple linear regression were in harmony with those obtained by ValiollahRameeh (2016) and similar with Seyed zavar *et al.* (2014), who found that the stepwise regression analysis in the average stress condition showed that the number of rows ear^{-1}, 300-seed weight, number of kernels row^{-1}, number of leaves ear^{-1} explained totally 83% of kernel yield variation.

Table 11. Regression parameters of the accepted variables according to stepwise multiple linear regression under 125% ETo irrigation treatment for Sudan-grass dry forage yield

Reg. Parameters Characterstics	Regression coefficient (b)	Standard Error (SE)	Probability level (P-Value)	Varience Inflation Factor (VIF)
Leaves No.	0.892**	0.021	0.000	1.453
Protein	-0.136**	0.037	0.265	2.150
Carbohydrates	-0.293**	0.021	0.012	1.599
Intercept	1.461			
Model sig.	000			
R^2 (%)	91.0			
R^2_{Adjusted}	89.1			

Data presented in table 12 shows the partial regression coefficients under ETo 100% irrigation treatment as well as their significance for the accepted limiting three variables that significantly contributing to variation of dry forage yield. These variables were leaves number, ash and carbohydrates. According to the results 98.9% and 98.6% (expressed as R^2 and R^2 adjusted, respectively) of the total variation in dry forage yield could be attributed to these aforementioned traits. The other five traits were not included in the model due to their very low relative contribution.

The prediction equation for Sudan-grass yield formula was as follows:

$$DFY = 0.915 + 0.43\ (Ash) - 0.293\ (Carb)$$

Table 12. Regression parameters of the accepted variables according to stepwise multiple linear regressions under 100%ETo irrigation treatment for sudan-grass dry forage yield

Reg. Parameters Characterstics	Regression coefficient (b)	Standard Error (SE)	Probability level (P-Value)	Varience Inflation Factor (VIF)
Leaves No.	0.915**	0.005	0.000	1.106
Ash	0.430**	0.033	0.000	7.043
Carbohydrates	-0.250**	0.013	0.005	7.022
Intercept	0.158			
Model sig.	000			
R^2 (%)	98.9			
$R^2_{Adjusted}$	98.6			

Data presented in table 13 shows the partial regression coefficients under ETo 75% irrigation treatment as well as their significance for the accepted limiting three variables that significantly contributing to variation of dry forage yield. These variables were leaves number, protein, carbohydrates and fibers. According to the results 96.0% and 94.8% (expressed as R^2 and R^2 adjusted, respectively) of the total variation in dry forage yield could be attributed to these aforementioned traits. The other four traits were not included in the model due to their very low relative contribution.

The prediction equation for Sudan-grass yield formula was as follows:

DFY = - 0.34 + 1.119 (LNo.) – 0.35 (Pro) + 0.093 (Carb) – 0.113 (Fib)

The current results of stepwise multiple linear regression were inharmony with those obtained by Nasri *et al* (2014), who found that the stepwise regression was used to remove the effects of ineffective or low impact on yield traits in the regression model. Important traits for grain yield in this study included; biological yield (biomass), harvest index and weight spike unit^{-1}. The model has a coefficient of determination of 0.984.

Table 13. Regression parameters of the accepted variables according to stepwise multiple linear regresstion under 75 ETo irrigation treatment for sudan-grass dry forage yield

Reg. Parameters Characterstics	Regression coefficient (b)	Standard Error (SE)	Probability level (P-Value)	Varience Inflation Factor (VIF)
Leaves No.	1.119**	0.018	0.000	2.856
Protein	-0.350**	0.044	0.068	10.083
Carbohydrates	0.093**	0.026	0.449	4.636
Fibers	-0.113**	0.019	0.315	3.831
Intercept	-0.340			
Model sig.	000			
R^2 (%)	96.0			
$R^2_{Adjusted}$	94.80			

Based on the results of the present study it could be concluded that:

Average amounts of applied irrigation water under 125, 100, and 75% ETo irrigation levels treatment were 4450, 3710and 2980m^3 ha^1, respectively.

There was a significant effect of the tested irrigation levels onforage yield and quality(Sudan-grass), number of plant height (cm), number of tillers plant^{-1}**,** number of leaves plant^{-1}, dry leave stem ratio and green yield (ton ha^{-1}**)**, and quality (dry yield, protein, ash and fiber).

Average green yield (ton ha^{-1}) values were 31.13, 22.33, and 16.30 t ha^{-1} for the 125, 100, and 75 % ETo irrigation treatments, respectively.

The percentages of saved water were 20 and 50% for the 100 and 75 ETo, respectively as compared to the 125% ETo treatment.

In case of water shortage, irrigating Sudan-grass in sandy soils with 100% ETo will save 20% of applied irrigation water used for irrigation, gives the water use efficiency of 7.76 green yield/m^3 water consumed and water productivity of 6.02 kg green yield/m^3 under sprinkler irrigation system and fertigation practice.

The results revealed that there was a highly significant positive correlation between green forage yield and each of leaves number (0.954**), dry leaf stem ratio (0.944**) and plant height (0.780**), tillers number (0.832*) and protein (0.571*).However, insignificant associations were observed between green forage yield and carbohydrate (0.337) and ash (0.253) and insignificant negative correlation with fibers (-0.315).

The result obtained from this study could be useful for forage breeders and seed producers in order to increase forage yield and quality.

It should be taken into consideration that all the investigated traits are quantitative characters and are affected by environmental conditions to a great extent; therefore, the result may be changed from environment to environment.

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