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Pearl millet forage productivity under sprinkler irrigation system in sandy soil

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A field experiment was conducted in a private farm (30°40' N latitude, 32°15' E longitude, and 10.0 m above mean sea level), Ismailia Governorate, Egypt, during the 2020 and 2021 summer growing seasons. The aim was to study the effect of four irrigation treatments (125, 100, 75% ETo, and farmer practice) on pearl millet forage yield. Average amounts of applied irrigation water under 125, 100, 75% ETo and farmer practice were 4637, 3710, 2782, and 5950 m^3/ha, respectively with respective average water consumption values of 4130, 3308, 2482, and 5302 m^3/ha. Compared to the farmer practice, the saved water was 22, 38, and 53 % for the 125, 100, and 75% ETo treatments. Average water use efficiency values were 7.91, 7.55, 6.96 and 4.59 kg/m^3, and average water productivity values were 7.04, 6.73, 6.21, and 4.08 kg/m^3 for 125, 100, 75% ETo and farmer treatments, respectively. The Ky factor was 1.17 indicating that the pearl millet crop is moderately sensitive to water stress. Irrigating pearl millet in sandy soils with 100% ETo will save 38% of applied irrigation water, achieve water use efficiency of 7.55 green yield/m^3 of water consumed, and water productivity of 6.73 kg green yield/m^3 of water applied.

Keywords: Pearl millet, BIS model, sprinkler system, sandy soil, water use efficiency and water productivity

INTRODUCTION

Water is considered a scarce resource in many areas of the world, especially in arid and semiarid regions. Egypt is facing a shortage in water resources and demand for water is increasing due to the growing population, competition between different water-consuming sectors, expansion in irrigated agriculture areas and the negative effect of climate change. Hence, attempts are required to increase water use efficiency of the cultivated crops. Management of irrigation water demand at the on-farm level should be a focal point to reduce the increasing demand for water to match future supplies, thereby reducing the effect of the water deficit that the country will face. Egypt depends on irrigated agriculture for more than 95% of its agricultural area (Abou-Zeid, 2002). Water availability to the agricultural sector is becoming a major constraint to agricultural production, where it is the largest consumer of Egyptian water resources. Egypt’s water policy mainly depends on the expansion of modern irrigation techniques in the newly reclaimed lands of the desert and on the improvement of irrigation practices in old lands of the Nile Valley and Delta. The adoption of modern irrigation systems, such as drip, bubbler and sprinkler to increase irrigation efficiency is one of the measures used for competent use of water (NWRP, 2002). Effective irrigation water management is a good agricultural practice to maximize water productivity under this situation. One of the most important methods of water conservation is the use of modern irrigation systems (sprinkler and drip) and irrigation scheduling in sandy soils. Under clay soils conditions, increasing irrigation intervals or decreasing irrigation depths are effective water 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; 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 by supplying 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 their effects on crop productivity. The soils in the newly reclaimed lands are mainly sandy, with low water storage capacity and low in fertility and organic matter content (Page et al., 1982).Under such conditions, the choice of an irrigation method, which accomplishes efficient water use, higher crop yield, and quality, saves energy and enhances 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).Using irrigation scheduling and fertigation practices in sandy soil are considered useful practices to maximize unit productivity land, water, and fertilizer unit Productivity (Taha, 2012).

In Egypt, animal production is suffering from forage scarcity due to the competition between production of human food and animal feed. There is shortage of fresh feed materials for livestock feeding during summer season, from May until November. One of the most important problems for animal production is the reduction in forage crops productivity during summer. So, increasing forage crop productivity per unit area during summer or/and increasing the cultivated area of summer forage crops especially in the newly reclaimed lands become the backbone to solve this problem.

Pearl millet (Pennisetum glaucum L.) is a very important forage crop in Africa, Asia and America and it provides nutritionally superior and staple food for millions of people (Dakheel et al., 2009).It has a high nutritive value as summer-annual forage crop, popular among livestock producers for grazing, silage, hay and green crop. Pearl millet can also be utilized as emergency forage that regularly performs, as well as an economical one-year forage crop option. It is a highly cross-pollinated diploid (2x=14) annual C4 crop with protogynous flowering and wind-borne pollination mechanism, amenable for development of heterozygous populations, which can be utilized for the production of high yielding hybrids (Bhasker et al., 2017). The crop is adapted to different adverse conditions such as drought, salinity, and soil poor in nutrients. Under suitable climatic conditions, pearl millets have great capacity of rooting, enabling to take two or three cuts of green forage (Maiti and Rodriguez, 2010). The crop is commonly grown under difficult farming conditions, including those in drought–stricken areas, where soil fertility is low, and food supplies are dependent on rainfall (Vanderlip, 1991). Pearl millet is a summer forage crop which can be cultivated in the newly reclaimed lands to overcome the problem of summer forage shortage. Furthermore, there is an increase in pearl millet cultivation on a large scale in Egypt in newly reclaimed areas to face that shortage. Increasing water stress decreased biomass production, but sub-surface drip irrigation with full water requirement increased biomass production compared to sprinkler irrigation with full water requirement. Irrigation water use efficiency was decreased by increasing water stress and number of cuts (Saleh, 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 (NAMA, 2017). In addition, 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, and the relative area of coverage), crop factors (type of crop, size of plants, and plant density) and other production systems characters (Smajstrla et al., 1998). Also, climate factors including solar radiation, temperature, humidity and wind speed have an effect on the pumped irrigation water (El-Qousy et al., 2006).

The objectives of this study were to evaluate the effect of different ETo-dependent irrigation levels on pearl millet forage yield, forage quality, amounts of applied irrigation water, water consumptive use, water use efficiency, water productivity and saving both energy and irrigation water. Also, to develop yield response factor (Ky) and a local crop coefficient (Kc).

MATERIALS AND METHODS

Experimental site description

A field experiment was conducted in a private farm (30o 40' N latitude, 32o 15' E longitude, and 10.0 m above mean sea level), Ismailia Governorate, Egypt, during 2020 and 2021 summer growing seasons. The experimental site represents the newly reclaimed sandy soil of East Nile Delta region. The climate is cool in winter with, a mean air temperature of about 13.0°C. Summer is hot with no rain, and mean air temperatures varies from 25.6 to 30.6°C during June, July, and August, as well as mean wind speed of 2.93 m/h during the daytime for these months. Average monthly weather data at the experimental site for the period from 2015 to 2019 are presented in table 1.

Table 1: Mean monthly values (2015-2019) of solar radiation (Srad), maximum (Tmax), minimum (Tmin) air temperatures, wind speed (Ws), dew point (Td), and the calculated reference evapotranspiration (ETo) at the experimental site during the growing season

Month	Srad (MJ m^{-2} day^{-1})	Tmax (°C)	Tmin (°C)	Ws (m s^{-1})	Td (°C)	ETo (mm day^{-1})
May	27.68	33.46	17.80	3.00	20.50	6.40
June	28.10	36.33	20.19	3.10	21.92	7.17
July	28.90	38.05	21.90	2.90	22.93	7.30
August	25.15	38.14	22.98	2.82	22.28	7.11
September	23.10	34.84	21.20	2.85	20.50	5.30

Table 1.

Data in table 1 were used to calculate monthly reference evapotranspiration (ETo) values at 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 intervals to determine the soil physical, chemical properties and soil-moisture constants (Table 2). Chemical and physical soil parameters were determined according to the standard method described by Tan (1996). The values of available macronutrients (N, P, and K) were 16.7, 5.5, and 65.1 mg kg−1, respectively. Accordingly, the soil was characterized by low fertility and insufficient available water for plant growth.

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

Soil properties	Soil depth (cm)			
	0-15	15-30	30-45	45- 60
Coarse sand, %	68.5	73.5	74.1	77.1
Fine sand, %	25.8	22.1	22.2	18.9
Silt, %	3.67	2.90	2.80	3.10
Clay, %	2.00	1.40	0.90	0.80
Textural 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)	7.61	7.58	7.56	7.40
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

Table 2.

As for irrigation water, the electrical conductivity (EC) value was 0.54 dS m−1 and pH value was 7.54.

Experimental design and tested treatments

The field experiment was implemented in a strip plot design, with four replicates. The horizontal plots were devoted to the irrigation treatments (plot size was 576 m2).

The tested treatments were as follows:

I1: Irrigation with amounts of water equal to 125% ETo.

I2: Irrigation with amounts of water equal to 100% ETo.

I3: Irrigation with amounts of water equal to 75% ETo.

I4: Farmer practice (Control). The farmer applied irrigation and fertilizer amounts without interference from the researcher.

Cultural practices

Pearl millet seeds (Shandaweel-1 variety) were cultivated on the 3rd and 5th of May in 2020 and 2021 seasons, respectively. The seed rate was 48 kg/ha. Pearl millet was cultivated under sprinkler system in a total area (main plot) of 576 m2 (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 discharge rate at 2.80 bars nozzle pressure was used to irrigate the crop. The sprinkler system consists of main PVC pipeline (160 mm diameter), sub main PVC pipelines (110 mm diameter), and PVC lateral lines (50 mm diameter). The laterals were spaced at 12 meters apart. Application of the irrigation water treatments started from the tenth irrigation from sowing date. Fertilizers were applied through irrigation water (fertigation) in 80% of irrigation time using the differential pressure tank. According to the findings of Taha (2012), all macronutrient fertilizers were added in equal doses (3 doses per week). The fertigation started 15 days from sowing in both growing seasons. Nitrogen fertilizer (ammonium nitrate, 33.5% N) at the rate of 286 kg N/ha, potassium sulfate at the rate of 120 kg K2O/ha, and 55.40 kg P2O5/ha of phosphoric acid (60%) were added.

Furthermore, cutting of pearl millet plants was done three times, 50 days from sowing, the second cutting was 40 days from the first cut and the third cutting was 30 days from the second cut in both growing seasons.

Measurements of agronomic traits and crop yield

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

2- Number of leaves per plant.

3- Number of tillers per m2.

4- Dry leaves/stem ratio.

5- Fresh forage yield (kg/plot): plants of the plot where hand clipped and weighed. Total fresh yield was calculated by the sum of the three cuts.

6- Dry forage yield (kg/plot): Samples of 100 g were dried at 60 oC and dry matter percentages (DM, %) was estimated. The dry forage yield (t/ha) was calculated by multiplying fresh forage yield (t/ha) by dry matter percentage.

Chemical analysis

The forage nutritive values were estimated on dry matter basis (%) for the three cuts in both seasons to determine crude protein percentage (CP, %), crude fiber (CF, %) and ash content. A sub sample of dry matter (10 g) was grounded and passed through 0.5 mm sieve and preserved for chemical analysis. The dry matter and ash contents were determined according to Official Agriculture Chemists (AOAC, 1999). Ash contents were calculated by incineration of the highly grounded samples at 550oC for three hours. For crude protein, the nitrogen content of the feed sample was determined by Kjeldahl N (AOAC, 1999) and the 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 carbohydrate's percentage was determined in plants using colorimetric method as 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 soil moisture depletion method according to Majumdar (2002) and calculated as follows:

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

.

Where:

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

i = Number of soil layer.

θ2 = Soil moisture content after irrigation, (%, by mass).

θ1 = Soil moisture content just before irrigation, (%, by mass).

Bd = Soil bulk density, (g/cm3).

d = Depth of soil layer, (mm).

Applied irrigation water

The depth of applied irrigation water was 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 were calculated using BISm.

I = irrigation intervals (days)

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

LR = leaching requirements (was not considered in this experiment due to its indirect effect on the amount of water applied for water stress treatment, 0.75% ETo).

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

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

.

Where:

Y= Pearl millet yield (kg ha–1).

WCU = Water consumed by the crop during entire growing season (m3 ha–1).

Water productivity (WP)

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

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

.

Energy saving (ES, %)

Energy saving percentage: is the amount of energy saved from operating the irrigation pump according to the tested treatments compared with farmer practice (kw h). The ES values were calculated using the following formula:

$$Energy\ saving(\%) = \frac{(Actual\ energy\ used\ )}{(\ Energy\ used\ by\ farmer)} \times 100$$

.

Statistical analysis

Data were statistically analyzed according to Steel and Torrie 1980), and treatments means were compared by least significant difference test (LSD) at 0.05 level of significance.

RESULTS AND DISCUSSION

Pearl millet fresh and dry yields and vegetative growth parameters

Results in table 3 indicated significant effect of the adopted irrigation treatments on fresh and dry yields, plant height (cm), number of tillers per plant, number of leaves per plant, and dry leave to stem ratio in the two growing seasons. Results showed that under the application of 125% ETo treatment, pearl millet crop was able to develop sufficient biomass leading to significantly higher fresh and dry yields, plant height, number of tillers per plant, number of leaves per plant, and dry leaves to stem ratio as compared with the other treatments. Results also showed that,the highest values of fresh (12.5 and 13.1 t/ha) and dry yields (3.20 and 3.43 t/ha), average number of leaves (8.3 and 8.8), and dry leave to stem ratio (29.2 and 29.7) were reported in the 1st cut in the 1st and 2nd seasons, respectively. The highest values of plant height (117.3 and 121.0 cm) and number of tillers per plant (92 and 94) were reported in the second cut from irrigation with 125% ETo treatment, as compared with the other treatments in the 1st and 2nd seasons, respectively. These results are attributed to water availability and efficient distribution of fertilizer under field conditions. The lowest values of the examined traits were recorded for the 75% ETo water stress treatment. Results revealed also that increasing the amount of irrigation water increased number and length of internodes as well as number of leaves per plant due to the promoting role of water in cell division, expansion and enlargement. These results were in line with those obtained by Zahid et al. (2002) and Afzal et al. (2013),who found that green forage yield increased linearly with increasing irrigation water and nitrogen fertilization rates. The results are similar to the results found by Ismail et al. (2017), who stated that decreasing water application decreased yield attributes under sprinkler irrigation. The obtained results were also confirmed by Nezami et al. (2008), Gholinezhad et al. (2009) and El-Dakrourry (2015).

Table 3: Effect of irrigation treatments on pearl millet fresh, and dry yields, and vegetative growth parameters in 2020 and 2021 growing seasons

Season	2020			2021		
	Fresh forage yield (t/ha)					
Cuts	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
125 % ETo	12.5 a	10.9 a	8.86 a	13.1 a	11.3 a	8.62 a
100% ETo	9.65 b	8.85 b	6.36 b	10.21 b	8.31 b	6.56 b
75% ETo	6.11 c	5.65 c	4.11 c	7.60 b	6.50 c	4.50 c
Farmer	9.40 b	8.60 b	6.20 b	9.90 b	8.10 b	6.40 b
LSD 0.05	0.59	0.38	0.36	0.66	0.93	0.61
Irrigation	Dry yield (t/ha)					
125 % ETo	3.20 a	2.86 a	2.60 a	3.43 a	3.18 a	2.53 a
100% ETo	2.38 b	2.30 a	1.80 b	2.59 b	2.25 b	1.85 b
75% ETo	1.47 c	1.50 c	1.08 c	1.86 c	1.70 c	1.22 c
Farmer	2.11 b	1.89 b	1.71 b	2.26 b	2.10 b	1.67 b
LSD 0.05	0.52	0.67	0.62	0.44	0.47	0.35
Irrigation	Plant height (cm)					
125 % ETo	106.7 a	117.3 a	80.3 a	109.3 a	121.0 a	83.7 a
100% ETo	92.3 b	91.7 b	65.7 b	94.3 b	95.3 b	70.3 b
75% ETo	54.3 c	65.7 c	47.7 c	56.0 c	68.3 c	51.0 c
Farmer	92.2 b	93.4 b	68.1 b	95.3 b	96.1 b	71.1 b
LSD 0.05	9.72	2.07	7.64	11.2	5.51	5.66
	Number of tillers					
125 % ETo	84.3 a	92.0 a	53.0 a	87.7 a	94.0 a	56.0 a
100% ETo	77.0 b	81.3 b	47.0 b	79.0 b	84.0 b	49.3 b
75% ETo	49.3 c	63.7 c	40.3 c	53.0 c	65.7 c	42.3 c
Farmer	75.8 b	80.5 b	46.4 b	78.8 b	83.4 b	48.5 b
LSD 0.05	4.66	5.19	4.96	4.78	4.78	5.23
	Number of leaves					
125 % ETo	8.33 a	7.53 a	6.70 a	8.83 a	7.77 a	6.84 a
100% ETo	7.40 b	6.23 b	4.93 b	7.63 b	6.43 b	5.14 b
75% ETo	6.20 c	5.40 c	4.20 c	6.60 c	5.67 c	4.35 c
Farmer	7.24 b	6.10 b	4.77 b	7.50 b	7.22 b	4.99 b
LSD 0.05	0.50	0.61	0.44	0.84	0.67	0.41
	Dry leave to stem ratio					
125 % ETo	29.2 a	21.6 a	19.1 a	29.7 a	21.9 a	19.3 a
100% ETo	24.4 b	18.56 b	17.0 b	25.1 b	18.8 b	17.3 b
75% ETo	13.6 c	11.66 c	10.8 c	14.2 c	12.0 c	11.0 c
Farmer	23.8 b	18.0 b	16.7 b	24.5 b	18.3 b	16.7 b
LSD 0.05	1.56	1.82	0.69	1.55	1.83	0.68

1st cut: 50 days after sowing - 2nd cut: 40 days from 1st - 3rd cut: 30 days from 2nd.

Table 3.

Results in table 3 indicated that all tested parameters including fresh and dry yields, plant height, number of tillers per plant, number of leaves per plant, and dry leave to stem ratio increased slightly in the 2nd season as compared to the 1st season under all irrigation treatments. This could be attributed to higher distribution uniformity in the 2nd season with more efficient water and fertilizer distributions and availability to the plants. The results were also close to those reported by Taha et al. (2019), who indicated that the highest values of plant height and number of tillers per plant of Sudan-grass was found after the second cut from irrigation with 125% ETo treatment, compared to 100 and 75% ETo treatments under same conditions. The first cut was superior to the second and third cuts in both seasons.

Pearl millet technical parameters

Results in table 4 indicated significant effects of the adopted irrigation treatments on protein content, ash, fiber and carbohydrate (%) in the two growing seasons. Results showed that the lowest values of the tested traits were recorded under the 75% ETo water stress treatment. It can be noticed from Table 4 that all the studied characters slightly increased in the second growing season compared to the first season under all irrigation treatments. 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 distribution and fertilizer uptake. The highest significant values of the tested traits were recorded under the 125% ETo treatment, indicating more water availability, which helps in the absorption and translocation of nutrients from the soil to the growing parts of the plants. These results were similar to what was obtained by Taha et al. (2019), who reported significant effects of the adopted irrigation treatments on protein contents, ash and fiber (%) in Sudan-grass in the two growing seasons. The highest values of protein, ash and fiber of three cuts were produced from the irrigation with 125% ETo under sandy soil and sprinkler irrigation.

Table 4: The effect of irrigation treatments on forage yield and quality (dry yield, protein, ash and fiber) of pearl millet in two growing seasons (2020 and 2021)

Season	2020			2021		
Cuts	1st cut	2nd cut	3rd cut	1st cut	2nd cut	3rd cut
	Protein					
125 % ETo	9.33 a	9.87 a	8.92 a	9.37 a	9.94 a	8.97 a
100% ETo	8.34 b	9.38 a	7.99 b	8.37 b	9.43 a	8.03 b
75% ETo	8.05 b	8.52 b	7.72 b	8.11 b	8.59 b	7.77 b
Farmer	8.21 b	8.26 b	7.89 b	8.24 b	8.32 b	7.94 b
LSD 0.05	0.40	0.73	0.57	0.40	0.68	0.57
	Ash					
125 % ETo	7.01 a	8.10 a	6.82 a	7.03 a	8.13 a	6.84 a
100% ETo	6.88 b	7.93 ab	6.77 b	6.90 b	7.96 ab	6.80 a
75% ETo	6.78 c	7.81 b	6.70 c	6.80 c	7.84 b	6.73 b
Farmer	6.43 d	7.44 c	6.45 d	6.45 d	7.47 c	6.47 c
LSD 0.05	0.06	0.21	0.05	0.08	0.23	0.05
	Fiber					
125 % ETo	35.4 a	28.6 a	36.4 a	35.4 a	28.6 a	36.5 a
100% ETo	34.8 a	28.2 a	35.7 b	34.8 b	28.3 a	35.8 b
75% ETo	34.2 a	27.4 b	35.5 b	34.2 c	27.5 b	35.5 b
Farmer	33.7 a	27.2 b	34.7 c	33.7 d	27.2 b	34.7 c
LSD 0.05	1.93	0.47	0.25	0.17	0.47	0.25
	Carbohydrate					
125 % ETo	37.2 a	37.6 a	35.4 a	37.2 a	37.1 a	35.5 a
100% ETo	34.5 b	35.1 b	32.4 b	34.6 b	35.1 b	32.5 b
75% ETo	32.5 c	32.7 c	30.5 c	32.6 c	32.7 c	30.5 c
Farmer	34.15 b	34.5 b	32.5 b	34.2 b	34.0 b	32.6 b
LSD 0.05	2.00	1.08	0.49	1.92	1.07	0.45

1st cut: 50 days after sowing - 2nd cut: 40 days from 1st - 3rd cut: 30 days from 2nd.

Table 4.

Water distribution uniformity (DU)

The distribution uniformity tests were conducted at the beginning of each growing season. The calculated values were 78 and 80% in the 1st and 2nd growing seasons, respectively. The obtained results showed a small increase in DU values in the second season as compared to the first season. The obtained results were similar to those reported by Taha (2012 and 2013), El-Mehy et al. (2018) and Taha et al. (2019) who reported that the values of distribution uniformity of irrigation water for the second season increased compared to the first season.

Applied irrigation water, water consumption and saved water

The effect of tested treatments on the depths of applied irrigation water and saved water during the 2020 and 2021 seasons is presented in table 5. Results indicated that the depths of applied water were 470, 376 and 282 mm during 2020 season and were 457.5, 366 and 274.5 mm during 2021 season for the 125, 100 and 75 ETo treatments, respectively. The farmer irrigation practice exceeded the other tested treatments by values that varied from 22 to 53%, which reflects the need of the extension program to avoid over irrigation and to reduce the cost of energy used for pumping water. The percentages of saved water were 22, 38 and 53% for the 125, 100 and 75% ETo, respectively, as compared with the farmer irrigation practice. The results indicated, in general, that increasing water availability to the plants increased water consumption. The highest values of seasonal water consumptive use were 5374 and 5230 m3/ha under farmer irrigation practice in the first and second growing seasons, respectively. Whereas, the lowest values of seasonal water consumptive use were 2514 and 2450 m3/ha obtained under irrigation with 75% ETo in the first and second seasons, respectively. These results were close to those obtained by El-Mehy et al. (2018), who found that the sprinkler system method saved 19.9% and 48.8% of irrigation water under 100% and 80%ETo as compared with 120% ETo treatment. Moreover, the obtained results were close to what was reported by Taha et al. (2019),who found that 20% and 50% of the applied irrigation water for Sudan-grass were saved under sprinkler system in sandy soil when 100 and 60%ETo were applied as compared to the 125% ETo irrigation treatment.

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 pearl millet during 2020 and 2021 growing seasons

Irrigation treatments	2020			2021		
	Applied water mm (m^3/ha)	% saved	Water consumption (m^3/ha)	Applied water mm (m^3/ha)	% saved	Water consumption (m^3/ha)
125% ETo	470 (4700)	22	4185	457.5 (4575)	22	4075
100% ETo	376 (3760)	38	3350	366 (3660)	38	3265
75% ETo	282 (2820)	53	2514	274.5 (2745)	53	2450
Farmer	603 (6030)	---	5374	587 (5870)	---	5230

Table 5.

Water use efficiency and water productivity

Results in table 6 indicated that increasing irrigation water increased water use efficiency (WUE) values except for farmer treatment in the two growing seasons. Also, WUE values tended to increase in the second growing season compared to the first growing seasons as a result of higher distribution uniformity value in the second season resulted in efficient water and fertilizer distribution utilization. The highest WUE values of 7.71 and 8.11 kg/m3 obtained from irrigating with 125% ETo in 1st and 2nd seasons, respectively. This result could be due to the increase in distribution uniformity of the sprinkler system in the 2nd season which resulted in more efficient water and fertilizer distribution and uptake and the increase in fodder green yield in second season compared to first season. The lowest water use efficiency values of 4.50 and 4.67 kg/m3 were obtained under farmer practice. This result could be due to the excessive application of irrigation water, which led to nutrients leaching from the effective root zone. The obtained results were close to those reported by Taha et al. (2019), who found that the highest water use efficiency values of 8.08 and 8.88 kg/m3 were obtained from irrigating with 125% ETo. They also stated that the lowest water use efficiency values (7.45 and 7.77 kg/m3) were obtained from the 75% ETo treatment. The results were also in close agreement with those obtained by Seghatoleslam et al. (2008), who stated that water use efficiency (WUE) was significantly reduced by water stress. They stated that the decreased water use efficiency under 75% ETo treatment is attributed to the effect of water stress on the plant at different phenological stages of growth. Similar results were also obtained by Ibrahim et al. (1995), who showed that drought stress of millet at ear emergence stage caused the greatest reduction in water use efficiency (WUE) values.

The results in table 6 also showed that water productivity (WP) increased with increasing the applied irrigation water from 75 to 125% ETo. Also, the WP values increased in the second growing season compared to the first growing seasons as a result of increasing water distribution uniformity and with direct effect of fertilizer distribution and uptake in the field. The highest water productivity values of 6.87 and 7.22 kg/m-3 were obtained from irrigating with 125% ETo in 1st and 2nd seasons, respectively. The WP values of 5.63 and 6.78 kgm-3 were obtained from the 75% ETo treatment, which could be attributed to decrease water availability for the plants grown in the field under 75% ETo. The lowest WP values of 4.01 and 4.16 kg/m3 of applied water in the 1st and 2nd seasons, respectively, were recorded under farmer practice. The obtained results was in agreement with those obtained by Taha et al. (2019), who found that the highest water productivity of 6.79 and 7.20 kg/m-3 for Sudan grass were obtained from irrigating with 125% ETo in 1st and 2nd seasons, respectively, while the lowest values of 5.22 and 5.73 kg m-3 were obtained from the 75% ETo irrigation treatment in sandy soil under sprinkler irrigation.

Table 6: Water use efficiency, and water productivity of pearl millet as affected by irrigation treatments in 2020 and 2021 growing seasons

Irrigation treatments	Water use efficiency (kg/m^3)		Water productivity (kg/m^3)	
	2020	2021	2020	2021
125 % ETo	7.71	8.11	6.87	7.22
100% ETo	7.42	7.68	6.61	6.85
75% ETo	6.32	7.59	5.63	6.78
Farmer	4.50	4.67	4.01	4.16

Table 6.

Consumed electrical energy

Results in table 7 indicated that the highest values of the seasonal consumed energy were 9885 and 9782 kilowatts in the 1st and 2nd growing seasons, respectively, under farmer irrigation practice. Application of the tested irrigation treatments reduced the consumed electric energy in the both growing seasons by values varied between 24 and 53% compared to farmer irrigation. The lowest value of seasonal consumed energy was obtained under irrigation, with 75% ETo in both seasons. Energy saving was a result of using deficit irrigation technique, which reduced the number of hours used to operate the irrigation pump in all the proposed irrigation treatments. The result agreed with that reported by Taha (2018, and 2020), who stated that application of 120, 100,80 and 60%ETo irrigation treatments led to reduce consumed energy by values varied from 25 to 62% compared with farmer irrigation.

Table 7: Effect of irrigation treatments on saving electric energy in the two growing seasons

Irrigation treatments	2020		2021	
	Energy consumed (kW)	Saving (%)	Energy consumed (kW)	Saving (%)
125 % ETo	7531	24	7520	23
100% ETo	6125	38	6060	38
75% ETo	4600	53	4590	53
Farmer	9885	---	9782	----

Table 7.

Crop coefficient (Kc)

The calculated Kc values for the 125% ETo irrigation treatment are illustrated in figure 1. Results indicated that Kc values increased in the third cut compared to the second and first cuts. The obtained results are attributed to climatic conditions and variation in crop canopy during the growing season. The Kc values for the 125% ETo irrigation treatment under first, second and third cut were 0.37-0.44 - 0.49; 0.48-0.5-0.52 and 0.78-0.85-0.87 for initial, crop development, late-season growth stages, respectively. The obtained Kc values under the present experimental conditions were close to those reported by Rao et al. (2012), who reported that the average crop coefficients for crop development, mid-, and late-season growth stages were 0.42, 0.85 and 0.44 in respective order.

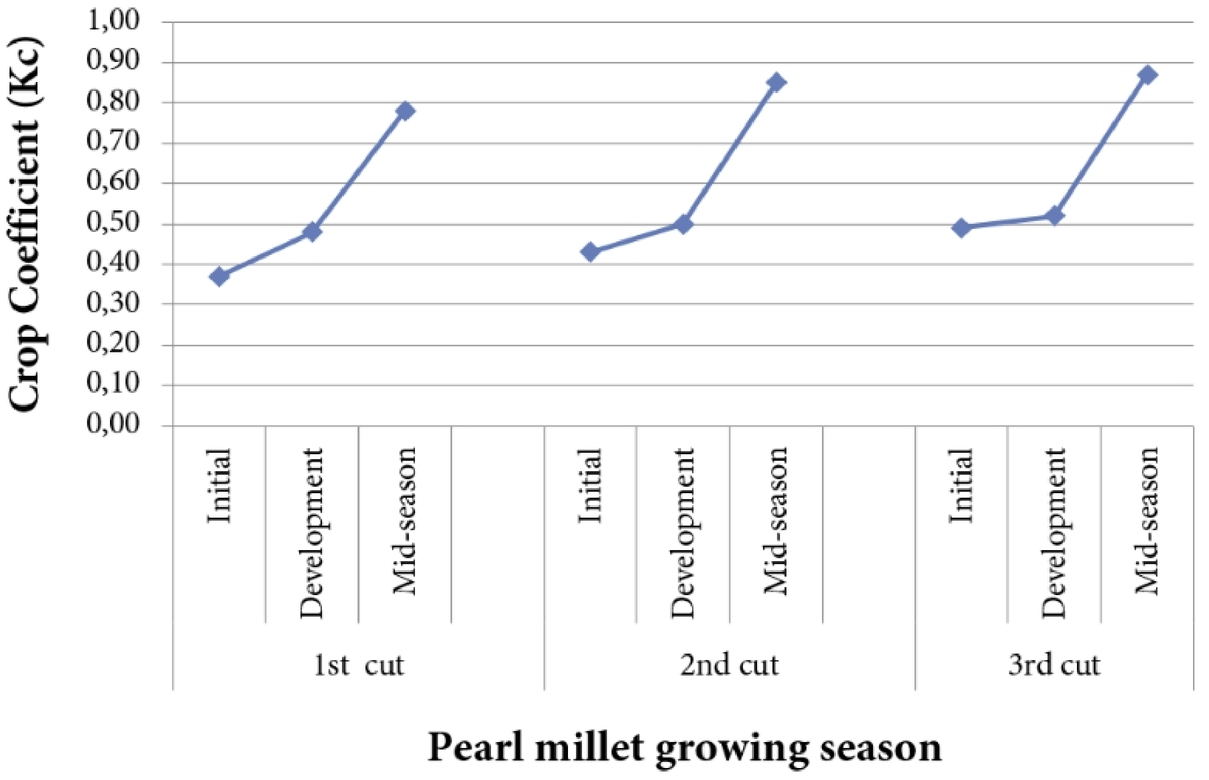

Figure 1: Crop coefficient values for the 125% ETo treatment for the three cuttings of the pearl millet crop

Figure 1.

Yield response factor (Ky)

Average values of pearl millet yields obtained from the tested irrigation treatments (75 - 125% ETo) in the two growing seasons were fitted into a linear equation relating the relative decrease in yield to the relative decrease in applied irrigation water (Figure 2). The equation representing the obtained relation can be expressed as:

Y = 1.168 X, R2 = 0.986

Where:

Y: represents relative yield reduction (1 – Ya/Ym),

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X: represents a relative reduction in applied irrigation water (1 – AIWa/AIWm) and 1.17 is the slope that represents the yield response factor (Ky) showing the sensitivity of pearl millet crop to the reduction of applied irrigation water.

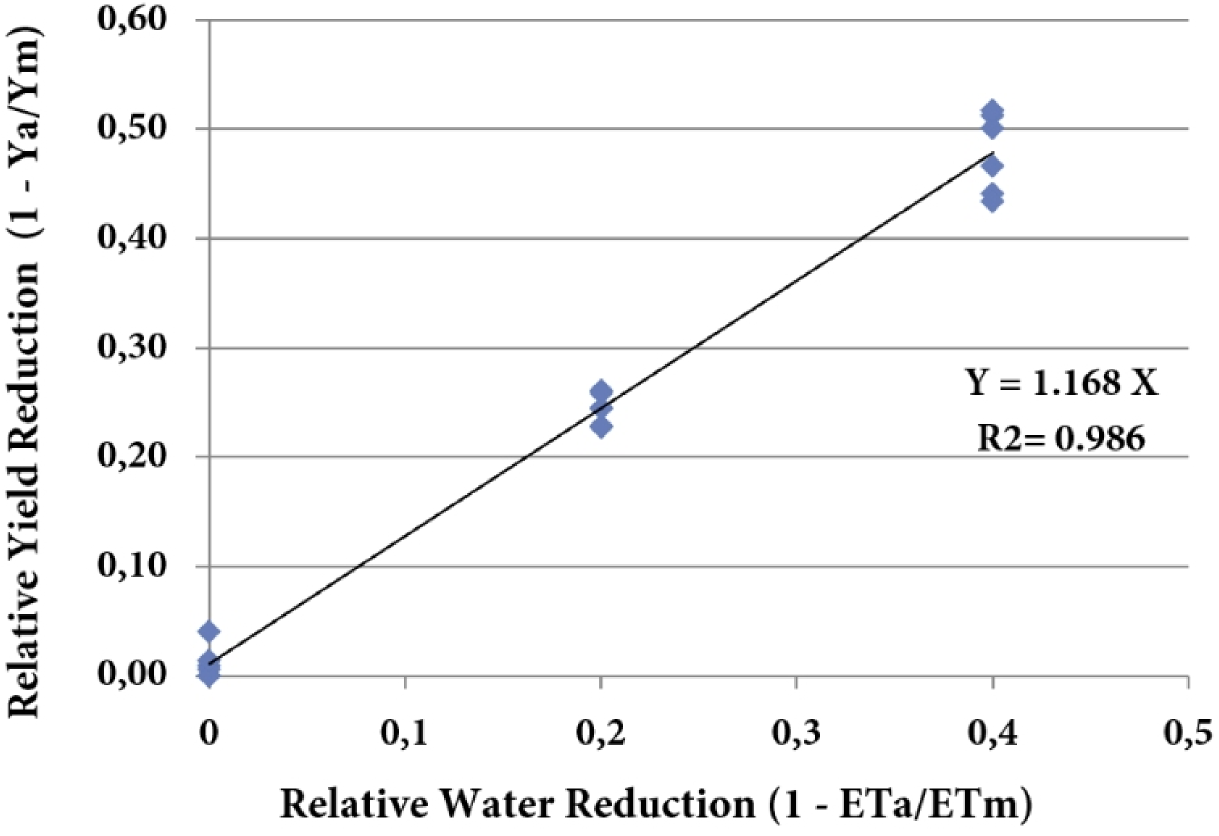

Figure 2: Pearl millet yield response factor (Ky)

Figure 2.

The obtained Ky value under the experimental condition was more than 1, indicating that the pearl millet fodder crop is moderately sensitive to water stress (i.e. up to 75% ETo). The result agreed with that reported by Djaman et al. (2013), who stated that the yield response factor was determined as 1.65 for maize is sensitive to low and mild drought stress during the growth period and severe stress caused a significant yield reduction.

CONCLUSION

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 treatment were 4638, 3710 and 2783 m3/ha, respectively.

There was a significant effect of the tested irrigation levels on forage yield, yield components, and quality parameters.

The green yield increased with increased the applied irrigation amounts and reached its highest value under irrigation with 125% ETo. The total green yield of the first season was 32.3, 24.9 and 15.9 t/ha for 125, 100, and 75% ETo irrigation treatments, respectively. Total green yields in the second season were 33.04, 25.1 and 18.6 t/ha for 125, 100 and 75% ETo irrigation treatments, respectively.

In case of water shortage, irrigating pearl millet in sandy soils with 100% ETo will save 20% of applied irrigation water, gives the water use efficiency of 7.55 kg green yield per cubic meter of water consumed and water productivity of 6.73 kg green yield per cubic meter under sprinkler irrigation system.

The Kc values for the 125% ETo irrigation treatments under first, second and three cuts were 0.37-0.44- 0.49, 0.48-0.5-0.52, and 0.78-0.85-0.87 for initial, crop development, and late-season growth stages, respectively. The pearl millet yield response factor (Ky) was 1.17 indicating that the crop is moderately sensitive to water stress.

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