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Optimizing water requirements for green and dry fodder yield in Egyptian clover (*Trifolium alexandrinum* L.) using sub-surface irrigation in old lands

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Abstract

Egyptian clover (*Trifolium alexandrinum* L.) holds significant importance as a leguminous forage crop in Egypt. This study aimed to investigate the optimal water requirements for Egyptian clover (cv Gemiza I) and assess water use efficiency concerning forage yield under a sub-surface irrigation system. A two-year field experiment was conducted at Gemiza Agricultural Research Station, Gharbia, Egypt, spanning the winter seasons of 2020/2021 and 2021/2022. The experimental design employed a split-plot design with three replications. The main plots consisted of four irrigation levels (40, 60, 80, and 100% of water requirements), while the subplots entailed four irrigation frequencies (3, 5, 7, and 9-day intervals). The experiment involved four cuttings of green fodder, with the first cut executed 50 days after planting and subsequent cuts taken every 30 days thereafter. The findings revealed that the water requirement for Egyptian clover varied between 2150-2250 m^3/fed, contingent upon the prevailing climate and growth period. Notably, an irrigation interval of 7 days exhibited the highest forage yield when applied under a 100% irrigation level, while an 80% irrigation level demonstrated the highest water use efficiency (24.4 kg/m^3 water), closely followed by the 100% irrigation level. Remarkably, the implementation of the sub-surface irrigation system with a 40% water regime, coupled with a 7-day irrigation interval, resulted in the most substantial water conservation. In summary, the utilization of the sub-surface irrigation system has demonstrated its efficacy as a viable approach for addressing the constraints posed by diminishing irrigation water availability in response to the challenges posed by climatic changes.

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Introduction

In the near future, it is imperative to conduct a thorough investigation into the impact of utilizing irrigation water of substandard quality in agriculture, given the anticipated increase in water resource limitations. The forthcoming challenge lies in maintaining or even enhancing water productivity with reduced or poor-quality water. The scarcity of water remains a paramount global issue. As water resources become increasingly limited in the future, coupled with population growth, water has become the most invaluable natural resource in arid and semi-arid regions. Furthermore, irrigation poses a significant challenge to agricultural production under Egyptian conditions. To achieve sustainable agriculture, it is imperative to efficiently utilize the limited available water resources to conserve them and enhance productivity. Therefore, there is an urgent need to acquire reliable information regarding the optimal amount of water required to achieve maximum economic returns (Priyan, 2021).

Egypt is currently grappling with escalating water demands due to a rapidly growing population, increased urbanization, higher standards of living, and an agricultural policy emphasizing expanded production to feed the growing populace (Kenawy *et al.*, 2020). Considering its geographical position as a downstream country, Egypt stands poised as a country particularly vulnerable to the ramifications of climatic shifts. Numerous investigations have substantiated the assertion that the Nile, being highly responsive to alterations in temperature and precipitation patterns, renders Egypt exceptionally susceptible to the impacts of climatic changes (Moursy *et al.*, 2023). The flood irrigation system, which currently dominates irrigation practices in Egypt encompassing 60% of the total irrigated area, operates at an efficiency level ranging between 40 and 50%. Consequently, there arises a crucial imperative to amplify the implementation of contemporary irrigation systems as a strategic endeavor to realize the objectives outlined in the Sustainable Development Strategy 2030. This strategy espouses the adoption of an integrated water resources management approach, thereby addressing the need to enhance the efficiency of the irrigation system from its existing range of 40% to a target of 80% (Conway and Hulme, 1996; Wahba *et al.*, 2018).

In the present scenario, the imperative of addressing water scarcity necessitates the adoption of contemporary technologies to augment productivity per unit area. Drip irrigation emerges as a highly efficacious approach wherein water is dispensed in the form of droplets, either singularly or at multiple points, directly onto or beneath the soil surface near the plant's root zone (Rajurkar *et al.*, 2012). This method affords efficient management of both water and fertilizers, thereby engendering several advantageous outcomes. Drip irrigation enhances the unit productivity of water and land, facilitates efficient fertilizer utilization, enables the judicious distribution of nutrients, mitigates plant stress, accelerates the onset of harvests, minimizes yield losses, augments crop quality, and fosters greater uniformity in yield production (Moursy *et al.*, 2023).

Egyptian clover (*Trifolium alexandrinum* L.), a primary forage crop cultivated during the winter season in Egypt, necessitates a consistent supply of easily accessible soil moisture to sustain vigorous growth (Abuzaid *et al.*, 2021). This crop has been introduced as an unconventional forage crop with particular emphasis on the agricultural sector. Its significance lies in its ability to yield high-quality forage throughout the winter and spring seasons (Salama, 2020). Clover demonstrated outstanding adaption and dominance in the Mediterranean regions. Although clover has high yield and protein content, its production in Egypt is hindered by obstacles such as excessive water demands, inadequate dry matter content in the first cut, and high vulnerability to climate change, particularly increasing temperatures due to global warming (Salama, 2015). Mahrous *et al.* (1984) reported that maintaining the available soil moisture depletion between 40% and 60% is crucial for obtaining optimal yields of Egyptian clover.

Most cultivated lands in the Nile Valley and Delta employ surface irrigation systems, which exhibit low efficiency. Consequently, a crucial objective of the Egyptian government is to reduce irrigation, thereby conserving water in older lands through the adoption of appropriate irrigation systems such as drip irrigation and sub-surface drip irrigation. The primary challenge in implementing these systems lies in the limited availability of water and the need for water conservation. Therefore, the objective of this investigation is to optimize water usage for Egyptian clover by implementing a sub-surface drip irrigation system in older lands of the Egyptian Nile Delta. Additionally, the study aims to analyze the influence of various irrigation levels on the green and dry forage yield of Egyptian clover.

Materials and methods

Experimental site

This study was conducted at the experimental farm of Gemiza Research Station, Gharbia, Egypt (30° 79′ 514″ N, 31° 12′ 269″ E). The study spanned across the winter seasons of 2020-2021 and 2021-2022, with the primary objective of examining the water requirements and optimizing water use efficiency in the cultivation of Egyptian clover (*T. alexandrinum* L.) variety Gemiza I (var. Gm1) in the old land of the Nile Delta region under a sub-surface drip irrigation system. The mechanical, physical, and chemical characteristics of the used soil, as well as the chemical analysis of the irrigation water utilized in the study are presented in Table 1 and 2, respectively. The weather data of the experimental site are provided in Table 3.

Experiment setup and treatments

The experimental setup involved the cultivation of Egyptian clover (*Trifolium alexandrinum* L.) cv. Gemiza I. The cultivation dates were October 5th in the first season and October 10th in the second season. A seeding rate of 20 kg/fed was used. Before sowing, the seeds underwent surface sterilization by immersing them in 80% ethanol for five min., followed by rinsing with distilled water. The prepared soil was divided into plots, each measuring 17 meters in length and 1 meter in width (17×1). During the soil plowing process, superphosphate fertilizer was incorporated at a rate of 50 kg/fed in the form of P_2O_5. The seeds were then sown using the dry broadcasting method, specifically in rows measuring 17 m^2. The initial irrigation was carried out through immersion in water to ensure uniform moisture distribution for germination. Subsequently, an irrigation network was established within each row, consisting of a central hose with 34 GR emitters spaced at intervals of 50 cm.

After seven days, during the second irrigation, the plots were divided into subplots using a split-plot design with three replications. The main plots represented four different irrigation levels, namely 40, 60, 80, and 100% of the water requirements, applied using a sub-surface drip irrigation system. The subplots encompassed four different irrigation intervals of 3, 5, 7, and 9 days. All field practices, apart from the experimental manipulation, were conducted following the recommendations provided by the Egyptian Ministry of Agriculture and Land Reclamation for the cultivation of old lands. Fertilization was carried out through fertigation, adhering to the recommended doses of nitrogen and potassium. Nitrogen was applied at a rate of 20 kg/fed in the form of 33.5% NH_3NO_3, while potassium was applied at a rate of 50 kg/fed in the form of K_2O. The initial dose of fertigation was administered ten days after sowing, with subsequent doses provided after the second and third cuttings.

The treatments considered in this study were the irrigation levels and irrigation intervals. The irrigation levels were categorized as follows: A1 represented 40% of the water requirement, A2 represented 60% of the water requirement, A3 represented 80% of the water requirement, and A4 represented 100% of the water requirement. The irrigation intervals were denoted as B1 (3 days), B2 (5 days), B3 (7 days), and B4 (9 days).

Table 1. Physical and chemical analysis of the study soil

		Physical properties		
Depth (cm)	Clay	Silt	Sand	Texture
0-20	52.55	32.88	14.57	Clay
20-40	52.57	35.39	12.04	Clay-loamy
40-60	60.77	27.60	11.63	Clay-loamy
	Field capacity (FC), wilting point (WP), and available water (AW)			
Depth (cm)	FC (%)	WP (%)	AW (%)	
0- 20	38.14	14.63	23.51	
20-40	39.14	14.60	24.54	
40-60	39.63	14.70	24.93	
		Chemical properties		
pH		7.77	Total macronutrients	
EC (dS m^{-1})		1.67	N (%)	0.144
Soluble ions (mmol l^{-1})			P (%)	0.032
Ca^{2+}		6.13	K (%)	0.356
Mg^{2+}		5.32	Available N (mg kg^{-1})	33.42
Na^{+}		7.46	Available P (mg kg^{-1})	10.63
K^{+}		0.23	Available K (mg kg^{-1})	315.72
CO_3^{2-}		0.00	Organic matter (%)	2.50
HCO_3^{-}		3.62	Organic carbon (%)	1.45
Cl^{-}		8.13	C/N ratio	10.07
SO_4^{2-}		7.39		
		Extractable micronutrients (ppm)		
Fe^{2+}		3.83	Zn^{2+}	4.46
Mn^{2+}		3.15	Cu^{2+}	1.53

Table 2. Chemical properties of irrigation water

EC (dS m^{-1})	Soluble cations (mmol/1)				Soluble anions (mmol/1)				SAR
	Ca^{2+}	Mg^{2+}	Na^{-}	K^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	
1.3	5.49	5.58	6.54	0.103	0.88	4.07	5.55	7.80	2.78

SAR = sodium adsorption ratio

Table 3. Weather data of Gemiza Agricultural Research Station, Gemiza, Gharbia, Egypt. Monthly means of October to April (2020-2021 and 2021-2022)

Month	Temperature			RH %	Rin	Eto
	Tmax	Tmin	Average			
October	34.30	20.11	27.20	53.48	0.90	5.32
November	25.65	15.25	20.45	61.09	17.22	3.65
December	23.53	11.51	17.52	60.34	1.13	3.08
January	22.16	9.64	15.9	61.74	8.09	3.15
February	22.35	9.48	15.91	62.68	33.10	3.30
March	23.68	10.15	16.91	59.88	45.81	4.40
April	31.62	12.54	21.9	40.44	0.75	5.00

Tmax = Maximum air temperature (°C), Tmin = Minimum air temperature (°C), RH = Average relative humidity (%), Rin = Average precipitation (mm/monthly), Eto = Reference evapotranspiration (mm/monthly)

The determination of irrigation requirements was based on the following formula:

$$In = \frac{0.623 \times A \times Kc \times ET0}{IE}$$

Whereas, In is the irrigation water volume (m^3); A is the canopy area (m^2); Kc is the crop coefficient; ETo is the weekly potential evapotranspiration; and IE is the irrigation efficiency (Chaichi *et al.* 2015).

The formula used to calculate the reference evapotranspiration (ET0) was as follows:

$$ET0 = \frac{0.408\Delta\,(Rn - G) + \gamma \frac{900}{T+273} u_{2\,(es-ea)}}{\Delta + \gamma(1 + 0.34u_2)}$$

Whereas, ETo represents the reference evapotranspiration (mm day^{-1}), Rn indicates the net radiation at the crop surface (MJ m^{-2} day^{-1}), G represents the soil heat flux density (MJ m^{-2} day^{-1}), T is air temperature at 2m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), $e_s - e_a$ is saturation vapor pressure deficit (kPa), Δ is the slope of the saturation vapor pressure curve (kPa °C^{-1}), and γ is the psychrometric constant (kPa °C^{-1}) (Allen *et al.* 1994).

Throughout the experiment, four cuttings of green fodder were taken at approximately 50-day intervals after planting, with subsequent cuts occurring around 30 days after the previous cut in both seasons. Each cutting involved the selection of a random sample from three replicates to record growth attributes. Additionally, plants covering an area of one square meter were harvested from three replicates of each treatment to calculate yield components/fed.

Evaluation of clover growth attributes and forage yield components

At each cut, ten randomly selected plants were sampled from each plot to measure plant height, stem thickness, leaf count, and various yield components. The parameters assessed included plant height (cm), stem thickness (mm), number of leaves plant^{-1}, weight of green leaves (g), weight of dry leaves (g), weight of green stem (g), weight of dry stem (g), fresh leaf/stem ratio, dry leaf/stem ratio, dry matter (%), fresh forage yield (ton fed^{-1}), and dry forage yield (ton fed^{-1}). To calculate the dry matter components, oven-dried samples were utilized. The samples were subjected to a constant temperature of 70°C until achieving a constant weight.

Water use efficiency (WUE)

Water use efficiency (WUE) represents the amount of biomass produced per unit of water consumed. WUE values (kg m^{-3}) were calculated for both green and dry forage yields in each treatment. The calculation followed the equation proposed by Jensen (1980) as follows:-

$$\text{WUE (kg m}^{-3}\text{)} = \frac{\text{green or dry forage yield (kg fed}^{-1}\text{)}}{\text{sesonal applied water (m}^{3}\text{ fed}^{-1}\text{)}}$$

Water saving

Water saving was calculated for each treatment to quantify the potential water conservation achieved through the implemented treatments. The calculation of water saving involved comparing the recommended water requirements (RWI) with the actual irrigation applied (IR). The water saving (m^3/fed) was determined using the formula:-

Water saving = RWI - IR.

Statistical analysis

The acquired data were subjected to statistical analysis based on the methodology outlined by Snedecor and Cochran (1980). Bartlett's test was employed to assess the homogeneity of error variances. Insignificant results obtained from this test indicated homogeneous variances across all traits. Consequently, a combined analysis was conducted, incorporating all studied traits across both seasons.

Results and discussion

Plant height and stem thickness

The data presented in Table 4 demonstrate that different irrigation rates have a significant impact on plant height and stem thickness in Egyptian clover. The highest values for these parameters were observed when plants were irrigated at a rate of 100% of their water requirements. Specifically, in the first, second, third, and fourth cuts, plant height measurements were 60.52, 69.69, 79.25, and 81.13 cm, respectively, while stem thickness measurements were 3.63, 4.90, 5.31, and 4.83 mm, respectively. The second highest values were recorded with an irrigation rate of 80% of water requirements, with plant height measurements of 52.95, 66.19, 75.43, and 79.48 cm, and stem thickness measurements of 2.77, 3.41, 4.25, and 4.05 mm for the respective cuts. The lowest values for plant height and stem thickness were observed when plants were irrigated at a rate of 40% of water requirements. These findings confirm the results reported by Zeng *et al.* (2009), who found that increased irrigation water levels led to increases in plant height and stem diameter.

Furthermore, the irrigation intervals also significantly influenced plant height and stem thickness in all cuts of Egyptian clover. The 7-day irrigation interval resulted in the highest plant height and stem thickness across all cuts, with measurements of

56.20, 63.84, 66.44, and 78.26 cm for plant height, and 3.41, 4.77, 5.10, and 4.40 mm for stem thickness in the respective cuts. Conversely, the 3-day irrigation interval led to the lowest plant height and stem thickness values. Specifically, plant height measurements were 42.14, 49.55, 56.41, and 64.37 cm, and stem thickness measurements were 0.95, 1.63, 2.20, and 2.40 mm for the respective cuts. These results align with the findings of Lin and Xing (2007).

The results presented in Table 5 elucidate the influence of different irrigation rates on the number of leaves per plant and the dry matter percentage of berseem clover across various cuts. The results indicate highly significant variations among all treatments, except for the comparison between irrigation rates of 60% and 40% of water requirements, regarding their impact on the average dry matter percentage. The irrigation rate of 100% of water requirements yielded the highest values, with an average of 9.94 leaves per plant and a dry matter percentage of 14.25%. This irrigation dosage resulted in 9.87, 9.90, 10.00, and 10.00 leaves per plant in the first, second, third, and fourth cuts, respectively. The irrigation rate of 80% of water requirements ranked second, with an average of 8.87 leaves per plant and a dry matter percentage of 13.02%. Conversely, the lowest values for the number of leaves per plant and total dry matter were obtained with an irrigation rate of 40% of water requirements, resulting in an average of 7.50 leaves per plant and a dry matter percentage of 12.03%.

Table 4. Effect of irrigation rates on plant height (cm) and stem thickness (mm) of berseem clover at different cuts (combined over two seasons)

Treatments	Plant height (cm)				Mean	Stem thickness (mm)				Mean
	1st cut	2nd cut	3rd cut	4th cut		1st cut	2nd cut	3rd cut	4th cut	
Irrigation water requirements (%)										
100	60.52	69.69	79.25	81.13	72.65	3.63	4.90	5.31	4.83	4.67
80	52.95	66.19	75.43	79.48	68.51	2.77	3.41	4.25	4.05	3.62
60	47.67	57.23	64.17	74.26	60.83	1.97	2.62	3.33	3.20	2.78
40	41.35	50.50	61.22	69.56	55.66	0.90	1.70	2.86	2.90	2.09
Mean	50.62	60.90	70.02	76.11	64.41	2.32	3.16	3.94	3.75	3.29
LSD at 5%	4.15	1.92	0.14	1.14	2.24	0.11	1.91	0.045	1.95	0.58
Irrigation intervals (day)										
3	42.14	49.55	56.41	64.37	53.11	0.95	1.63	2.20	2.40	1.79
5	48.16	57.36	60.85	69.21	58.89	2.60	3.22	4.00	3.90	3.43
7	56.20	63.84	66.44	78.26	66.18	3.41	4.77	5.10	4.40	4.42
9	43.23	51.33	55.36	63.25	53.29	1.71	2.21	3.20	3.10	2.55
Mean	47.43	55.52	59.76	68.77	57.86	2.16	2.95	3.62	3.45	3.04
LSD at 5%	2.61	3.70	1.89	0.16	2.27	0.15	0.55	0.43	0.54	0.51

Table 5. Effect of irrigation rates on number of leaves plant^{-1} and dry matter % of berseem clover at different cuts (combined over two seasons)

Treatments	Number of leaves plant^{-1}				Mean	Dry matter (%)				Mean
	1st cut	2nd cut	3rd cut	4th cut		1st cut	2nd cut	3rd cut	4th cut	
Irrigation water requirements (%)										
100	9.87	9.90	10.00	10.00	9.94	9.76	12.81	15.84	18.60	14.25
80	7.67	8.81	9.00	10.00	8.87	8.03	11.24	14.49	18.30	13.02
60	6.17	8.51	8.00	10.00	8.17	7.10	10.21	13.34	18.10	12.19
40	5.17	7.83	8.01	9.00	7.50	7.44	10.06	12.60	18.01	12.03
Mean	7.22	8.76	8.75	9.75	8.62	8.08	11.08	14.07	18.25	12.87
LSD at 5%	0.51	2.24	0.06	1.91	0.33	1.93	1.99	0.046	0.016	0.28
Irrigation intervals (day)										
3	5.60	6.20	7.04	8.02	6.71	7.04	10.02	12.31	18.00	11.84
5	7.70	8.78	9.00	10.01	8.87	8.00	11.20	14.22	18.21	12.90
7	8.80	9.83	10.05	10.03	9.67	9.70	12.50	15.71	18.50	14.10
9	6.30	7.41	8.03	9.00	7.68	7.18	10.16	12.53	18.07	11.89
Mean	7.10	8.05	8.53	9.26	8.23	7.98	10.97	13.69	18.19	12.70
LSD 5%	0.44	2.11	0.04	1.20	0.28	1.60	1.80	0.038	0.013	0.24

Table 6. Effect of irrigation rates on weight of green and dry leaves (g) of berseem clover at different cuts (combined over two seasons)

Treatments	Fresh weight of leaves (g)				Mean	Dry weight of leaves (g)				Mean
	1st cut	2nd cut	3rd cut	4th cut		1st cut	2nd cut	3rd cut	4th cut	
Irrigation water requirements (%)										
100	2.71	2.77	2.86	3.30	2.91	0.51	0.57	0.60	0.99	0.67
80	2.41	2.56	2.70	3.25	2.73	0.47	0.55	0.57	0.94	0.63
60	2.13	2.27	2.41	3.04	2.46	0.43	0.35	0.54	0.81	0.53
40	1.50	2.12	2.35	2.98	2.24	0.35	0.31	0.50	0.72	0.47
Mean	2.19	2.43	2.58	3.15	2.59	0.44	0.45	0.55	0.87	0.58
LSD at 5%	0.82	0.68	0.02	0.013	0.18	0.015	0.016	0.007	0.012	0.011
Irrigation intervals (day)										
3	2.05	2.14	2.28	3.00	2.36	0.41	0.32	0.41	0.77	0.47
5	2.40	2.50	2.62	3.15	2.66	0.45	0.54	0.55	0.80	0.58
7	2.60	2.66	2.77	3.20	2.80	0.49	0.56	0.59	0.93	0.64
9	1.53	2.01	2.22	2.75	2.12	0.34	0.28	0.35	0.70	0.41
Mean	2.14	2.32	2.47	3.02	2.48	0.42	0.42	0.47	0.80	0.53
LSD at 5%	0.72	0.55	0.01	0.011	0.15	0.012	0.014	0.005	0.009	0.008

Table 7. Effect of irrigation rates on the weight of green and dry stem (g) of berseem clover at different cuts (combined over two seasons)

Treatments	Weight of green stem (g)				Mean	Weight of dry stem (g)				Mean
	1st cut	2nd cut	3rd cut	4th cut		1st cut	2nd cut	3rd cut	4th cut	
Irrigation water requirements (%)										
100	9.22	8.45	7.62	7.74	8.26	0.98	0.89	1.00	1.95	1.21
80	8.21	7.77	7.31	7.40	7.67	0.87	0.81	0.95	1.80	1.11
60	6.75	6.17	5.60	6.50	6.26	0.72	0.58	0.89	1.60	0.95
40	4.14	5.93	3.70	5.10	4.72	0.63	0.50	0.77	1.50	0.85
Mean	7.08	7.08	6.06	6.69	6.73	0.80	0.70	0.90	1.72	1.03
LSD at 5%	0.092	0.019	0.025	0.019	0.063	0.015	0.018	0.021	0.001	0.023
Irrigation intervals (day)										
3	5.40	5.10	4.30	5.04	4.96	0.66	0.51	0.81	1.33	0.82
5	8.03	7.50	7.22	7.30	7.51	0.82	0.77	0.92	1.76	1.06
7	9.12	8.34	7.51	7.62	8.14	0.90	0.85	0.97	1.89	1.15
9	4.20	4.03	3.98	4.30	4.12	0.64	0.48	0.79	1.18	0.76
Mean	6.68	6.24	5.75	6.06	6.18	0.75	0.65	0.87	1.54	0.94
LSD at 5%	0.89	0.032	0.022	0.023	1.071	0.011	0.017	0.016	0.001	0.024

Table 8. Effect of irrigation rates on fresh and dry leaves/stem ratio of berseem clover at different cuts (combined over two seasons)

Treatments	Fresh leaves/stem ratio				Mean	Dry leaves/stem ratio				Mean
	1st cut	2nd cut	3rd cut	4th cut		1st cut	2nd cut	3rd cut	4th cut	
Irrigation water requirements (%)										
100	0.54	0.68	0.60	0.52	0.59	0.39	0.38	0.63	0.58	0.50
80	0.60	0.61	0.61	0.50	0.58	0.32	0.38	0.43	0.46	0.40
60	0.56	0.62	0.64	0.48	0.58	0.30	0.32	0.37	0.43	0.36
40	0.51	0.63	0.60	0.50	0.56	0.32	0.32	0.37	0.42	0.36
Mean	0.55	0.64	0.61	0.50	0.58	0.33	0.35	0.45	0.48	0.40
LSD at 5%	0.09	0.03	0.01	0.01	0.01	0.013	0.027	0.015	0.007	0.016
Irrigation intervals (day)										
3 days	0.51	0.62	0.60	0.50	0.55	0.31	0.33	0.43	0.44	0.37
5 days	0.58	0.62	0.62	0.51	0.58	0.32	0.35	0.42	0.43	0.38
7 days	0.55	0.67	0.61	0.53	0.59	0.38	0.37	0.61	0.57	0.48
9 days	0.50	0.57	0.60	0.48	0.53	0.30	0.31	0.36	0.39	0.34
Mean	0.53	0.62	0.60	0.50	0.56	0.32	0.34	0.45	0.45	0.39
LSD at 5%	0.07	0.04	0.02	0.01	0.02	0.011	0.021	0.014	0.008	0.015

Regarding irrigation intervals, significant differences were observed among the investigated intervals. The 7-day interval exhibited the highest values, with an average of 8.80, 9.83, 10.05, and 10.03 leaves per plant in the first, second, third, and fourth cuts, respectively. Similarly, this interval recorded the highest dry matter percentage, averaging 9.7, with a rate of 12.50, 15.71, 18.50, and 14.10% dry matter in the respective cuts. The irrigation interval of 3 days yielded the lowest average number of leaves per plant (6.71) and dry matter percentage (11.84%). These findings align with previous studies conducted by Lin and Xing (2007), Leghari *et al.* (2018), and Khot *et al.* (2012).

Fresh and dry weight of leaves

The data presented in Table 6 demonstrate the influence of varying irrigation rates and intervals on the leaves fresh and dry weight of berseem clover at different cuts. Statistically significant distinctions were observed among all treatment groups. The highest fresh and dry leaf weights were recorded when the irrigation rate corresponded to 100% of the water requirements, with average values of 2.91 and 0.67 g, respectively. This irrigation level resulted in fresh leaf weights of 2.71, 2.77, 2.86, and 3.30 g at the first, second, third, and fourth cuts, respectively. Additionally, dry leaf weights of 0.51, 0.57, 0.60, and 0.99 g were obtained at the corresponding cuts. On the other hand, a decrease in the irrigation level, specifically to 40% of the water requirements, led to a decrease in both fresh and dry weights of berseem clover, with average values of 2.24 and 0.47 g, respectively.

Regarding irrigation intervals, the highest yield was observed when the plants were irrigated every 7 days, resulting in average fresh and dry leaf weights of 2.80 and 0.64 g, respectively. This interval produced fresh leaf weights of 2.60, 2.66, 2.77, and 3.20 g at the first, second, third, and fourth cuts, respectively. Similarly, dry leaf weights of 0.49, 0.56, 0.59, and 0.93 g were obtained at the corresponding cuts. In contrast, the longest interval of 9 days resulted in the lowest fresh and dry leaf weights, averaging 0.34 and 0.41 g, respectively.

Reduced photosynthesis caused by diminished stomatal conductance is often the primary reason for decreased biomass accumulation under water stress (Husen *et al.*, 2014). Additionally, limited photosynthesis due to reduced leaf area contributes to lower fresh and dry weight yields. Under conditions of reduced irrigation, an increase in reactive oxygen species occurs, disrupting the electron transport system and generating oxidative activity in the chloroplasts and mitochondria, consequently reducing the plant's fresh weight (Khorasani *et al.* 2023). Furthermore, water deficit stress leads to reduced soil moisture and uneven nutrient distribution in the soil, resulting in decreased nutrient uptake through roots and hindered nutrient transfer from roots to leaves, ultimately reducing the plant's dry weight.

Stem fresh and dry weights

The tabulated results in Table 7 elucidate the impact of varying irrigation rates and intervals on the fresh and dry weight of berseem clover stems across different cutting stages. Significant statistical differences were observed among all treatment groups. The maximum fresh and dry weights of the stems were observed when the irrigation rate corresponded to 100% of the water requirements, yielding average values of 8.26 and 1.21 g, respectively. At this irrigation level, the fresh weight of the stems measured 9.22, 8.45, 7.62, and 7.74 g in the first, second, third, and fourth cuts, respectively. Correspondingly, the dry weight of the stems recorded 0.98, 0.89, 1.00, and 1.95 g at the respective cutting stages. Conversely, a decrease in the irrigation level to 40% of the water requirements resulted in reduced fresh and dry weights of berseem clover stems, with average values of 4.72 and 0.85 g, respectively.

Regarding irrigation intervals, the highest yield was obtained when the plants were irrigated every 7 days, resulting in average fresh and dry stem weights of 8.14 and 1.15 g, respectively. This interval generated fresh stem weights of 9.12, 8.34, 7.51, and 7.62 g at the first, second, third, and fourth cuts, respectively. Similarly, the dry stem weights recorded were 0.90, 0.85, 0.97, and 1.89 g at the corresponding cutting stages. In contrast, the longest interval of 9 days resulted in the lowest fresh and dry stem weights, averaging 4.12 and 0.79 g, respectively.

Table 9. Effect of irrigation rates on fresh and dry forage yield (ton/fed) of berseem clover at different cuts (combined over two seasons)

Treatments	Fresh forage yield (ton/fed)				Total fresh yield (ton/fed)	Dry forage yield (ton/fed)				Total dry yield (ton/fed)
	1st cut	2nd cut	3rd cut	4th Cut		1st cut	2nd Cut	3rd Cut	4th cut	
Irrigation water requirements (%)										
100	9.92	12.44	12.61	14.40	49.37	0.97	1.59	2.00	2.68	7.24
80	7.72	11.16	10.20	12.45	41.53	0.62	1.25	1.48	2.28	5.63
60	6.32	9.46	8.05	9.90	33.73	0.45	0.97	1.07	1.79	4.28
40	5.21	7.51	7.18	8.94	28.84	0.39	0.76	0.90	1.61	3.66
Mean	7.29	10.14	9.51	11.42	38.37	0.61	1.14	1.36	2.09	5.20
LSD at 5%	0.42	0.50	0.026	0.233	6.341	0.041	0.049	0.006	1.023	0.713
Irrigation intervals (day)										
3	6.70	9.45	8.33	9.82	34.30	0.47	0.97	1.09	0.96	3.49
5	7.20	10.60	10.40	11.85	40.05	0.91	1.53	1.50	1.33	5.27
7	8.50	11.80	12.55	13.42	46.27	1.12	1.32	2.29	2.45	7.18
9	6.20	8.35	7.28	9.35	31.18	0.44	1.10	0.91	0.95	3.40
Mean	7.15	10.05	9.64	11.09	37.95	0.73	1.23	1.44	1.42	4.83
LSD at 5%	0.35	0.39	0.028	0.222	6.238	0.049	0.052	0.061	0.060	0.662

The reduction in fresh and dry biomass accumulation in response to drought stress primarily arise from a decline in leaf biomass due to reductions in leaf area, leaf number, and leaf size (Hessini *et al.*, 2019). Consequently, photosynthetic activities decrease due to the reduced photosynthetic area, stomatal closure, diminished chlorophyll pigment synthesis, and impaired photosynthetic machinery, ultimately leading to decreased biomass accumulation.

Fresh and dry leaves/stem ratios

The present study provides an analysis of the fresh and dry leaf/stem ratio of berseem clover at various cuts, examining the influence of irrigation rates and irrigation intervals. The findings, as summarized in Table 8, demonstrate significant variations among the treatments due to the different water application methods employed. Notably, the application of 100% of the water requirements yielded the highest values, with average fresh and dry leaf/stem ratios of 0.59 and 0.50, respectively. This irrigation regime correspondingly resulted in fresh leaf/stem ratios of 0.54, 0.68, 0.60, and 0.52 for the first, second, third, and fourth cuts, respectively. Similarly, the dry leaf/stem ratios were 0.39, 0.38, 0.58, and 0.58 for the respective cuts. A gradual decrease in the fresh and dry leaf/stem ratios was observed with a reduction in the applied water requirements. The lowest values were recorded when the irrigation rate was set at 40% of the water requirements, with mean fresh and dry leaf/stem ratios of 0.56 and 0.36, respectively.

Regarding the irrigation intervals, the results indicate that a watering interval of 7 days proved to be the most favorable for the fresh leaf/stem ratio and the dry leaf /stem ratio. This interval exhibited mean values of 0.59 and 0.48, respectively. The first, second, third, and fourth cuts under this watering interval demonstrated fresh leaf/stem ratios of 0.55, 0.67, 0.61, and 0.53, while the respective dry leaf/stem ratios were 0.38, 0.37, 0.61, and 0.57. Conversely, a watering interval of 9 days yielded the lowest fresh and dry leaf/stem ratios, with mean values of 0.53 and 0.34, respectively. These findings align with previous studies conducted by Mazher *et al.* (2012) and Sayed and Shaban (2016).

Fresh and dry forage yield

The findings of this investigation demonstrate a significant influence of irrigation rates and intervals on the production of fresh and dry forage yield in berseem across multiple cutting periods. The data presented in Table 9 reveals that the highest yields of fresh and dry forage were achieved when the irrigation rate was set at 100% of the water requirements. The mean values for fresh and dry forage yield under this irrigation regime were recorded as 49.37 and 7.24 ton/fed, respectively. Specifically, the first, second, third, and fourth cuts produced yields of 9.92, 12.44, 12.61, and 14.40 ton/fed for fresh forage, and 0.97, 1.59, 2.00, and 2.68 ton/fed for dry forage, respectively. Conversely, reducing the watering level led to a decrease in both fresh and dry forage yields. The lowest yields were observed when the irrigation dosage was set at 40% of the water requirements, resulting in a mean fresh forage yield of 28.84 ton/fed and a mean dry forage yield of 3.66 ton/fed. These findings highlight the significance of soil water availability in plant growth, as inadequate soil moisture adversely affects physiological processes and subsequently reduces yield and yield components. Zlatev and Lidon (2012) have previously reported that drought-induced stress often hampers growth and photosynthetic carbon assimilation, emphasizing the importance of metabolic flexibility and rapid acclimation to changing environmental conditions as essential adaptations to stress avoidance. Consequently, drought stress conditions ultimately lead to diminished forage yield components and total dry matter.

Regarding the irrigation intervals, statistical analysis revealed significant variations among the various intervals tested (ranging from 3 to 9 days). The highest fresh and dry forage yields were observed with a 7-day irrigation interval, yielding average mean values of 47.27 and 7.18 ton/fed, respectively. Specifically, the 7-day interval resulted in average yields of 8.50, 11.80, 12.55, and 13.42 ton/fed for the first, second, third, and fourth cuts, respectively. Additionally, this interval yielded 1.12, 1.32, 2.29, and 2.45 ton/fed of dry forage for the respective cuts. Conversely, the 3-day irrigation interval produced the lowest fresh and dry forage yields, averaging 34.30 and 3.49 ton/fed, respectively. Afsharmanesh (2009) has previously reported the significant impact of water deficit stress on the fresh and dry forage yield of alfalfa, whereby an increase in drought stress intensity leads to reduced yields. These findings align with the outcomes of the present study.

Water use efficiency (WUE)

The results presented in Table 10 demonstrated that among the different irrigation levels tested, an irrigation rate of 80% of the water requirements exhibited the highest water use efficiency (WUE) value, which was recorded as 24.4 kg m^{-3}. This superior WUE value may be attributed to the relatively lower amount of applied irrigation water, approximately 1700 m3/fad. Conversely, the irrigation levels of 100% and 40% of the irrigation water requirements resulted in lower WUE values, measuring 22.4 kg/m^3 and 21.4 kg/m^3, respectively. These findings align with the research conducted by Lazaridou and Koutroubas (2004), who reported that an irrigation rate of 80% of the water requirements led to higher water use efficiency for berseem clover. Additionally, the reduced WUE observed at lower irrigation rates could be attributed to frequent defoliation, which may result in increased water loss through evaporation when the canopy is frequently exposed and limited duration of maximum growth. These results suggest that the yield of clover is more susceptible to deficit irrigation due to its inefficient water use efficiency. Consequently, implementing deficit irrigation practices will generally result in a decrease in WUE, particularly if the deficit is severe (Neal *et al.*, 2011).

Total irrigation water requirements

The present study provides a comprehensive analysis of the irrigation water requirements for Egyptian clover across various treatments, as indicated in Table 11. The findings pertaining to the irrigation system demonstrate that the sub-surface irrigation method necessitates less water compared to the recommended requirements for clover cultivation. Specifically, the implementation of the sub-surface irrigation system resulted in a notable reduction of 52.3% in total irrigation water requirement compared to the system based on recommended water requirements, with a 100% water regime and an irrigation interval of 7 days.

Regarding water regimes, the results obtained underscore the significant role they play in influencing the total irrigation water requirements. A rise in the water regime from 40% to 100% led to an increase in the total irrigation water requirements from 1296 to 2200 (m^3/fed) under a 7-day irrigation interval. Additionally, the months of October and November exhibited the lowest water consumption, amounting to 240 m^3/fed/M, while the month of April recorded the highest water consumption at 400 m^3/fed/M. These findings align with the conclusions drawn by Farsiani *et al.* (2011) and Leghari *et al.* (2018).

Table 10. Water use efficiency (WUE, kg m^{-3}) as affected by irrigation rates of berseem clover (combined over two seasons)

Irrigation rates (%)	Total fresh forage yield (ton fed^{-1})	Total irrigation water requirements (m^3 fed^{-1})	WUE (kg m^{-3})
100	49.37	2200	22.4
80	41.53	1700	24.4
60	33.73	1450	23.2
40	27.84	1296	21.4

Table 11. Irrigation requirement of Egyptian clover (m^3/fed/M) under the sub-surface irrigation system in old lands (combined over two seasons

Month	ETO (mm/day)	Kc	ETC (mm/day)	IR (m^3/fad/M)
October	4.45	0.44	2.006	240
November	2.81	0.80	2.24	240
December	2.30	0.95	2.20	270
January	2.63	0.95	2.53	300
February	3.46	0.95	3.33	350
March	4.63	0.93	4.36	400
April	6.20	0.57	3.59	400
Total				2200

ETO evapotranspiration; Kc crop constant; IR irrigation requirements; M = month

Table 12. The water saving of Egyptian clover under a sub-surface irrigation system (m^3/fed) as compared to the recommended water requirements

Irrigation system	Total irrigation water requirements (m^3/fed)	Water saving (m^3/fed)
Recommended water requirement	4200	2000
Sub-surface irrigation system	2200	

Water saving

The data presented in Table 12 illustrates the extent of water conservation achieved through various experimental treatments in comparison to the recommended water requirement of 4200 m^3/fed. The findings indicate that all sub-irrigation methods successfully reduced irrigation water requirements from 4200 m^3/fed to an average of 2000 m^3/fed. Consequently, the implemented sub-irrigation system resulted in saving the irrigation water requirement by 2000 m^3/fed. Furthermore, the outcomes revealed that the sub-surface irrigation system with a 40% water regime exhibited the highest level of water conservation when compared to the recommended water requirement. These findings align with the previous research conducted by Umair *et al.* (2019) and Besharat *et al.* (2020).

Conclusion

Implementing practical approaches to enhance forage yield and optimize the efficient utilization of limited irrigation water resources in old land areas holds the potential to bolster the sustainability of feed production in these regions. This study focused on the application of deficit irrigation techniques, based on the weekly water requirements of berseem clover, in response to the prevailing environmental conditions facing old land regions. As the severity of water limitation intensified, the growth and yield parameters of berseem clover exhibited a decline. However, optimal moisture balance within the plants at irrigation levels of 100% and 80% facilitated improved vegetative growth and yield parameters in berseem clover. This balance created favorable conditions for nutrient uptake, photosynthesis, and metabolite translocation. Furthermore, the increased availability of water and nutrients accelerated the rate of vegetative growth. Overall, the combination of Egyptian clover cv. Gemiza I with an irrigation level of 80% demonstrated the most favorable outcomes for Egyptian clover production, with a focus on maximizing water use efficiency (WUE) in this study. Notably, the adoption of an 80% irrigation level outperformed the 100% irrigation level when irrigation water availability was limited. Additionally, the sub-surface irrigation system with a 40% water regime yielded the highest water conservation value compared to the recommended water requirement.

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