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Influence of Water Stress on Water Use Efficiency and Dry-Hay Production of Alfalfa in Al-Ahsa, Saudi Arabia

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Abstract: The main objective of this study was to study the performance of alfalfa under water stress conditions and determine water use efficiency (WUE) for optimal forage production under the arid climatic conditions of Al-Ahsa having limited irrigation water supplies. Plant growth parameters of alfalfa were significantly affected by different irrigation treatments. Mean alfalfa dry forage (hay) yield ranged between 2.21-5.33 MG ha^{-1} in different irrigation treatments. The WUE was higher in T_1 (irrigation at field capacity soil moisture level) than other water stress treatments. It was noticed that alfalfa dry forage yield was severely affected by irrigation stress. In conclusion, the WUE of alfalfa crop was highest in T_1 (irrigation at field capacity level of soil moisture) than other irrigation treatments. The study provided an excellent opportunity for scheduling irrigation of alfalfa crop for optimal dry-forage production under arid climatic conditions of Al-Ahsa, Saudi Arabia.

Key words: Irrigation scheduling, alfalfa, water deficit, soil field capacity, dry-forage yield, water use efficiency

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is an important forage crop in the Kingdom of Saudi Arabia for the success of dairy industry. It accounts for about 30% of the total crop production. Among the various factors limiting crop growth, water stress plays an important role in alfalfa hay production. Because its growth is highly sensitive to water stress conditions especially under arid environments. In the Kingdom of Saudi Arabia, groundwater is the main source of irrigation water which in limited and non-renewable. Therefore, adoption of improved water conservation measures is necessary for increasing land productivity. Normally, irrigation scheduling is based on either direct measurements or indirect calculations of evaporation losses. The direct measurements involve either water balance techniques using hypsometers (Norman, 1974) plot and catchment studies (Dunne and Leopold, 1978) or monitoring soil water (Merriam, 1960; Bauder and Lundstrom, 1977; Gear *et al*., 1977). Indirect methods include the use of various plant characteristics as indicators of water stress and/or formulae to calculate potential consumptive use of water by different crops using physical weather parameters. Singh and Tiwari (1987) stated that the Stress Day Index Method with 50% depletion of available soil moisture was statistically superior and had the maximum water use efficiency. Ageeb *et al*. (1989) reported that irrigation to Faba bean at 7-days intervals increased seed yield and number of plants m^{-2}, while the number of pods/plant and the 100-seed weight were decreased. Koto *et al*. (1992) conducted three experiments to determine the effects of irrigation amount, irrigation frequency and plant cover on soil temperature and plant growth. They showed that frequent irrigation reduced soil temperature in hot season and increased annual yield of alfalfa by 10% whereas the reduction in soil temperature was not remarkable in cool season. Saeed and El-Nadi (1997) stated that maximum yields for six harvests of alfalfa were 15.3, 12.9 and 11.2 Mg ha^{-1} and WUE values were 0.12, 0.10

and 0.08 Mg ha^{-1} cm^{-1} for the frequent, less-frequent and infrequent irrigation regimes, respectively. It was concluded that alfalfa grown under semiarid conditions should be watered lightly and frequently to attain high yields and high WUE. Karimi *et al*. (1983) reported that the WUE of alfalfa was higher in deeply irrigated treatments than in shallow irrigated treatments. Also, the rate of root growth was increased in non-irrigated alfalfa as a result of limited water stress.

Recently, Lazaridou and Koutroubas (2004) studied the effect of drought on plant water use efficiency at various phonological stages of berseem clover (*Trifollium alexandrinum* L.) and Alfalfa (Mitochis and Orphanos, 1981; Lazaridou and Noitsakis, 2003). This resulted in a reduction of the above ground biomass to one third of irrigated plants (2.3 vs 6.8 g plant^{-1}). Berseem clover is an annual legume crop and is well adopted to various environments but its yield is related to irrigation (El-Bably, 2002). Also, the efficient water use by the plants plays a predominant role particularly in the areas where the water is limiting factor of production. In addition, the WUE could be used as selection criterion, to improve yield in a dry environment (Tardieu, 1997). More recently, Shock *et al*. (2007) investigated the effects of deficit irrigation for optimum alfalfa seed yield and quality. They concluded that seed weight increased with increasing ET_c replacement level, but the largest increase occurred from 20-60% ET_c. With an ET_c replacement of 50%, the seed yield was maximum. They further suggested that alfalfa seed production can be optimized with 50% ET_c replacement using drip irrigation.

Information on the effect of water stress on alfalfa fresh or dry-hay production is limited under local climatic conditions. It is, therefore, imperative to study the response of alfalfa as forage crop under water stress irrigation regimes in an arid environment where irrigation water is in short supply and the mean annual rainfall is very low. The main objective of this research was to investigate the influence of water stress on water use efficiency and dry-hay production of alfalfa in Al-Ahsa, Saudi Arabia.

MATERIALS AND METHODS

The experiment was carried out at Agricultural and Veterinary Training and Experimental Station, King Faisal University, Al-Ahsa. The experimental station is situated about 20 km West of Hofuf town on Main Hofuf-Qatar Highway.

Experimental Treatments

The experimental treatments include one crop (alfalfa), four irrigation treatments [application of water at field capacity, T_1 (control treatment), 15% (T_2), 30% (T_3) and 45% (T_4) soil moisture depletion at field capacity to apply water stress to plants] and one type (loamy-sand) of soil. The treatments were replicated three times. The alfalfa crop was planted during the summer cropping season in 2002. The experimental area was divided into 24 plots and the water stress treatments were allotted randomly. The dimension of each experimental plot was 6×6 m. A border strip of 4 m was maintained between plots to minimize the interference and effect of horizontal irrigation water flow movement. The experimental layout is presented in Fig. 1.

Cultural Practices

A fine seed bed was prepared by sub-soiling the soil up to a depth of 60 cm which was followed by plowing the top 30 cm soil layer. Then farm-yard-manure was added at the rate of 50 Mg ha^{-1}, then mixed in the top 15 cm soil and followed by leveling the soil. Later on, the experimental field was divided into the desired number of plots.

Alfalfa crop was sown manually in rows using seed rate of 60.0 kg ha^{-1} on April 8, 2002. The row to row distance was 20 cm. Thirty five kilograms triple super phosphate (45% P_2O_5) was added at the time of seedbed preparation. Nitrogen was added at the rate of 150 kg N ha^{-1} in the form of urea

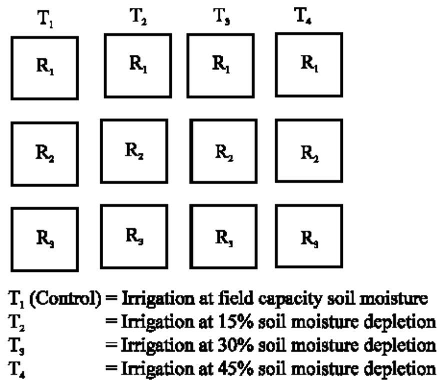

Fig. 1: Layout of experimental irrigation system

Table 1: Physical and chemical properties of experimental soils

Depth (cm)	Mechanical analysis Sand (%)	Silt (%)	Clay (%)	Soil texture	SP (%)	FC (%)	PWP (%)	AWC (%)	Bulk density (g cm^{-3})	$CaCO_3$ (%)
0-30	81.76	16.00	2.24	Loamy sand	30.0	14.1	7.03	7.07	1.60	8.81
30-100	80.58	15.18	4.24	Loamy sand	37.5	17.3	8.50	8.80	1.56	12.13

Table 2: Upper and lower limits of soil moisture and the available water capacity of experimental soils

	FC			PWP			AWC		
Depth (cm)	Weight (%)	Volume (%)	As irrigation depth (mm)	Weight (%)	Volume (%)	As irrigation depth (mm)	Weight (%)	Volume (%)	As irrigation depth (mm)
0-30	14.1	22.56	225.6	7.03	11.248	112.48	7.07	11.312	113.12
30-100	17.3	26.98	269.9	8.50	13.260	132.60	8.80	13.728	137.30

Table 3: Allowable moisture deficit (AMD) (mm)

T_1	T_2	T_3	T_4
----	18.78	37.56	56.34

in four equal split applications i.e., after planting and then after each cut. The alfalfa crop was harvested only three times i.e., first on June 1, 2002, second cutting on July 10, 2002 and the third cutting was taken on August 20, 2002.

Soil Analysis

Soil samples were taken randomly from 0-30 cm (surface soil depth) and 30-100 cm soil depth (sub-surface soil depth) from two different locations in the experimental plots. The soil samples were analyzed mechanically by following the procedure as described by Jackson (1973) and chemically by following the methods described in USDA Handbook No. 60 (1954). The physical and chemical analysis of experimental soil are presented in Table 1.

The soil moisture upper limits, lower limits and the total available soil water capacity is presented in Table 2. The moisture allowable deficit of the soil is given in Table 3.

In situ soil moisture contents in the root zone were measured by a Neutron Moisture Probe 3300 series before and after each irrigation followed by the subsequent measurements 2-3 days after each irrigation. The moisture probe was calibrated by following methods as described by Eeles (1969) and Bell (1973, 1976).

Leaching Requirements (LR)

Leaching requirement was considered to predict the proper amount of water to be applied each time during irrigation. The EC of the irrigation water was 1.77 dS m^{-1} and the electrical conductivity of soil saturation paste extract (ECe) was 4.17 dS m^{-1}), which is associated with a negligible degree of salinity problem. The leaching requirement, for the site under sprinkle irrigation, came to 0.1 using the following equation:

$$LR = \frac{EC_w}{5EC_e - EC_w} \times \frac{1}{LE}$$

Where:

EC_w = Electrical conductivity of irrigation water (dS m^{-1})
EC_e = Electrical conductivity of the soil saturation extract
LE = Leaching efficiency assumed to be 90% for loamy sand soil

Irrigation System

Fully automated solid set sprinkler irrigation system was installed to achieve high irrigation application efficiency. The irrigation system supplied water to each experimental plot through PVC laterals of 5 cm diameter having 30 m length which is fitted with 3 impact sprinklers assigned for each one plot. The laterals were connected to a sub-main pipe, which was connected to the main water supply line. The index used to evaluate the system was Christiansen's coefficient of uniformity (cu). This index shows how uniformly nozzles distribute water over the irrigated area. In general, the irrigation efficiency of sprinkle system is 70% under Saudi Arabia conditions (Al-Zeid *et al*., 1988). The evaluation test was made prior to the growing season to eliminate the influence of crop to the falling drops in the cans. The test was carried out in the early morning to minimize the effect of evaporation. The cu value for this system came to 98.1%. This means that the water was evenly distributed in the whole area. The uniformity of the water distribution from the permanent sprinkle irrigation system was tested in the field site.

Gross Irrigation Requirements (GIR)

The net depth of irrigation water applied included the losses due to the system efficiency and the additional water required for leaching requirements. The following equation was sed to calculate the Gross Irrigation Requirement (GIR) per unit area for the whole growing season:

$$GIR = \left(\frac{MAD}{\eta} \times \frac{1}{1 - LR}\right) - R_{eff}$$

Where:

MAD = Moisture allowable deficit (mm)
η = Efficiency of irrigation method, 0.7
LR = Leaching requirement.
R_{eff} = Effective rainfall $\geq$ 5 mm

The GIR for the three water treatments is given in Table 4.

Table 4: The gross irrigation requirement (GIR) in mm depth

T_1	T_3	T_4
29.81	59.62	89.43

In order to initiate irrigation, the soil water contents were compared with the irrigation depth at field capacity which was 248 mm (Table 2). If the soil water content is less than 248 mm by 18.78, 37.56 and 56.34 mm for 15, 30 and 45% soil moisture depletion treatments, respectively; then water must be added to refill the soil reservoir to the field capacity level (248 mm).

Water Use Efficiency(WUE)

Water use efficiency is defined as the yield obtained per unit of water applied to the crop. Hence, the WUE was calculated based on the total amount of water applied and the total fresh weight of crop as follows:

$$\text{Water use efficiency (WUE)} = \text{Total Yield (kg ha}^{-1}\text{)/Total water applied (mm)}$$

Crop Measurements

Crop growth measurements include plant height, fresh weight of leaves and stems, dry weight of leaves and stem and fresh weight yield. A total of four cuttings of alfalfa were taken, the first was taken 47 days after sowing, the second 40 days after the first cutting, the third 41 days after the second cutting and the last cutting 42 days after the third cutting. The experimental data were subjected to appropriate statistical analysis and the treatment means were compared using Duncan (1955) multiple range test, as mentioned by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Alfalfa

The ranges for different mean fresh plant growth parameters were: 22.9-46.8 cm (height), 200.6-487.2 g m^{-2} (leaves), 287.3-598.7 g m^{-2}(stems) and 4.88-10.79 Mg ha^{-1}(forage yield) in different water stress treatments (Fig. 2a-d). Similarly, the mean ranges for different plant growth parameters on dry-weight basis were 90.5-2333.6 g m^{-2} (leaves), 130.2-299.5 g m^{-2} (stem) and 2.21-5.33 Mg ha^{-1} (dry-hay) in different irrigation water treatments (Table 5). All the plant growth parameters decreased significantly with increasing water stress application to plants i.e., irrigation application at soil moisture less than the soil field capacity level. On relative basis, the decrease was 25, 48 and 61% in dry weight of leaves; 26, 36 and 56% in dry weight of stems and 26, 41 and 59% in dry forage yield in T_2, T_3 and T_4 irrigation treatments , respectively as compared to the control treatment (irrigation at field capacity soil moisture level). The study findings were comparable to those obtained by Saeed and El-Nadi (1997) who stated that maximum yields for six harvests of alfalfa were 15.3, 12.9 and 11.2 Mg ha^{-1} and the WUE values were 0.12, 0.10 and 0.08 Mg ha^{-1} cm^{-1} for the frequent, less-frequent and infrequent irrigation regimes, respectively. They also concluded that alfalfa crop when grown under semiarid conditions should be irrigated watered in small increments and frequently to attain high yields and high WUE. The results were comparable with the findings of (Lazaridou and Noitsakis, 2003) who reported a reduction in the above ground biomass to one third of irrigated plants (2.3 vs 6.8 g $plant^{-1}$).

Table 5: Effect of irrigation treatments on dry weight of leaves, dry weight of stems and dry forage (hay) yield of alfalfa crop during the summer season of 2002

Irrigation treatments	Dry weight of leaves (g m^{-2})	Dry weight of stems (g m^{-2})	Dry forage yield (t ha^{-1})
T_1	233.6^{a}	299.5^{a}	5.33^{a}
T_2	174.5^{b} (25)	221.2^{b} (26)	3.96^{b} (26)
T_3	120.5^{c} (48)	191.2^{c} (36)	3.12^{c} (41)
T_4	90.5^{d} (61)	130.2^{d} (56)	2.21^{d} (59)
F-test	**	**	**

The values in column followed by the same letter(s) are not significantly different by LSD at 5% level of significance

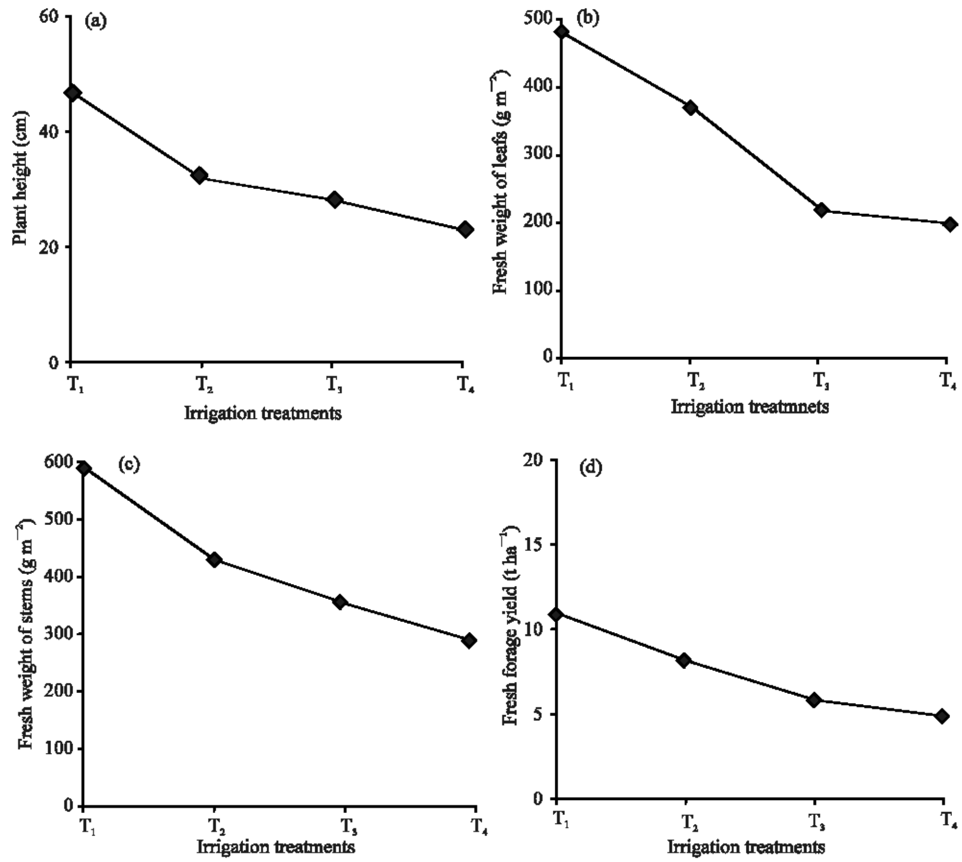

Fig. 2: Effect of different water stress treatments on plant height (cm), fresh weight of leaves (g m^{-2}), fresh weight of stems (g m^{-2}) and fresh weight of yield (g m^{-2}) of Alfalfa crop

Table 6: Effect of irrigation treatments on total quantity of water applied and the water use efficiency (WUE) of alfalfa crop

	Alfalfa	
	Summer 2002	
Irrigation treatments	Total quantity of water applied* (mm)	WUE (kg m^{-3})
T_1	1221.0	0.88
T_2	1187.0	0.68
T_3	1148.7	0.50
T_4	1140.9	0.51

*: Quantity of total irrigation water applied is the irrigation water plus 38.1 and 38.6 mm (Rainfall in the first and 2nd season, respectively)

Water Use Efficiency (WUE)

Mean water use efficiency (WUE) of alfalfa crop ranged from 0.51-0.88 kg m^{-3}. The WUE was affected significantly by the different irrigation treatments and the difference in WUE among the different irrigation treatments was significant (Table 6). The WUE was higher in T_1 followed by T_2, T_3 and T_4 treatments in descending order, respectively. The total amount of irrigation water applied to alfalfa crop ranged between 1140.9-1221.0 mm in different irrigation treatments. The study results don not agree with those of Singh and Tiwari (1987) who stated that the Stress Day Index Method with 50% depletion of available soil moisture was statistically superior and had the maximum water use efficiency.

Overall, the results indicate that proper scheduling of irrigation to alfalfa, a perennial forage crop, required more experimentation to achieve conclusive results for obtaining higher WUE under extreme arid climatic conditions where Pan-evaporation is extremely high.

CONCLUSIONS

Plant growth parameters of alfalfa crop were significantly affected by the different irrigation treatments. Mean alfalfa dry forage (hay) yield ranged from 2.21-5.33 Mg ha^{-1} in different irrigation treatments. The WUE was higher in T_1 (irrigation at field capacity soil moisture level) than other treatments. This showed that alfalfa dry forage (hay) yield could be was severely affected under water stress irrigation management. In conclusion, the study provided useful information as guidelines for scheduling irrigation of alfalfa crop and planning future studies for obtaining higher water use efficiency of forage crops under arid environmental conditions.

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