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RESEARCH ARTICLE

SOIL WATER UPTAKE EFFICIENCY OF SOME IRRIGATED INDIGENOUS AND EXOTIC FORAGE SPECIES UNDER GCC DESERT CLIMATIC CONDITIONS

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ABSTRACT

The desert environment of the Gulf countries is characterized by high temperatures and limited water resources. Agriculture is by far the largest water user; most of it is used for production of fodder crops. Exotic fodder species, especially Rhodes grass (*Chloris gayana*) is the dominant forage plant grown. This species is poorly adapted to the harsh environment and consumes substantial amounts of water. This study was designed to compare indigenous forage species to Rhodes grass with regard to their ability to utilize water from deep soil layers. Four indigenous forage species were tested; these were *Cenchrus cilliaris, Panicum turgidum, Lassiurus scindicus* and *Coelachyrum piercie* together with Rhodes grass in a randomized design with 3 replications. The irrigation regimes tested were; application of the full crop requirement; 50% above and 50% below crop requirement. Water extraction was monitored daily in two soil layers (0-30 and 30-60 cm) using Time Domain Refractrometry (TDR). Result indicated that, except under *Cenchrus cilia*ris, residual soil moisture was high in the subsoil layer indicating poor extraction of water from this layer under limited water conditions. *Cenchrus ciliaris* however, was significantly different in extracting subsoil moisture, indicating high adaptation to water deficit conditions. There were small differences in water extraction mode when irrigation water is not limited. This study recommended the expansion in indigenous forage species especially *Cenchrus ciliaris* at the expense of the exotic species under current water resources of the Gulf region.

INTRODUCTION

The Gulf Cooperation Council (GCC) countries are located in a desert region, which is characterized by high temperatures, high evaporation rates and low and erratic rainfall. Irrigated agriculture is by far the largest water user with around 78% on average of the total water use in all GCC countries (World Bank, 2005). Most agricultural water (85%) is groundwater, which is largely non-renewable (Bazza, 2005). The amount of abstraction of ground water is by far greater than the recharge and aquifer levels are rapidly declining and ground water is increasing in salinity by intrusion of sea water (World Bank, 2005). There is a sharp decline in availability of underground water to be used for irrigation in the GCC region. The dairy industry in the Gulf region uses more than half the irrigation water, mainly for growing pasture. The native plant biodiversity of the GCC region which comprises over 3500 species (Ghazanfar and Fisher, 1998) is being rapidly depleted, mainly due to rapid increase in the livestock population.

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In order to compensate for the shortfall of forage, exotic species, mainly Rhodes grass (Chloris gayana) is being grown. This exotic species is poorly adapted to the harsh environment in GCC region since it requires large quantities of water (Peacock et al., 2000). Cenchrus ciliaris, a forage species indigenous to GCC region (Osman et al., 2008) is currently being cultivated as a fodder crop in parts of Australia, India and Pakistan. While some indigenous grazing plants are known for their ability to survive under drought conditions, no quantification of their water requirement was done yet (Peacock et al., 2000). Plants adapt to water limited environment by reducing evapotranspiration and exploring deep soil layers in search for water (Bohnert et al. 1995; Bray, 1997). Ability of plants to extract water from deep soil layers is considered an advantage in water limited environments (Levitt, 1980). The aim of this study was to compare soil water depletion from different soil layers by some indigenous forage species to an exotic widely grown species under the conditions of GCC region. The hypothesis is that plants indigenous to local environment in the GCC region have higher capability to extract water from deep soils than the exotic species.

MATERIALS AND METHODS

Forage crops used in this study

Four indigenous forage species viz., *Cenchrus ciliaris*, *Panicum turgidum*, *Lasiurus scindicus* and *Coelachyrum piercei* and one exotic widely grown forage species namely Rhodes grass (*Chloris gayana*) as control were used. The experiment was conducted at Al Dheid experimental station (Eastern United Arab Emirates UAE) during the year 2002.

Soils and water sampling and analyses

Four soil profiles 60 cm deep were dug within the experimental site for the determination of soil physical properties. Undisturbed soil samples in duplicates were collected from soil depths at which soil moisture changes are being monitored (i.e. 0-30 and 30-60 cm) for the determination of bulk density. Disturbed soil samples were also collected at these depths for laboratory measurements of electrical conductivity of saturated soil pastes (EC), pH, gravel content, soil texture and $CaCO_3$ contents. Water retention characteristics for these soil samples were also measured in the laboratory at the following tensions (0.1, 0.3, 0.5, 1.0, 2.0, 3.0, 5.0 and 15 bar) using pressure plate apparatus. Water sample at the source output was collected from and analyzed for EC and pH.

Experimental details

After establishment, grasses were cut down to the same height (10-cm). This has marked the beginning of the experiment. Thereafter, plots were irrigated with well water using drip irrigation system according to the water treatments shown below and harvested at intervals of 4-6 weeks to ground level. Three water application rates were used. The water application rate for the control treatment (T1) was designed to satisfy the full crop requirement based on the maximum evaporation losses expected under no restriction condition (i.e. potential evapotranspiration PET). The latter was estimated based on Penman-Monteith equation for estimating the reference evapotranspiration (ET_0) as formulated by FAO program (CropWat 4 windows 4.3) using long-term climatic data from a weather station located in Al Dheid farm (less than 100 m from the experimental site). The potential evapotranspiration (PET) for each month of the year was then computed assuming a monthly average crop factor (Kc) value of 1 and considering irrigation efficiency of 95% for the drip system. Two more treatments (T2 and T3) indicate application of irrigation water equivalent to 50% above and 50% below the control level, respectively, in order to study the impact of surplus irrigation (as currently practiced by most farmers in the region) and deficit irrigation on crop water use. Daily water application rate for each treatment during the various months of the year is shown in Figure 1.

Since the automated operation system for irrigation could only be adjusted to a lowest duration of 1 minute, some differences between the actual water application rates and the calculated ET were inevitable. Soil moisture was monitored on daily basis immediately before irrigation using Time Domain Reflectrometery TDR instrument (TDR, Trase System I, Soil Moisture

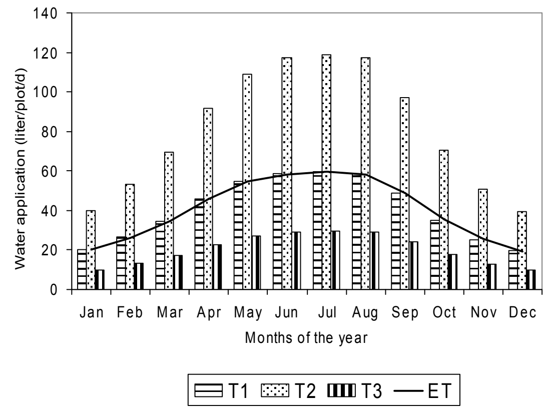

Figure 1: Daily water application rate for different treatments

Equipment Corp., USA) which measures volumetric soil water content. No calibration for the instrument was needed as per the operational manual as long as the same probe that is provided with the instrument is being used. The experimental design used was a completely randomized split plot design with 3 replications, where the three irrigation levels occupy the main plots and the five grass species occupy the subplots. Each species occupies a plot size of 2.5 x 2.5 m in each main plot treatment.

RESULTS AND DISCUSSION

Soils of the Arabian Peninsula

The soils of the Arabian Peninsula (i.e. GCC region and the Yemen) reflect the aridity of the climate. Most are poorly developed, shallow, or are enriched in lime, gypsum, or salts. In addition, transported materials, such as sand dunes and sheets, cover large areas. The soils are mostly formed by the physical breakdown of geological materials and their subsequent removal, sorting and deposition by wind and water (Eddy de Pauw. 1998).

Description of main soil features

Soils are generally course in texture dominated by sand soil particles comprising 80-95% of the soil materials. Gravel content of soil matrix is considerably high in both soil layers but more gravelly in the subsoil layers. Soils are generally non saline, EC not exceeding 4 dS/m. Soils are alkaline in reaction (pH 8.7 to 9.2). Distribution of $CaCO_3$ is homogenous within each of the two soil sampling depths. This was around 22% for the topsoil and 10% for the subsoil. Table 1 presents the general soil characteristics of the experimental site. The irrigation water used in the study has EC of 1.67 dS/m and pH of 8.5.

Soil moisture characteristics

Data on volumetric soil water capacity for both soil layers are shown in Table 1. Field capacity was evaluated at 0.1 bar tension as recommended by Hanson and Orloff (1998) whereas wilting point WP was measured at 15 bar tension. For topsoil, the average value for FC was around 15.90% and this was reduced to 11.53% in subsoil. As for WP, the average values for topsoil and subsoil were 5.88% and 6.63%, respectively. The soil in the top layer has around 50% higher available water capacity values than the soil in sub-layer. These values are 10.02% and 4.91% for topsoil and subsoil, respectively. This might be

Table 1. Soil characteristics of the study area.

Soil Profile No.	Soil Depth (cm)	Soil Texture	Gravel (%)	EC dS/m	pH	$CaCO_3$ (%)	Bulk Density (g/cm^3)	Field Capacity (%)	Wilting Point (%)	Available water (%)
1	0-30	Loamy sand	32	2.18	8.9	23.00	1.43	15.16	5.58	9.58
	30-60	Sand	47	2.31	9.2	8.33	1.59	11.24	6.41	4.82
2	0-30	Loamy sand	27	1.61	8.9	23.67	1.47	15.58	5.68	9.90
	30-60	Sand	47	1.74	8.9	12.67	1.57	12.35	6.80	5.55
3	0-30	Sand	33	3.42	8.7	23.00	1.54	16.94	6.42	10.52
	30-60	Sand	42	3.28	8.9	9.33	1.62	9.45	6.48	2.97
4	0-30	Sand	25	1.64	9.0	21.67	1.54	15.91	5.85	10.06
	30-60	Sand	46	2.05	9.1	11.33	1.65	13.09	6.82	6.27

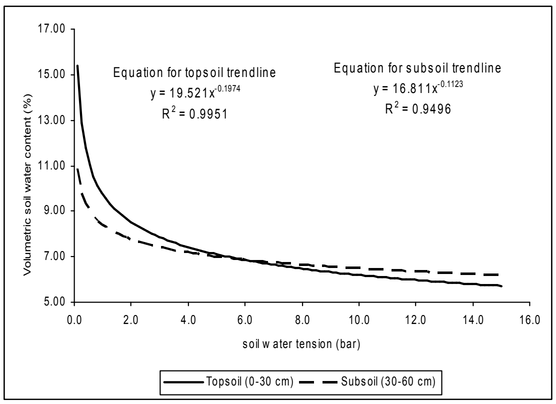

Fig. 2. Volumetric soil water contents for different water application treatments and forage species.

attributed to higher bulk density in the sub-soil layer. Because soil texture is dominated by course soil fraction, the available soil water contents are generally low in both soil layers. The soil moisture release curve which relates soil water potential to soil water content indicates that the sandy soils of the experimental site released most of its available water at low soil water potential (Figure 2). The high correlation coefficient values of above 0.94 imply strong correlation between soil moisture content and soil water tension for both soil layers.

Field soil water measurements

Table 2 presents TDR records of the volumetric soil water contents measured prior to each irrigation event for both soil layers [i.e. topsoil (0-30) cm and subsoil (30-60) cm]. Generally speaking, soil water contents for subsoil are lower than topsoil. This is attributed to the apparent differences in the available soil water capacity between the two soil layers as shown earlier. Table 2 shows that under sufficient water application (T1) and surplus water condition (T2), there is no apparent differences in the average soil water contents for all crop species due to the fact that the water requirement is fully satisfied under both treatments. Nevertheless, the exotic forage species Rhodes grass (*Chloris gayana*) extracted more water than all other species except *Lasiurus scindicus* under T1 and *(Panicum tugidum*) under T2 water treatments. Under stress water conditions (T3), however, significant differences in soil water contents can be denoted when comparing T3 with T1 and even more obviously with T2 treatment. Under stress conditions, *Cenchrus ciliaris* showed maximum ability to extract water from both soil layers but more obviously from subsoil layer where extraction was significantly different from all other

Table 2: Residual soil water contents before irrigation for different water application treatments and forage species.

Treatments	Forage species	Volumetric soil water content prior to irrigation (%)		
		Top soil	Sub soil	Average
T1	CP	18.4 ^{abc}	13.9 ^{a}	16.2 ^{ab}
	CG	16.0 ^{bcd}	10.5 $^{a-d}$	13.3 ^{cd}
	CC	19.1 ^{ab}	10.3 $^{a-d}$	14.7 ^{abc}
	PT	19.8 ^{a}	11.5 $^{a-d}$	15.3 ^{abc}
	LS	15.9 ^{bcd}	10.0 ^{bcd}	13.0 ^{cd}
T2	CP	21.3 ^{a}	12.1 $^{a-d}$	16.7 ^{a}
	CG	20.3 ^{a}	10.5 $^{a-d}$	15.4 ^{abc}
	CC	20.0 ^{a}	11.4 $^{a-d}$	15.7 ^{abc}
	PT	19.6 ^{ab}	10.6 $^{a-d}$	15.4 ^{abc}
	LS	18.5 ^{abc}	13.8 ^{ab}	16.1 ^{ab}
T3	CP	13.8 ^{d}	8.5 ^{d}	11.2 ^{de}
	CG	15.4 ^{bcd}	10.9 $^{a-d}$	13.2 ^{cd}
	CC	13.1 ^{d}	3.8 ^{e}	8.5 ^{e}
	PT	15.2 ^{cd}	12.4 ^{abc}	13.8 ^{bcd}
	LS	13.8 ^{d}	8.5 ^{cd}	11.3 ^{de}

CC: *Cenchrus ciliaris*, PT: *Panicum tugidum*, LS: *Lasiurus scindicus*
CP: *Coelachyrum piercei*, CG: *Chloris gayana*.
Means followed by the same letter in a column are not significantly different at P<0.05.

species. In a similar work, Osman, et al. (2008) suggests that the desert grasses of the Arabian Peninsula, such as *Cenchrus ciliaris*, could be useful grass species in reducing the use of scarce irrigation water. Al Tamimi et al. (2001) found that local forage species utilize water more efficiently compared to exotic ones. They recommended the use of *Cenchrus ciliaris* and *Panicum tugidum* as fodder crops highly efficient in water use. Akram, et al. (2008) attributed drought tolerance in *Cenchrus ciliaris* to its ability to accumulate N, P, K^+ and Ca^{+2} in its tissue.

CONCLUSION

This study clearly demonstrates the superiority of indigenous forage species over exotic species in water uptake efficiency under stress condition. Indigenous species, namely *Cenchrus ciliaris* could take water from deep soil layers under conditions of deficit irrigation while the exotic species *Chloris gayana* could not. With the current situation of water resources in the region, it is recommended to expand in plantation of indigenous forages at the expense of exotic ones.

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