4th International Conference on Water Resources and Arid Environments (ICWRAE 4): 523-530
5-8 December 2010, Riyadh, Saudi Arabia

Screening of Drought Resistant Range Plants for Controlling Desertification in Saudi Arabia

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Abstract: The study was carried at Al-Muzahmiyia Research Station, KACST, Riyadh, Kingdom of Saudi Arabia for screening drought resistant range plants for the establishment of sustainable range lands and to combat desertification with minimum irrigation water supplies. Mean plant yield (kg/plant) ranged between 7.32-11.14 kg (*Prosopis juliflora*), 1.94-3.82 kg (*Acacia nilotica*), 0.71-1.55 kg (*Acacia farnesiana*) and 1.73-4.12 kg (*Parkinsonia aculeate*) in different water stress treatments. Mean plant fresh biomass decreased significantly with an increase in water stress of *Acacia farnesiana* and *Acacia nilotica,* but *Perkinsonia aculeate and Prosopis juliflora* fresh biomass increased with increasing water stress. Mean plant height rangd between 216.25-232.57 cm (*Prosopis juliflora*), 185.75-213.82 cm (*Parkinsonia aculeate*), 159.19-219.64 (*Acacia nilotica)* and 153.22-177.32 (*Acacia farnesiana)* under different water stress treatments. The plant height showed significant decreases with increasing water stress. Mean protein contents of all the plants ranged between 7.44-15.50 % in different water stress treatments. In conclusion, the range plants can produce appreciable amount of fresh biomass with irrigation between 40-60 % moisture depletion of field capacity, thus showing a net saving of around 50 % of irrigation water supplies. The experiment showed that *Perkinsonia aculeate and Prosopis juliflora* are potentially viable range plants for controlling desertification and development of sustainable range lands.

Key words: Water stress • Plant height • Fresh biomass • Protein • Moisture depletion • Growth

INTRODUCTION

Saudi Arabia is an arid country where water resources are limited and non-renewable. Currently, more than 90 % of the agricultural water needs are fulfilled by the groundwater [1]. Most of the agricultural soils of Kingdom are coarse textured and have low water holding capacity which is one of the most important factors limiting land productivity. Inadequate supplies of fresh waters encourage farmers in Saudi Arabia to sustained their land productivity by growing crops and plants with less water requirements.

Presently, there is a growing interest in the farming community to diversify their land and water resources as a way of increasing water use efficiency. This could involve irrigating a crop, when required and at appropriate time for its optimum growth. Diversity of tropical forests as well as species distribution patterns are strongly influenced by the amount of annual rainfall and length of dry periods [2-4]. There is also increasing evidence for the importance of water availabitity for determining species microhabitat distributions [5, 6]. Drought has been associated with increased mortality and decreased growth in seedlings as well as adult tropical trees [7, 8]. Seedlings of 28 species of tropical woody plants showed a very large variation of the effects of drought on both growth and survival among species [9]. Differences in species drought resistance, their capacity to withstand periods of dryness together with the variation in water availability, may therefore be a major factor influencing species population dynamics and their mircohabitat and large scale distribution in the tropics [10]. Li, *et al.* [11] studied the drought-resistant physiological characteristics of four native species, i.e., *Sophora davidiana*, *Bauhinia faberi* var. *microphylla*, *Convolvulus tragacanthoides* and *Artemisia gmelini* in China. The results provided a basis for vegetation restoration, especially it improved survival of planted species in May and June when plant species exhibit the weakest drought resistance.

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Al-Homaid and Khan [12] studied *Prosopis juliflora* in different geomorphic units. They concluded that xerophytic plants such as *P. juliflora c*an be successfully grown with moderate watering in an open sandy desert ecosystem. Abebe [13] investigated the growth performances of some multipurpose trees and shrubs for five years at two locations in the semi-arid areas of Southern Ethiopia. The best performance in terms of rates of survival and growth rates (height and diameter growth) were attained by *Acacia nilotica, A. Cyanophylla, A. seyal, Cassia siamea* and *Prosopis juliflora*. Given the ecological limitations of semi-arid areas, growth rates of these species is promising and this indicates that sustainable production system can be realized using proper agroforestry technologies in the semi-arid areas of the world. Pasiecznik *et al.* [14] stated that *Prosopis juliflora* is a multipurpose dry land tree or shrub native to South America, Central America and the Caribbean. It has been introduced and naturalized in many parts of the world (Africa, Asia and Australia) during the last 100-150 years. However, despite its qualities and uses in its natural range, prosopis becomes a serious invading weed when introduced into non-native areas without proper management [15]. Lima e Silva *et al.* [16] concluded that *Prosopis juliflora* and *Mimosa caesalpiniaefolia* showed the highest stem diameter and plant height values, respectively and both showed the highest canopy diameter under arid environments. Nativ *et al.* [17] found in the field experiment that dry matter (DM) production of *Acacia saligna* under irrigation was only 14% greater (not significant) than under dryland. In the pot experiment, DM production was significantly reduced and water use efficiency (WUE) and chlorophyll content increased with reduced availability of water.

An extensive review showed that a very little has been accomplished on screening drought resistant landscape trees for desert greenification and establishment of windbreaks to avoid land encroachment by moving sand dunes under local environmental conditions. Keeping in view the water resources available, it is imperative to investigate drought resistant plant species that can grow successfully with limited irrigation supplies. Therefore, the main objective of this study was to determine drought resistant limits of some landscape tree for desert greenification and establishment of windbreaks around oil refineries, productive agricultural lands and highways to combat desertification with minimal irrigation supplies.

MATERIALS AND METHODS

The experiment was carried at Al-Muzahimiyah Research Station, King Abdulaziz City for Science and Technology (KACST), Riyadh, Kingdom of Saudi Arabia from 1999 – 2002.

Treatments

1. soil	=	1 (sandy)
2. Irrigation level	=	4 (20, 40, 60 and 80 % depletion of soil moisture at field capacity).
3. Water salinity	=	1 (1600 mg L•^{1})
4. Irrigation system	=	1 (bubbler system)
5. Plants	=	4 (Prosopis juliflora, Acacia nilotica, Acacia farnesiana Parkinsonia aculeate).
6. Replications	=	4 (Total plots = 1 x 4 x 1 x 1 x 4 x 4 = 64)

Statistical design. Complete Randomized Block Design

Experimental Procedure: The experiment was laid out in the field in an area of 200 m x 30 m. The area was divided into four blocks of equal size measuring 20 m x 30 m for four drought resistant levels. There were 4 rows in each block with each row having 4 plants. The plant to plant distance was 1 m and row to row distance was 2 m.

Table 1: Layout Plan of Screening of Drought Resistant Range Plants

Treatment No. 1 (Control) Irrigation at 20% depletion of Field Capacity				Treatment No. 2 Irrigation at 40% depletion of Field Capacity				Treatment No. 3 Irrigation at 60% depletion of Field Capacity				Treatment No. 4 Irrigation at 80% depletion of Field Capacity			
R-1	R-2	R-3	R-4	R-1	R-2	R-3	R-4	R-1	R-2	R-3	R-4	R-1	R-2	R-3	R-4
1	3	4	2	1	3	4	2	1	3	4	2	1	3	4	2
2	4	1	3	2	4	1	3	2	4	1	3	2	4	1	3
3	2	4	1	3	2	4	1	3	2	4	1	3	2	4	1
4	3	1	2	4	3	1	2	4	3	1	2	4	3	1	2

Plants: 1. Prosopis juliflora, 2. Acacia nilotica, 3. Parkinsonia aculeate, 4. Acacia farnesiana

Table 2: Initial physical and chemical characteristics of soil

Parameter	Reading
Texture	Sand
Saturation Percentage	20
ECe (dS m^{-1})	1.26
pH	7.85
TDS (mg L^{-1})	810
Ca (mg L^{-1})	101
Mg (mg L^{-1})	26
Na (mg L^{-1})	87
K (mg L^{-1})	12
Cl (mg L^{-1})	243
CO_3 (mg L^{-1})	4
HCO_3 (mg L^{-1})	113
SAR	2

Plants seedlings of 3-4 month old were planted in these blocks. There were 16 plants per block. The distance between plants was kept according to the standard practices being followed for their cultivation under local desert environmental conditions. The layout plan of study is presented in Table 1. The plants were transplanted from nursery to field during November 1999. The initial physical and chemical characteristics of soil are given in Table 2.

Irrigation of Plants: The total amount of water required to fulfill field capacity level of soil of plant basin measuring 1 m (diameter) and 0.5 m depth was calculated from the soil moisture data. The amount of water applied was based on field capacity (8.5% by weight). The irrigation was done at 20 % (T-1), 40 % (T-2), 60 % (T-3) and 80 % (T-4) depletion of soil moisture at field capacity. The plants were irrigated with drip (Bubbler) system of irrigation when the soil attained the desired level of soil moisture depletion in each treatment. The interval of irrigation determined the moisture stress (drought conditions) for each treatment. Soil moisture was measured in each treatment before and after irrigation to determine the level of stress being encountered by plants. The total amount of irrigation per plant per irrigation came to 10 liters for all the treatments. The irrigation was applied when the soil moisture depletion reached to 20, 40, 60 and 80 % depletion of the field capacity. The irrigation interval for different treatments were 1, 3, 5 and 7 days during winter and 1, 2, 3 and 4 days during summer through out the experiment. The depletion of soil moisture was monitored with the help of tensiometer installed at selected places in all experimental blocks. All the plants received 15 % excess water above the irrigation water as leaching requirement to maintain soil salinity within acceptable limits for normal plant growth. The deep well water having the EC approximately 2.5 dS m^{-1} was used for irrigation. Chemical analysis of water used for irrigation is given in Table 3.

Installation of Tensiometers: Two sets of tensiometers (each set of two tensiometers) were installed in each block at 12 cm distance on either side from the main trunk of a plant at 15 and 30 cm depth of soil to monitor soil moisture depletion. In all, there were 8 sets of tensiometers in 4-blocks.

Plant Growth Measurements: Plant growth measurements included plant height and total fresh biomass. Plants were harvested after completion of one year growing season and two crops were harvested (November 2000 and November 2001). Fresh biomass was recorded for each plant at the time of harvesting.

Plant Samples: Plant samples were collected at the time of each harvesting. The plant samples were washed, dried and ground according to the standard procedure for chemical analyses. The plant tissues were analyzed for protein which was calculated from total N% by multiplying with a factor of 6.25 to determine the effect of drought on plants forage nutritional value for treatment evaluation.

Table 3: Chemical Composition of Well, Pond and Water Treatments

Parameter	Pond Water	Treatment (Well Water)	Treatment 2	Treatment 3	Treatment 4
EC (dS m^{-1})	23.1	2.5	7.0	12.5	18.8
pH	7.4	7.7	7.8	8.1	7.8
TDS (mg L^{-1})	14,800	1,654.0	4,474.0	7,970.0	12026.0
Calcium (mg L^{-1})	1260	212.0	424.0	665.0	957.0
Magnesium (mg L^{-1})	665	59.0	216.0	336.0	497.0
Sodium (mg L^{-1})	3623	227.0	938.0	1755.0	2814.0
Potassium (mg L^{-1})	209	14.0	46.0	99.0	162.0
Chloride (mg L^{-1})	6995	653.0	2135.0	3926.0	5524.0
Carbonate (mg L^{-1})	15	0.0	9.0	15.0	7.0
Bicarbonate (mg L^{-1})	143	152.0	150.0	118.0	112.0
SAR	20.0	3.5	10.0	15.1	20.4

Soil Samples: Initial soil samples were taken from 0-15, 15-30, 30-60 and 60-90 cm depth of soil from each site before starting the irrigation of plant seedlings. Post harvest soil sampling was done to measure salt build up in soil receiving saline water. The soil samples were analyzed for pH, Ec_e, SAR and physical texture (sand, silt and clay %).

Water Analysis: Water samples were collected on monthly basis and analyzed for pH, EC, Ca, Mg, Na, K, CO_3, HCO_3, Cl and SO_4. The soil moisture was measured for 0-15 and 15-30 cm depth with the help of tensiometers.

Statistical Analysis: Data were subjected to the proper statistical analysis according to the method prescribed by Snedecor & Cochran [18]. Means were verified according to the Duncan's Multiple Range Test [19].

RESULTS AND DISCUSSION

Drought Resistant Range Plants

Prosopis Juliflora

Plant Height: Mean plant height ranged between 181.50-198.13 cm (1st Year), 251.0-275.88 cm (2nd year) and overall mean plant height ranged between 216.25-232.57 cm in various water stress treatments (Table 4). The plant height decreased significantly with an increase in water stress than the control treatment. The difference in height was not significant among T-1, T-2 and T-4 as well as between T-3 and T-4 treatments. This shows that water stress adversely affected the plant height.

Plant Fresh Biomass: Mean biomass per plant ranged between 3.65-6.01 kg (1st Year), 10.99-17.25 kg (2nd year) and overall mean ranged between 7.32-11.14 kg in various water stress treatments (Table 4). The biomass yield increased significantly with increase in water stress than the control treatment. The difference in yield was significant between T-1 and T-4 as well as between T-3 and T-4, but it was not significant between T-1 and T-2 as well as between T-1 and T-3 treatments. The data indicate that this plant can survive with shortage of irrigation water.

Protein Contents: Mean protein contents ranged between 12.56-15.50 % in different water stress treatments (Table 5). The mean protein contents increased significantly with increasing water stress than the control. The difference in protein contents was not significant among T-1, T-2 and T-3 as well as between T-3 and T-4 treatments.

Parkinsonia Aculeate

Plant Height: Mean plant height ranged between 149.75-174.63 cm (1st Year), 221.75-253.00 cm (2nd year) and overall mean plant height ranged between 185.75-213.82 cm in various water stress treatments (Table 6). The mean plant height decreased significantly with an increase in water stress than the control treatment.The difference in plant height was significant between T-1 and T-2, between T-2 and T-3, T-4 while it was not significant between T-1 and T-3 as well as between T-3 and T-4 treatments. The data suggest that increasing the irrigation water stress adversely affected the plant height.

Plant Fresh Biomass: Mean biomass per plant ranged between 1.42-1.78 kg (1st Year), 1.91-6.46 kg (2nd year) and overall mean ranged between 1.73-4.12 kg in various water stress treatments (Table 6). Although the biomass yield showed increasing trend with increasing water stress but the yield was significantly low in T-2 (40 % moisture depletion) than all other treatments. This could be due to the position of the plant where its growth was adversely affected in this treatment only.

Protein Contents of Plant: Mean contents (%) of protein ranged from 11.29-13.06 in different water stress treatments (Table 7). Although the protein contents increased appreciably but the difference was not significant among various water stress treatments.

Acacia Nilotica

Plant Height: Mean plant height ranged between 115.50-180.57 cm (1st Year), 189.38-258.71 cm (2nd year) and overall mean plant height ranged between 159.19-219.64 cm in various water stress treatments (Table 8). Mean plant height decreased significantly with an increase in water stress to plants than the control treatment. The difference in height was significant between T-1 and all other treatments. Although plant height showed decreasing trend with increase in water stress but it was not significant among T-2, T-3 and T-4 treatments.

Plant Fresh Biomass: Mean biomass per plant ranged between 0.79-2.53 kg (1st Year), 3.08-5.10 kg (2nd year) and overall mean ranged between 1.94-3.82 kg in various water stress treatments (Table 8). The mean Plant Fresh Biomass decreased significantly with increasing water stress to plants than the control treatment. The difference in yield/ was significant between T-1 and all other treatments but it was not significant between T-2 and T-3 as well as between T-3 and T-4 treatments. The decrease in biomass yield could be attributed to inadequate supply of water to

Table 4: Effect of Irrigation Water Stress on Growth Parameters of *Prosopis juliflora*

Parameter	Treatment	Growing Seasons 2000	2001	Mean (Per plant)
Plant Height (cm)	T1	188.63	275.88	232.26 a
	T2	198.13	267.00	232.57 a
	T3	181.50	251.00	216.25 b
	T4	193.50	253.13	223.32 ab
Fresh Biomass (Kg)	T1	5.21	11.65	8.43 bc
	T2	6.01	14.23	10.12 ab
	T3	3.65	10.99	7.32 c
	T4	5.02	17.25	11.14 a

Mean values in the column followed by the same letter are not significantly different, LSD at 5%= 11.53 for plant height, 2.55 for fresh biomass

Table 5: Effect of Irrigation Water Stress on Protein Contents(%) of *Prosopis juliflora*

Parameter	Treatments	Growing Seasons 2000	2001	Mean
Protein	T1	12.00	13.13	12.56 b
	T2	11.81	13.94	12.87 b
	T3	13.38	13.38	13.37 ab
	T4	16.88	14.06	15.50 a

Mean values in the column followed by the same letter are not significantly different, LSD at 5%= 2.14

Table 6: Effect of Irrigation Water Stress on Growth Parameters of *Parkinsonia aculeate*

Parameter	Treatment	Growing Season 2000	2001	Mean (Per plant)
Plant Height (cm)	T1	174.63	253.00	213.82 a
	T2	149.75	221.75	185.75 c
	T3	162.75	252.00	207.38 ab
	T4	161.25	249.25	205.25 b
Fresh Biomass (Kg)	T1	1.63	3.84	2.74 ab
	T2	1.55	1.91	1.73 b
	T3	1.42	3.86	2.64 ab
	T4	1.78	6.46	4.12 a

Means values followed by the same letter are not significantly different, LSD at 5%= 8.19 for plant height, 1.77 for fresh biomass

Table 7: Effect of Irrigation Water Stress on Protein Contents (%) of *Parkinsonia aculeate*

Parameter	Treatments	Growing Seasons 2000	2001	Mean
Protein	T1	9.00	13.56	11.29 a
	T2	10.19	13.13	11.60 a
	T3	11.75	14.31	13.06 a
	T4	12.44	10.75	11.62 a

Mean values in the column followed by the same letter are not significantly different, LSD at 5%=2.66

Table 8: Effect of Irrigation Water Stress on Growth Parameters of *Acacia nilotica*

Parameter	Treatment	Growing Seasons 2000	2001	Mean (Per plant)
Plant Height (cm)	T1	180.57	258.71	219.64 a
	T2	142.63	204.00	173.32 b
	T3	140.25	189.38	164.82 b
	T4	115.50	202.88	159.19 b
Fresh Biomass (Kg)	T1	2.53	5.10	3.82 a
	T2	1.49	4.42	2.96 b
	T3	1.79	3.12	2.46 bc
	T4	0.79	3.08	1.94 c

Mean values in the column followed by the same letter are not significantly different, LSD at 5%= 16.74 for plant height, 0.68 for fresh biomass

Table 9: Effect of Irrigation Water Stress on Protein Contents (%) of *Acacia nilotica*

Parameter	Treatments	Growing Seasons 2000	2001	Mean
Protein	T1	9.69	8.19	8.94 ab
	T2	7.44	7.44	7.44 b
	T3	10.13	8.06	9.12 ab
	T4	12.13	7.88	10.00 a

Mean values in the column followed by the same letter are not significantly different, LSD at 5%=1.76

Table 10: Effect of Irrigation Water Stress on Growth Parameters of *Acacia farnesiana*

Parameter	Treatment	Growing Season 2000	2001	Mean (Per plant)
Plant Height (cm)	T1	147.13	207.50	177.32 a
	T2	143.63	204.13	173.88 ab
	T3	126.75	193.00	159.88 bc
	T4	137.43	169.00	153.22 c
Fresh Biomass (Kg)	T1	1.41	1.69	1.55 a
	T2	0.73	2.04	1.39 a
	T3	0.82	1.54	1.18 ab
	T4	0.60	0.81	0.71 b

Mean values in the column followed by the same letter are not significantly different, LSD at 5%= 15.63 for plant height, 0.51 for fresh biomass

plants than its requirements for normal growth thus causing adverse effect on plant production. This plant can also be categorized as less drought resistant.

Protein Contents of Plant: Mean protein contents (%) ranged from 7.44-10.00 in different water stress treatments (Table 9). The protein contents of plant increased significantly with increase in water stress than the control treatment. The difference in protein contents was not significant among T-1, T-2 and T-3 as well as among T-1, T-3 and T-4 treatments.

Acacia Farnesiana

Plant Height: Mean plant height ranged between 126.75-147.13 cm (1st Year), 169.00-207.50 cm (2nd year) and overall mean plant height ranged between 153.22-177.32 cm in various water stress treatments (Table 10). Mean plant height decreased significantly with increase in water stress application than the control treatment. The difference in plant height was significant between T-1 and T-4 treatments but it was not significant between T-1 and T-2, between T-2 and T-3 as well as between T-3 and T-4 treatments.

Table 11: Effect of Irrigation Water Stress on Protein Contents (%) of *Acacia farnesiana*

		Growing Seasons		
Parameter	Treatments	2000	2001	Mean
Protein	T1	11.44	11.63	11.54 b
	T2	11.25	12.25	11.75 b
	T3	12.44	12.13	12.31 b
	T4	14.88	12.56	13.75 a

Mean Values in the column followed by the same letter are not significantly different, LSD at 5%=1.41

Plant Fresh Biomass: Mean biomass per plant ranged between 0.60-1.41 kg (1st Year), 0.81-2.04 kg (2nd year) and overall mean ranged between 0.71-1.55 kg in various water stress treatments (Table 10). Mean plant fresh biomass decreased significantly with increase in water stress to plants as compared to the control treatment. The difference in biomass was not significant among T-1, T-2 and T-3 but it was significantly less in T-4 when compared to other low water stress treatments (Table 10).

Protein Contents of Plant: The mean protein contents (%) ranged from 11.54-13.75 in different water stress treatments (Table 11). The protein contents of plant increased significantly with increasing water stress than the control treatments. The difference in protein contents was not significant among T-1, T-2 and T-3 but it was significant between T-4 and all other treatments.

DISCUSSION

Generally, any increase in water stress (supplying less amount of water than requirement) has negative effects on plant growth. In the present study, mean plant fresh biomass decreased significantly with an increase in water stress of *Acacia nilotica* and *Acacia farnesiana* than *Perkinsonia aculeate and Prosopis juliflora* where the fresh biomass increased with increasing water stress. Similarly, the plant height showed significant decreases with increasing water stress. Mean protein contents of plants ranged between 7.44-15.50 % in different water stress treatments. Similar studies carried by Al-Homaid and Khan [12] concluded that xerophytic plants such as P. juliflora *c*an be successfully grown with moderate watering in an open sandy desert ecosystem. Abebe [13] stated that the best performance in terms of rates of survival and growth rates (height and diameter growth) were attained by *Acacia nilotica* and *Prosopis juliflora*. The study results were also supported by Pasiecznik *et al.* [14] who stated that *Prosopis juliflora* is a multipurpose dry land tree or shrub native to South America, Central America and the Caribbean. However, despite its qualities and uses in its natural range, Prosopis becomes a serious invading weed when introduced into non-native areas without proper management [15]. Whereas, Lima e Silva *et al.* [16] concluded that *Prosopis juliflora* and *Mimosa caesalpiniaefolia* showed the highest stem diameter and plant height values, respectively and both showed the highest canopy diameter under arid environments. Nativ *et al.* [17] found in the field experiment that dry matter (DM) production of *Acacia saligna* under irrigation was only 14% greater (not significant) than under dry-land. In the pot experiment, DM production was significantly reduced and water use efficiency (WUE) and chlorophyll content increased with reduced availability of water.

In conclusion, the range plants such as *Acacia nilotica, Acacia farnesiana, Perkinsonia aculeate and Prosopis juliflora* can produce appreciable amount of fresh biomass with irrigation between 40-60 % moisture depletion at field capacity, thus showing a net saving of around 50 % of irrigation water supplies. Overall, the results showed that, among the various range plants, *Perkinsonia aculeate and Prosopis juliflora* proved highly drought resistant and are potentially viable range plants to combat desertification, developing sustainable range lands, desert greenification and for establishment of shelter belts around oil refineries, productive agricultural lands and highways besides desert greenification an arid environment.

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