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Full Length Research Paper

Optimizing productivity and irrigation water use efficiency of pearl millet as a forage crop in arid regions under different irrigation methods and stress

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A field experiment was carried-out at the Agriculture Experimental Station of King Abdulaziz University located at Hada Alsham, 110 km north east of Jeddah, to optimize the productivity and irrigation water use efficiency of pearl millets (*Pennisetum glaucum* L.), as green fodder under different irrigation methods and stress. Five treatments were investigated in this study: three with full irrigation requirements including sprinkler irrigation (SPI), drip irrigation (DI) and sub-surface drip irrigation (SDI), the remaining two treatments were stress treatment namely: sub-surface drip kept at 85% of field capacity (SDI 1) and sub-surface drip kept at 70% of field capacity (SDI 2). Irrigation water for all treatments was precisely supplied using water electronics module (WEM). Results indicated that SDI treatment gave the highest fresh and dry biomass, followed by SDI 1 compared to other treatments. Increasing number of cuts sharply decreased biomass production. Increasing water stress decreased biomass production but SDI with water stress increased biomass production compared to SPI with full irrigation requirement. Irrigation water use efficiency (IWUE) was decreased by increasing water stress and number of cuts. Results also proved that WEM is a practical tool to precisely supply irrigation water when needed, and can be effectively used to precisely control water stress.

Key words: Irrigation methods, pearl millet, precision irrigation, water stress.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* L.) is a high nutritive-value summer-annual forage crop, popular among livestock producers for grazing, silage, hay and green crop.

Pearl millet can also be utilized as emergency forage that regularly performs well as an economical one-year forage crop option. It is an important forage crop of Africa, Asia and America (Dakheel et al., 2009; Newman et al., 2010). Pearl millet is extensively used in different countries as forage of high nutritional quality (Maiti and Rodriguez, 2010).

It is rich in protein and energy and poor in fiber and lignin concentration.

Crude protein can range from 9 to 11% in unfertilized soils and to 14 to 15% under nitrogen-fertilized conditions. It is also rich in calcium, iron and has balanced amino acids, but its sulfur-containing amino acid concentration is low.

The forage is readily consumed by livestock when used at vegetative stages (Newman et al., 2010). Peal millet prefers well-drained soils, and at the seedling stage, looks much like a corn or sorghum plant. Compared to sorghum, it is less tolerant of water logging and flooding. The crop is adapted under different adverse conditions such as drought, salinity and soil poor in nutrients.

This is why world-wide researchers are motivated to introduce this crop in arid and semiarid regions of their countries. Under suitable climatic conditions, pearl millets have great capacity of rooting enabling to take two or three cuts of green forage (Maiti and Rodriguez, 2010). The ability to tolerate drought and their acceptable yields are limited among cultivars within a species.

Pearl millet is a potentially productive, high-quality grain or silage crop that appears superior to sorghum concerning establishment and production under limited soil moisture (Serraj and Sinclair, 2002; Purcell et al., 2002; Dakheel et al., 2009).

Saudi Arabia is an arid country with limited water resources and its agricultural activities totally depend on groundwater source. In different places of Saudi Arabia, groundwater is brackish water with high salinity level ranging from 2000 to 6000 ppm.

Due to these environmental conditions, pearl millet is considered to be a good option to grow as a forage green crop. The current research tries to achieve the greatest aboveground biomass production per unit of water by two methods.

First is the application of precision irrigation technique to add the required amount of water when and where needed. Second is the evaluation of production per unit of water for each cut of pearl millet. Precision irrigation means applying irrigation water in the right place with the right amount at the right time (Almarshadi and Ismail, 2011).

There are some existing technologies to be adapted for precision irrigation. These include: speed-control systems, pulse concept to control single sprinkler (Frassie et al., 1995a, b), single span or small segments along each span and through solenoid valves (Omary et al., 1997; Camp et al., 1998).

However, all these methods need software to control their operation. Recently, a very sophisticated technology called water electronic module (WEM) was found to be able to apply precision irrigation by adding the right amount of water directly when and where needed.

Brief description of WEM will be presented in the methodology section; however, the detailed description was presented in the study of Ismail and Almarshadi (2011). The western part of Saudi Arabia is characterized by warm weather along the year with high temperature compared to other parts.

These weather conditions encourage some growers to plant Pearl millets in December as green forage. However, the normal date for planting millet is in summer, since it considers a relatively high heat unit requirement. Moreover, the western part of Saudi Arabia is rainless so that, the cultivated pearl millet is fully subjected to irrigation regardless of its planting time. For better understanding in term of maximizing the production per unit of water, two planting cycles were investigated in the current study. The first cycle was in December, 2009 and the second was in May, 2010.

The objectives of the study were to: 1) quantify the relationship between different irrigation methods and biomass production of pearl millets; 2) quantify the relationship between water stress and biomass production of pearl millet; 3) evaluate irrigation water use efficiency in relation to investigated water treatments; 4) evaluate irrigation water use efficiency in relation to number of cuts for pearl millets and 5) evaluate WEM as new applied technology to add irrigation water when and where needed.

MATERIALS AND METHODS

Experimental location, design and treatments

Two planting cycles were investigated under the current study. The first planting cycle was conducted during the period from December, 2009 to the end of April, 2010 as a normal practice in the western part of Saudi Arabia. Again, pearl millet was grown from 12th of May till the end of October 2010, since it considers a relatively high heat unit requirement. The experiment was carried-out at the Agriculture Experimental Station of King Abdulaziz University (KAU) located near Hada Alsham village, 110 km north east of Jeddah, KSA. The soil texture is sandy loam. Detailed description of soil physical properties is presented in Table 1. The climate of the area is arid, with high temperatures during summer season. The design of the experiment was block design (BD), consisting of five water treatments and four replicates with plot size of 2 × 3 m. Three water treatments out of five were given full irrigation water requirement. The remaining two were stress treatments. The salinity of used irrigation water was 2850 ppm.

Table 2 presents the investigated water treatments and their abbreviations. Data were subjected to analysis of variance as described by Gomez and Gomez (1984), and the Duncan's multiple range test was used for mean separation. In sprinkler irrigation, 2045-PJ Maxi-Bird™ rotator was used. The inlet pressure on the system was 1.7 bars. With this pressure the radius of the rotator was 8 m with a maximum discharge of 0.58 m^3/h. The design of the sprinkler system was based on the features of the rotator, where the distance between each adjacent sprinkler and lines was 8 m to give about 90% overlapping. In sub-surface drip irrigation systems, the field was leveled and the dripper lines were installed at 10 cm deep on 40 cm between two adjacent dripper lines. The distance between drippers was 30 cm. The type of the dripper line was Rain Bird LD- 06- 12-1000 landscape drip 0.6 G/h @12".

The downstream end of each dripper line was connected to a manifold for convenient flushing. Inlet pressure on each tape was about 1.5 bars. The system used 125 micron disk filter. The water source was two containers with a capacity of 6000 L each. They were always filled with water via the main irrigation network. The lay-out of drip irrigation was exactly the same as in subsurface drip except for the positions of dripper lines, where they were installed on soil surface. Figure 1 presents the detailed lay-out of the experiment.

Automated procedure used to control water supply

All systems were automatically controlled by water electronic module (WEM). In WEM technology, water requirement of the growing plants is calculated based on the available soil moisture of root zone area. There is a relationship between soil moisture content and soil tension. When the soil moisture decreases the soil tension increased. The WEM uses two watermark sensors placed at varying depths (10 and 30 cm below soil surface) within the root zone. The total tension is measured and averaged to report the overall condition within the root zone. This device typically works in conjunction with a standard 24 VAC irrigation controllers. The WEM is, in effect, a switch which interrupts the common ground connection between control valves and controller. The irrigation scheduler selects the appropriate moisture level on the dial of

Table 1. Soil physical characteristics of experimental site.

Characteristics		Value
Particle size analysis	Clay (%)	14.5
	Silt (%)	21.5
	Sand (%)	64.0
Texture grade		Sandy loam
Organic matter (%)		0.67
Welting point (cm^3/cm^3)		0.11
Field capacity (cm^3/cm^3)		0.23
Saturation (cm^3/cm^3)		0.43
Sat. hydraulic conductivity (cm/h)		1.52
Available water (cm^3/cm^3)		0.12
Bulk density (g/cm^3)		1.50

Table 2. Investigated treatments and their abbreviation.

Investigated water treatment	Abbreviation	Remarks
Sprinkler irrigation with full water requirement	SPI	
Drip irrigation with full water requirement	DI	
Sub-surface drip irrigation with full water requirement	SDI	
Sub-surface drip kept at 85% of field capacity	SDI 1	First stress treatment
Sub-surface drip kept at 70% of field capacity	SDI 2	Second stress treatment

Irrigation systems installation.

WEM, and the controller is allowed to run only the irrigation cycles necessary. The appropriate moisture level on the dial of the WEM was adjusted to be 2, to keep the moisture of soil at field capacitlevel in SPI, DI and SDI treatments while adjusted to 4 and 6 to supply the required soil moisture (stress treatments) in the fourth and the fifth treatments. The irrigation water was automatically supplied twice a day at 7:00 am and 6:00 pm.

Cultural practices

The pearl millet crop was sown manually in rows with 20 cm apart in a rate of 4 seeds for each hill with a distance of 20 cm between each consecutive hill. The recommended dose of nitrogen fertilizer was added in the form of urea for one time after planting for each planting cycle. The pearl millet was harvested when 10 to 20% of ears emerged.

Data collection

Data were collected for four agronomic parameters that is, plant height, number of tillers, fresh yield and dry matter. Two water parameters were also recorded that is, irrigation water supply and soil moisture tension. For plant height and number of tillers, 10 plants form each plot were randomly selected and their height and number of tillers were recorded. For fresh yield, 1 m^2 from the center of the plot of each replicate was cut, and the fresh weight was recorded immediately in the field. Sub-samples were put into paper bags for dry matter measurements. These samples were kept in a forced air oven at 80°C for 72 h to get uniform dry weight. Irrigation water supply was frequently recorded by collecting the reading from the gage installed of each irrigation treatment. Soil moisture tension was measured as an indicator for soil moisture content at certain time during the experiment using watermark data logger system.

RESULTS AND DISCUSSION

Effects of precise irrigation methods on growth parameters

The effects of investigated irrigation methods on growth parameters and yield include plant height, number of fresh tillers and dry matter yields are presented in Table 3. Results indicated that DI significantly increased the average plant height over the three cuts compared with SPI in both seasons. However, the increase was not significant compared with other treatments (SDI, SDI 1 and SDI 2). Plants were higher in second planting cycle than in first one. Results also showed that, plant height decreased from the first to the third cut where the shortest plant heights were obtained from 3rd cut in both planting cycles. SPI gave only two cuts during the first planting cycle. SDI generally increased the average number of tillers compared to the other treatments, but, the increase was significant only in the first cut of the second season. Number of tillers was generally increased

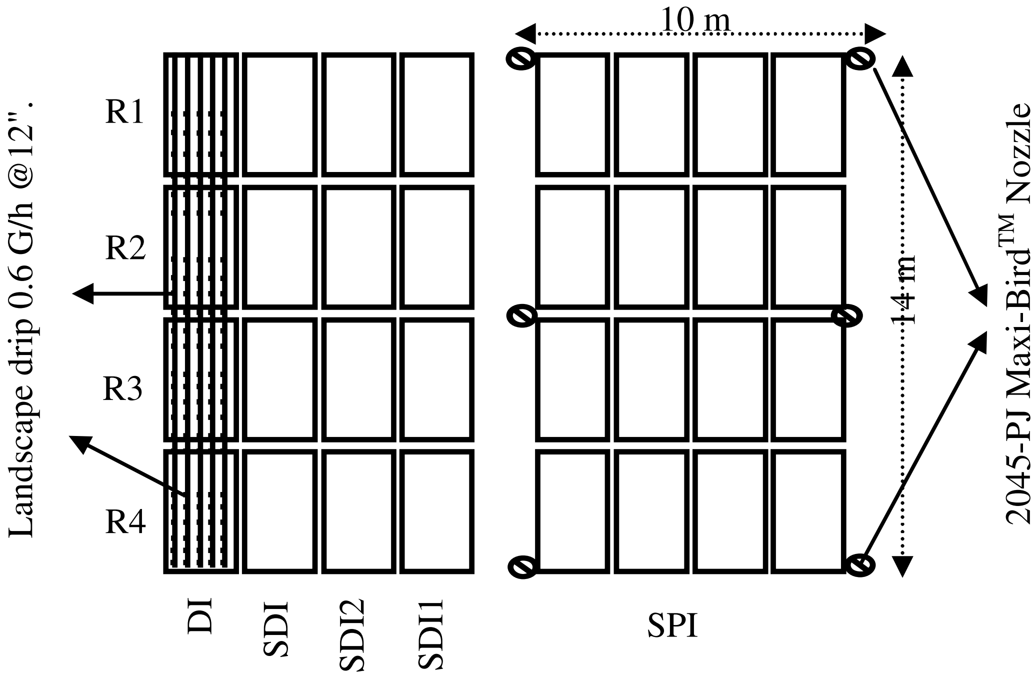

Figure 1. Schematic diagram for experimental lay-out.

by increasing the number of cuts (Table 3). The forage fresh and dry yield of pearl millet varied significantly among the investigated treatments (Table 3). The highest fresh and dry yields in all cuts obtained from SDI followed by SDI 1, DI and SDI 2, respectively. The least fresh and dry yields were recorded in SPI. Results indicated that the fresh yield sharply decreased from 1st to 3th and only two cuts were obtained from SPI during the first planting cycle. The results also showed that the yields of second planting cycle were greater than that in first one. Results of plant height showed that the least plant height was found in SPI, followed by SDI 2 compared to all other treatments. The reduction in plant height might be due to water stress as indicated by moisture tension data as follows. Drought and water stress reduces plant height (Conover and Soonic, 1989; Madakadze, 1999).

Sometimes the results showed a reduction in number of tillers under water stress. The reduction in number of tillers is an adoptive mechanism that has been induced in response to water stress. This reduction reduces the transpiration area and hence helps the plant to withstand against water stress. The findings of Ludlow and Mucho (1990) and Mahalakshmi and Bidinger (1985) confirmed these results. SDI gave the highest fresh and dry yield because it was grown under stress less condition, since it showed the least soil moisture tension values. The soil moisture tension in this treatment was almost 10 cb which equals to field capacity level (Shoack et al., 2005). The intensity of water stress and timing were found to be accounted for 70 to 85% of the variation of millets yield and dry matter production (Payne et al., 1990). Increasing soil moisture increased plant height, leaves size and number of tillers consequently, the total forage yield increased. Nagaz et al. (2010) reported that applying frequent irrigation to the millet crop increases dry matter by 9% and grain yield by 14%. Dry matter productions highly increase by increasing soil moisture (Newman et al., 2010). Increasing water supply increased biomass of pearl millets (Singh et al., 2010; Volesky, 2010). Results clearly indicated that the second planting cycle (May) is better than the first one in December in all growth characteristics and fresh and dry yield. These are due to high temperature requirement for millets growth and the day-length. Cultivating during May offer the opportunity to complete the temperature requirement of millets. Completing temperature requirements increased number of tillers and plant height and resulted in high yield.

The day-length in May is longer than that in December. Extended day-length resulted in great increase in vegetative dry weight. Increasing plant height in the second planting cycle might be due to the day-length. Planting millet in May increase plant height because temperature and day-length reach appropriate levels. The metrological data collected from weathering station of the experimental site presented in Table 4 supported the results of this study. These metrological data showed large differences between the two growing cycles in minimum and maximum temperature as well as sun shining hours. Carberry and Campbell (2006) found that plant height increased from 1.5 to 2.4 and 2.6 m as day-length increased from 13.5 to 14.5 and 15.5 h, respectively. Early in the plant growth, the rate of

Table 3. Effect of irrigation method on plant height, number of tillers, fresh and dry weights of pearl millet.

Growth characteristics	Treatment	Cut							
		First planting cycle (December)				Second planting cycle (May)			
		1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Plant height (cm)	SPI.	61.2[b]	82.8[ab]	-	48.0	175.4[ab]	166.3[a]	132.1[ab]	157.9
	DI	96.4[a]	88.9[ab]	66.4[a]	83.9	191.3[a]	163.3[a]	158.1[a]	170.9
	SDI	96.1[a]	72.0[b]	68.4[a]	78.8	179.3[ab]	161.2[a]	145.8[ab]	162.1
	SDI 1	92.1[a]	97.7[a]	61.8[a]	83.6	178.6[ab]	173.3[a]	145.7[ab]	165.9
	SDI 2	97.4[a]	85.8[ab]	66.5[a]	83.2	160.6[b]	165.3[a]	120.3[b]	148.7
LSD P = 0.05		13.1	18.1	7.23		26.3	19.8	29.2	
Number of tillers	SPI	2.45[a]	1.9[a]	-	1.45	1.15[b]	3.00[a]	2.65[a]	2.27
	DI	2.05[ab]	2.25[a]	2.55[a]	2.28	1.40[b]	2.95[a]	2.10[a]	2.15
	SDI	2.40[ab]	2.65[a]	2.50[a]	2.52	2.30[a]	2.95[a]	2.95[a]	2.73
	SDI 1	2.25[ab]	2.20[a]	2.90[a]	2.45	1.45[b]	3.15[a]	2.10[a]	2.23
	SDI 2	1.60[b]	1.75[a]	2.70[a]	2.02	1.45[b]	3.05[a]	2.65[a]	2.38
LSD P = 0.05		0.80	1.12	1.12		0.48	0.57	0.93	
Fresh yield (t/ha)	SPI	14.4[d]	7.88[c]	-	7.43	56.5[c]	45.7[b]	9.87[c]	37.4
	DI	18.6b[c]	8.39[bc]	3.22[b]	10.1	69.7[abc]	50.6[b]	25.0[a]	48.4
	SDI	22.7[a]	11.2[a]	4.50[a]	12.8	81.7[a]	68.4[a]	23.6[a]	57.8
	SDI 1	20.5[ab]	9.29[b]	4.30[a]	11.4	76.1[ab]	62.7[a]	19.3[ab]	52.7
	SDI 2	16.2[cd]	7.97[c]	3.22[b]	9.13	64.5[bc]	51.4[b]	13.9[bc]	43.3
LSD P = 0.05		3.53	0.94	0.58		15.6	8.06	7.70	
Dry yield (t/ha)	SPI	2.94[b]	1.82[ab]	-	1.59	9.42[b]	6.47[c]	1.30[b]	5.73
	DI	3.59[ab]	1.71[b]	0.68[b]	1.99	10.6[ab]	7.68[bc]	2.59[a]	6.96
	SDI	4.45[a]	2.91[a]	1.00[a]	2.79	12.0[a]	12.9[a]	2.82[a]	9.24
	SDI 1	3.66[ab]	2.08[ab]	0.91[ab]	2.22	11.3[ab]	10.9[ab]	2.61[a]	8.27
	SDI 2	2.98[b]	1.52[b]	0.66[b]	1.72	10.8[ab]	8.44[c]	2.63[a]	7.29
LSD P = 0.05		1.00	1.18	0.27		2.15	3.89	0.87	

Table 4. Metrological data recorded from Hada Alsham weathering station during the time of experiment.

Planting cycle	Month	Min temp. (℃)	Max. temp. (℃)	Sun shine (h)	Wind speed (km/day)	Relative humidity (%)
The first growing cycle	December	18.3	29.9	9	217	52.4
	January	18.3	30.0	8	181	58.9
	February	17.7	30.8	8	191	57.7
	March	19.8	34.4	9	196	44.8
	April	23.6	37.6	10	212	43.7
The second growing cycle	May	24.4	40.3	11	198	43.3
	June	26.5	42.7	12	227	35.4
	July	27.6	40.8	11	220	43.2
	August	29.3	41.6	11	211	51.2
	September	26	40.6	11	187	54.1
	October	25.1	39.8	9	198	42.6

Water supply as affected by investigated treatments.

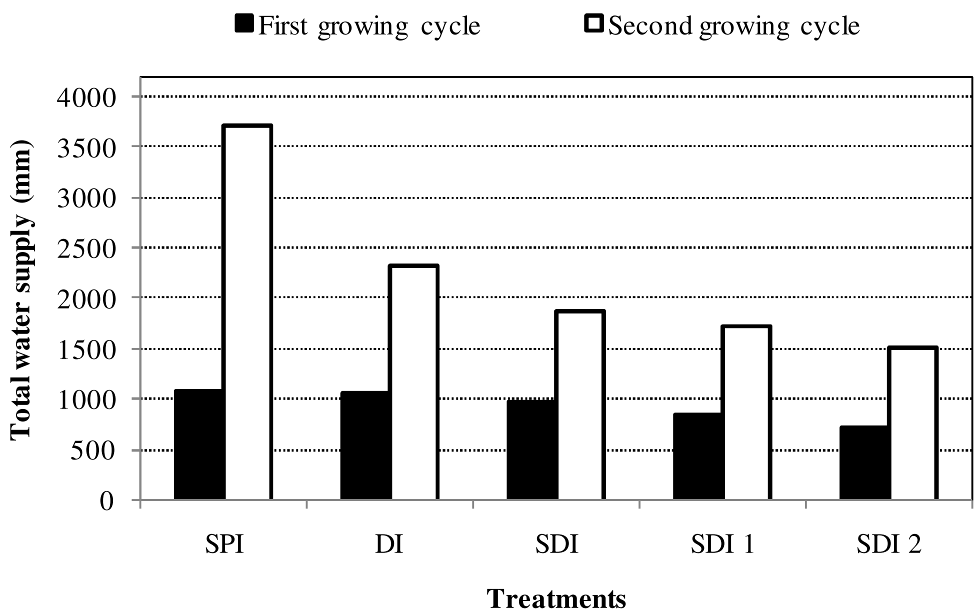

Figure 2. Total water supply for pearl millet during the first and second growing seasons.

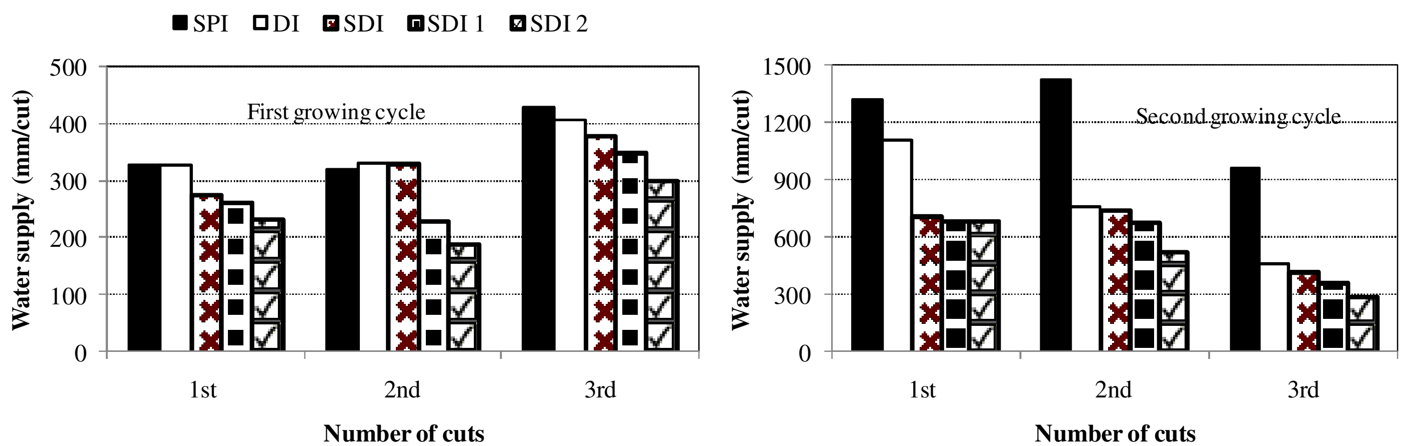

Figure 3. Water supply for each cut during the first and the second planting cycles for investigated treatments.

development of green leaf area per plant was the samefor the three day-lengths, but the rate of leave appearance decreased by increasing day-length. This implied an increase in leaf size with extended day-length. Extended day-length resulted in increase leaf areas per plant and increase final leave numbers, consequentially, fresh and dry yield increased (Carberry and Campbell,2006). Under suitable water supply, more than one cut can be taken from pearl millet as green fodder to the livestock because it has great capacity of rooting. Once plants are cut, they grow again for two or three cuttings depending on climatic conditions (Maiti and Rodriguez, 2010). Figure 2 shows total water supply for pearl millet in the first and second planting cycles. Results showed that total water supply for all treatments in the second growing cycle was higher than that in the first one. Results clearly indicated that the highest total water supply was recorded in SPI followed by DI, SDI, SDI1 and SDI2 respectively, especially in the second growing cycle. In the first growing cycle the total water supply was almost the same in SPI and DI treatments.

Results of water supply for each cut during first andsecond planting cycles are presented in Figure 3. Results were almost in line with those of total water supply (Figure 2). During the first planting cycle, water supply was the same in SPI and DI but higher than that in SDI followed by SDI 1 and SDI 2, respectively. Results also showed that water supply for first and second cuts of

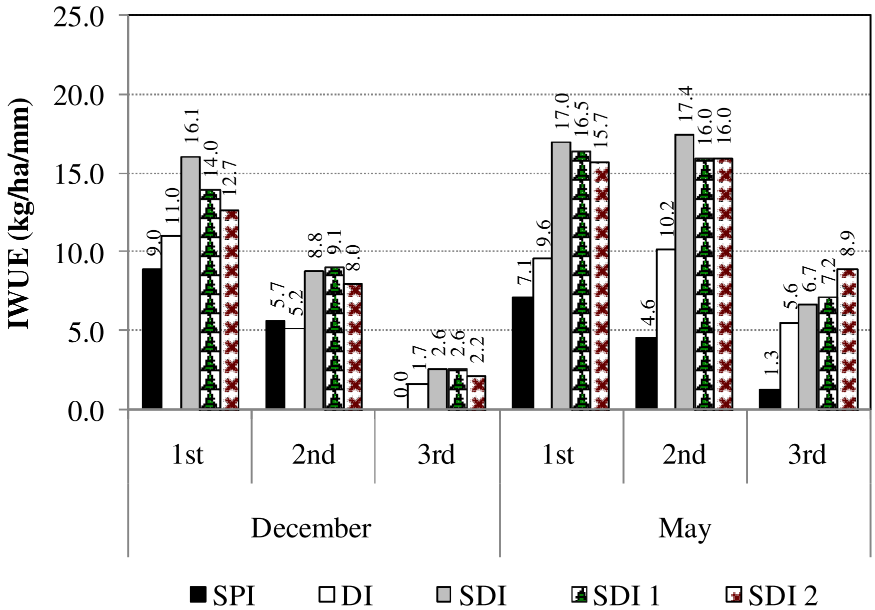

Figure 4. Irrigation water use efficiency in the first and second planting cycles as affected by irrigation treatments.

all treatments was almost similar, but lower than that recorded in the third cut. Results of water supply in the second planting cycle showed clear trend in water supply for each treatment and cut compared to that of the first one. The highest water supply found in SPI followed by DI, SDI, SDI 1 and SDI 2 respectively. However, water supply in SPI was very high compared with other treatments. Moreover, the highest water supply was in the first cut followed by second and third cuts,respectively. Result of water supply showed gradual decrease in total water supply from SPI to SDI 2 especially during the second growing cycles. Since the water supply was automatically controlled by WEM for all treatments as explained in the methodology section, the result observed might be due to the actual water requirement. Irrigation water supply under SPI was low compared to DI and SDI because of high evaporation demand under SPI especially during windy days. Increasing evaporation demand increased water supply. Similarly to SPI, DI received higher water supply compared to SDI due to surface evaporation, while SDI has no surface evaporation.

Table 4 presented the wend speed km/day which clearly indicated that wind speed was high in the second growing period than in the first one. Increasing wind speed increased evaporation demand especially in SPI system. Waddell et al. (1999) and Onder et al. (2005) reported that irrigation amount varies with irrigation methods and levels. Similar results were also reported by El-Damry (2006) and Ismail and Almarshadi (2011). The greatest reduction in water supply found in SDI2 followed by SDI1 might be due to the actual water requirement in addition to stress. Since SDI 2 and SDI 1 were stress treatments, the reduction in water supply is expected because in stress treatments plants were not fully irrigated as in field capacity treatments (Ismail and Almarshadi, 2011). The increase in water supply from cut 1 to 3 during the first planting cycle and its decrease in second planting cycle might be due to weathering conditions. During the first planting cycle, air temperature is gradually increased and relative humidity is gradually decreased resulting in high water supply from cut 1 to 3. While during the second planting cycle, air temperature decreased and relative humidity increased resulted in decreasing water supply from the first to the third cut (Table 4). Similar results were found by Orloff et al. (2005).

Effect of irrigation treatments on irrigation water use efficiency (IWUE)

One of the objectives of this study was to maximize pear millet production per unit of applied water. Achieving the greatest yield for a unit of water applied is known as irrigation water use efficiency (IWUE) which is defined as the ratio of the crop yield (t ha^{-1}) to seasonal irrigation water (mm) applied including rain (Howell, 1994). The IWUE values are affected by many factors such as: reducing the irrigation water lost to drainage, canopy interception, soil type, cultural and management practices, and variety choice. Results of IWUE are presented in Figure 4. They showed that the IWUE decreased by increasing number of cuts during the first

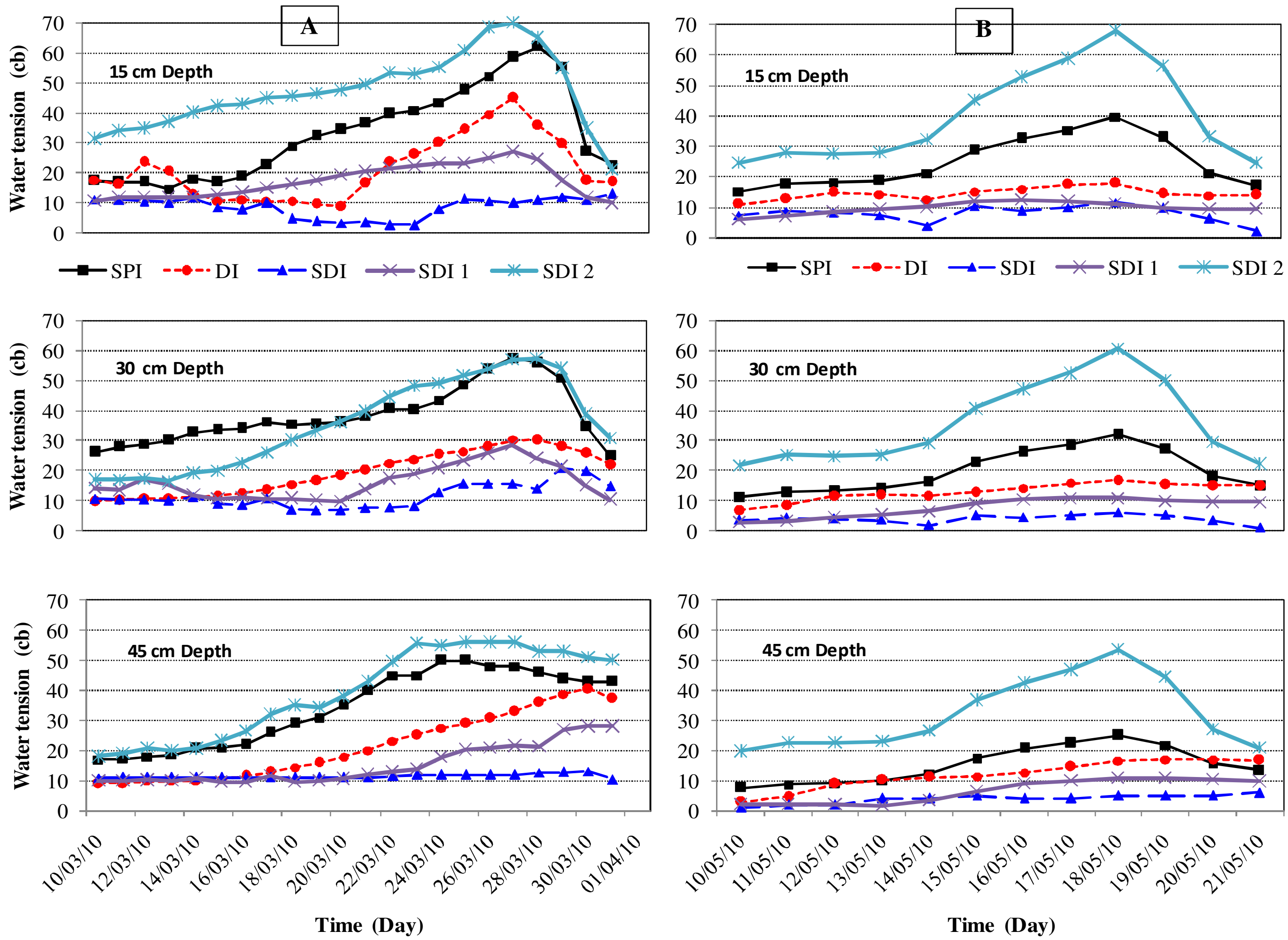

Figure 5. Soil water tension in centibar (cb) distribution for irrigation methods and treatments during the first planting cycle (A) and the second planting cycle (B).

planting cycle. The highest IWUE was recorded in the first cut followed by second and third cuts respectively. In the second planting cycle, the highest IWUE was obtained from the first and second cuts and was similar, while the least IWUE was recorded in the third cut. Results also show that the highest IWUE was obtained from SDI followed by SDI 1, SDI 2, DI and SPI respectively, for first and second planting cycles except for the third cut in the second planting cycle where the highest IWUE was recorded in SDI2 followed by SDI 1, SDI, DI and SPI, respectively (Figure 4). Moreover, the results showed that IWUE in the second planting cycle was higher than that in the first one. Maximum yield is obtained under field capacity conditions. In the current experiment, SPI, DI and SDI treatments were grown under field capacity conditions. However, the highest yield was obtained from SDI treatment compared to SPI and DI. This might be due to its minimal losses of supplied water.

No surface evaporation in SDI occurred compared to SPI and DI. Producing the maximum yield with the minimum irrigation water resulted in high IWUE. Producing millet under water stress decreased IWUE as in SDI 1 and SDI 2 compared to SDI. Water stress decreased the number of tiller, plant height and size of leaves and consequently reduced yield. The reductions in total yield reduce IWUE. Ibrahim et al. (1995) and Seghatoleslami et al. (2008) reported that water stress reduces IWUE of millet. Increasing IWUE of SDI 1 and SDI 2 compared to SPI and DI are probably due to the high obtained yield with less water supply compared to SPI and DI.

Soil moisture tensions

Water mark sensor readings in the period from 10 to 31/3/2010 for the first planting cycle (A) and from 10 to 25/5/2010 for the second planting cycle are presented in Figure 5. The sensors were buried at 15, 30 and 45 cm depth in the root zone. Results show that the highest soil moisture tension was measured in SDI 2 followed by SPI, DI, SDI 1 and SDI, respectively. The soil water tension was decreased by increasing soil depth. The average soil water tension ranged from 10 to 20 cb in SDI and SDI 1 for first and second planting cycle in all depths (15, 30 and 45 cm). The average soil moisture tension for DI ranged from 10 to 30 cb in the first growing cycle, and sometimes it reached 40 cm [(at 15 cm depth (Figure 5A)]. The average soil moisture tension for DI in the second planting cycle was below 20 cb in all depths. The highest soil water tensions ranged from 30 to 70 cm in SDI 2 and SPI, but SDI2 was higher in SPI. Results of soil moisture tensions are presented in Figure 5 indicating that the soil moisture tension of SPI, SDI and DI were almost equivalent to that at field capacity level. Shoack et al. (2005) reported that the watermark reading of 0 to 10 cb indicates that the soil is saturated, 10 to 20 cb indicates that the soil is near field capacity, 20 to 60 cb is the average field soil water tension prior to irrigation, varying with the crop, soil texture, weather pattern, irrigation system and 80 cb indicates dryness. This means that, the soil water content was almost at field or near field capacity level in SDI, SDI 1 and DI, especially during the second planting cycle, indicating that the WEM is considered as a good tool for automatically and precisely control irrigation. SPI showed high water tension especially at first planting cycle. These results might be due to high evaporation demand and low system efficiency of SPI due to the increase in temperature and wind speed as well as the decrease in relative humidity started from March (Table 4).

Increasing temperature and decreasing relative humidity increased evaporation demand while increasing wend speed drastically reduce SPI efficiency. All these parameter together reduced soil moisture and consequently increased soil water tension and sometimes happened in DI due to high surface evaporation. The highest water tension was found in SDI 2. This is expected because it is the highest water stress treatment. In this treatment, WEM succeeded to apply the required stress level during the whole growing period.

Conclusions

The findings of this study are very important for decision makers and growers of arid regions. SDI treatment gave the highest fresh and dry biomass followed by SDI 1 compared to other treatments. Increasing water stress decreased biomass production, but SDI with water stress increased biomass production compared to SPI with full irrigation requirement. In this respect using SDI with and without stress is better than using SPI. The maximum IWUE was obtained from SDI treatments. IWUE is decreased by increasing number of cuts. For efficient water use only one cut should be taken when cultivating millets in December and two cuts when cultivating in May. Results proved that WEM is a practical tool to precisely supply irrigation water when and where needed. In conclusion, SDI system with WEM technology can be successfully used to efficiently produce green fodder from millets with a maximum of two cuts per season under limited water resources in arid countries.

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