ORIGINAL ARTICLES

Effects of Water Stress Applied with Sub-surface Drip Irrigation on Forage Productivity and Water Use Efficiency of Alfalfa under Precise Irrigation Practice in Arid Climate

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ABSTRACT

A field experiment studied the effect of water stress on alfalfa productivity and water use efficiency was conducted at the Agricultural Experimental Station of King Abdul-Aziz University. The design of the experiment was Randomized Complete Block Design (RCBD) with four replicates, consists of three treatments namely: field capacity treatment (FC) as a control, 85% FC and 70% FC as stress treatments. The irrigation water for all treatments was precisely supplied using Water Electronics Module (WEM). The results indicated that, decreasing water supply decreased fresh and dry yield of alfalfa however it increases IWUE indicating more efficient use of water by the crop and consequently increasing water saving. 13% and 27% of irrigation water can be saved from 85% FC and 70% FC in each cut when it compared with FC treatment. The reduction of water supply resulted in yield reduction by 12% and 21.7% for 85% FC and 70% FC, respectively. The results also proved that WEM is a practical tool to precisely supplied irrigation water and can be use effectively to control deficit irrigation.

Key words: Sub-surface Drip Irrigation, Precise Irrigation, Alfalfa, Deficit Irrigation.

Introduction

Changes in water allocation precise use of water has important implications for the economic and environmental sustainability of agriculturally based economies. In many arid countries, declining groundwater is a bigger threat to irrigated agriculture like in Saudi Arabia. There is growing interest in the potential of limited irrigation in cropping systems as a means of addressing changing water supply and demand issues while still supporting profitable agricultural systems. Limited irrigation is a technique that irrigates the entire root zone with less evapotranspiration and leads to reduce the irrigation water use with maintaining farmers’ net profits (Hoffman et al., 1990).

Alfalfa is a good candidate crop for limited irrigation for several reasons. First, under full irrigation, alfalfa consumes large quantities of water during the growing season, thus leaving a large potential for water savings through limited irrigation practices. Second, alfalfa has drought and water stress tolerance mechanisms that make it biologically suited to limited irrigation. A third reason that alfalfa is suited for limited irrigation is the potential for managing limited irrigation supplies in a way that promotes higher quality hay, partially offsetting yield reductions with a higher sale price (Lindenmayer et al., 2008).

Jensen and Miller (1988) found that the amount of water needed to produce a ton of alfalfa hay during the 1984 and 1985 growing seasons were from 6.1 to 8.4 inches of water. The relationship of yield to ET is linear, with the slope of this line indicating an average yield of 0.156 Mg ha⁻¹ cm⁻¹ (5.6 in ton⁻¹). Although. There is a lot of variability in the yield and ET relationship, caused by factors such as climate variation, pest damage, and harvest method and timing, (Lindenmayer et al., 2008). Both spatial and seasonal climatic variation

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affects alfalfa water-use efficiency.

In a study carried out by Undersander, (1987) compared the yield and ET relationships for individual hay cuttings across growing season and found that the relationship changes depending on the cutting. In that study, the first and fourth cuttings had higher WUE than the middle two cutting. This makes sense because alfalfa is a C3 plant that is adapted to the cooler temperatures in the spring and fall cuttings and looses efficiency during the hotter summer cuttings. Lindenmayer et al. (2008) hypothesized that alfalfa water use efficiency in a limited irrigation system would be improved by applying the limited irrigation only during times with higher seasonal WUE rather than applying reduced amounts of irrigation throughout the entire growing season.

Some of the most advanced irrigation technology is subsurface drip irrigation (SDI). SDI is the slow, frequent application of small amounts of water to the soil through emitters located on a delivery line placed beneath the soil surface. SDI allows for highly productive crop production without leaching or runoff. Only the amount of water needed by the crop on a daily, or other very frequent basis need be diverted from a stream or reservoir, thus helping to also protect water quality (Neufeld, 2001). El-Damry (2006) said that subsurface drip irrigation system is one of the modern irrigation techniques used around the world, but it is applied in limited scale in Saudi Arabia. The subsurface drip irrigation has many advantages especially in regions have limited irrigation water sources such as in Saudi Arabia. Henggeler (1997) stated that alfalfa would benefit more than most crops from SDI because of its heavy water use.

Since a benefit of converting to SDI is a leap in system efficiency, the implication is that larger amounts of water (and thus money) are saved on crops like alfalfa. He lists several reasons why one might consider installing SDI in an alfalfa field: 1) increases hay yields due to the ability to apply water through harvest time, 2) potential water savings because alfalfa is a large user of water, increased water use efficiency will theoretically reduce the amount used resulting in lower costs; 3) decreases weed infestation because the surface is dry, the potential for weed infestations is reduced and 4) elimination of leaf burn and/or scalding since sprinkler applications can cause foliar burns when high levels of Na+ or Cl- are present in the water.

Neufeld, (2001) conducted an experiment with three acre SDI and he found that the amount of water needed to produce ton of alfalfa hay were from 1.94 to 2.33 inches of water. Phene et al. (1992) carried out an experiments related to the environmental aspects of SDI. On a clay loam soil with drip tubes placed 0.45 meters below the soil surface, they found that soil water remains in the root zone for utilization by growing plants, not lost to deep percolation. In a study conducted on alfalfa by Hutmacher et al. (1992) soil water data suggest little or no potential for deep percolation losses. Alam et al. (2002) found that the scope of losses due to deep percolation and surface evaporation is greatly reduced by SDI. Lamm et al. (1995) said that that it is possible to save 25 percent of total water diverted in the season by using SDI.

Orloff et al. (2005) reported that if a production system were developed that reduces the amount of water applied to alfalfa, it could result in a considerable water savings, while maintaining forage production systems. In their study they found that, during spring and early summer alfalfa cuttings are often higher in yield and forage quality than late summer or fall cuttings, then a deficit irrigation approach was suggested. The scenario is to adequately irrigate alfalfa in the spring until June or July, and then cease irrigation to conserve water. This approach allows for harvest of the first cutting(s) in the spring and early summer, which typically represent a significant portion of the annual production. Seasonal water use is highest in midsummer and lower in spring and fall. As a result, yield and water use pattern, the water use efficiency or the amount of crop per unit of water is greatest in spring. It is believed that, improving irrigation system performance to applied water uniformly over the field had received and stills, a great attention in research and technology or industry, and reached a stage, in which, any further improvements will not significantly increase in profitability. It is important now to shift toward and concentrate on maximization of the net profit from this water through applying it in the appropriate place and quantity.

Applying irrigation water in the right place with the right amount at the right time is known as precision irrigation, however, it is still in the development stages and requires a lot of experimental works to determine its feasibility and applicability (Al-Karadsheh et al. 2002). It is possible to take the advantages of some existing technologies to be adapted for precision irrigation, such as speed-control systems.

Other option is to take advantage of pulse concept to control single sprinkler (Frassie et al., 1995a and b), single span or small segments along each span (Omary et al., 1997; Camp et al., 1998), through solenoid valves, which are known in irrigation market, but this needs software to control its operation. Therefore, the next generation in irrigation scheduling should be re-defined to have the ability to apply the right amount of water directly where it is needed, therefore, saving water through preventing excessive runoff/leaching is expected. Our current research will apply precision irrigation technology using Water Electronic Module (WEM) as a tool to apply irrigation water when and where needed.

The main goal of this study is to maximize water use efficiency or obtained more crop per drop through not only the application of sub-surface drip irrigation but also through application of limited subsurface drip
irrigation during the whole growing season to fulfill the following detailed objectives: 1) determine the response of growth parameters and yield of alfalfa to identify the most appropriate strategy which reducing water use of alfalfa; 2) estimating irrigation water use efficiency associated with each treatment, and 3) estimate water savings that might be used for transfer elsewhere.

Materials and Methods

Experimental location and design:

The study was carried out at Agriculture Experimental Station belongs to King Abdulaziz University (KAU) located at Hada Alsham village, 110 km north east of Jeddah, KSA during the growing seasons of 2009 - 2010. The soil was classified as sandy clay loam. The Climate of the area is arid with a hot summer. The design of the experiment was RCBD, consists of three irrigation treatments and four replications with block size of 2 x 3 m. The 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

Installation sub-surface drip irrigation system and its automated procedure:

The field was level and the drip lines were buried at 10 cm below soil surface. Based on soil physical properties the distance between two adjacent drip lines was 40 cm and the distance between drippers was 30 cm. The type of the drip lines use in the experiment was RAIN BIRD LD 06 121000 Landscape drip 0.6 G/h @12”. Such distance between drip lines and drippers distribute the water and cover the whole root zone in subsurface drip irrigation. The water source was two containers with a capacity of 6000 L and each continuously fall of water from the main irrigation network. Irrigation was changed through the growing season based on precise irrigation technique known by WEM.

In WEM technology the 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 decreased 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 the control valves and the controller. The irrigation scheduler selects the appropriate moisture level on the dial of the WEM, and the controller is allowed to only run the irrigation cycles necessary. Then, truly automatic scheduling is provided.

Treatments:

Under the current study three irrigation treatments, one with fall irrigation requirement and two with deficit irrigation were investigated. A full irrigation treatment (FC) was 100% of the field capacity and considered as control. The second and third treatments were 85% FC and 70% FC. The appropriate moisture level on the dial of the WEM was adjusted to be 2, 4 and 6 to keep the moisture of the soil at field capacity level in first treatment and the required soil moisture in the second and the third treatments respectively. The irrigation water was automatically supplied every day.

Cultural Practices:

The alfalfa crop was sown manually in rows with 20 cm apart between each two adjacent rows and 10 cm apart from the drip lines using a seed rate of 60 kg ha\(^{-1}\) on 21 of December 2009. After sowing the seed the experiment was manually irrigated at filed capacity level until the first cut was taken, then the experiment was subjected to the investigated treatments and run automatically by WEM. The recommended dose of super phosphate fertilizer was applied at the time of seedbed preparation. The recommend dose of nitrogen fertilizer was added in the form of urea for one time after planting. The alfalfa crop was harvested twelve times starting from third of February, 2009. The following parameters were measured for each cut.

- **Plant length and number of tillers**: for each plot 5 plants were randomly selected and their length and number of tillers were recorded.
- **Leave to stem ratio**: the 5 plants which were used for measuring length and number of tiller for each treatment were clipped for fresh and dry determination leave to stem ratio.
• Fresh yield: for each irrigation method, one square meter from the center of the plot of each replicate was cut when 10% of plants were flowering and the fresh yield was determined, and the fresh yield per hectare was calculated. 12 harvesting were obtained during the course of the study.
• Dry yield: for each irrigation method plants within an area of 0.5 m² from the center of each plot were cut, oven dried at 70 °C until a constant weight was reached, and forage dry yield per hectare was calculated.
• Irrigation water supply: supplies irrigation water were daily recorded by collecting the reading of the gage installed with each irrigation system.
• Irrigation water use efficiency (IWUE): the IWUE (t.ha⁻¹ mm⁻¹) was estimated from dividing yield by depth of water applied including rainfall in mm.
• Soil water tension: soil water 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 stress treatments on growth parameters:

The effects of investigated treatments on growth parameters include plant length, number of tillers and fresh leave to stem ration were presented in table (1). The results indicated that there is no significant differences were found among treatments as indicated by means over the 11 cuts of 12. Only cut 7 showed significant differences between treatments where the highest plant length obtained from the treatments of 85% FC followed by 70% FC and FC respectively. The plant length ranged from 51.8 to 70.7 cm in all treatments. Number of tillers was not affected by stress treatments in 11 cuts of 12. Cut 7 showed significant increase in number of tillers for 85% FC compared with FC and 70% FC (table 1). 85% FC treatments generally increased leave to stem ratio however the increase was not significant in all cuts except for 10th cut where the highest leave to stem ratio obtained from FC treatments compared with other treatments. The results showed that plant length, number of tillers and leave to stem ration were slightly affected by water stress treatments because alfalfa (Medicago sativa) has genetic and morphological features that make it able to adapt and to grow with the conditions of seasonal rainfall and seasonal droughts. Similar results were published by Orloff et al. (2005) and Lindenmayer et al. (2008) who said that alfalfa has drought and water stress tolerance mechanisms that make it biologically suited to limited irrigation. The increase in plant length and number of tillers in 85% FC may be resulted from maintaining adequate oxygen and moisture in root zone area, similar results were reported by, (Irmak, 2008).

Fresh, dry yields and dry leave to stem ratio:

The forage fresh yield of alfalfa presented in table (2) varied significantly among the investigated treatments in the most of cuts except for cuts number 1 where no significant difference were found among treatments. The results showed that the highest fresh yield was obtained from control treatment which grown under field capacity conditions followed by 85% FC and 70% FC respectively. The forage productivity ranged from 10 to 14.2 ton/ha for FC, 8.82 to 13.8 ton/ha for 85% FC and from 7.46 to 11.7 ton/ha for 75% FC (table 2). The average decreases of forage fresh yield were 13% and 19% for 85% FC and 70% FC treatments compared with FC. The results of forage dry yield have similar trend as in forage fresh yield (table 2). The results indicated that stress treatments decreased the dry yield compare with FC. The production of dry yield ranged from 2.43 to 5.62 ton/ha for FC, from 1.79 to 5.32 ton/ha for 85% FC and from 1.99 to 4.06 ton/ha for 70% FC. The average decreases were 12% and 21.7% for 85% FC and 70% FC treatments compared with FC. Leaf to stem ratios were generally decreased by stress treatments however the decreasing were not significantly in 11 cuts out of the 12. Only significant decrease were obtained from the 5th cut where the highest leave to stem ratio obtained from FC followed by 85% FC and 70% FC treatments.

Table 1: Effect of water stress on plant length, number of tillers and fresh leaf/stem ratio of Alfalfa under precise irrigation practice

<table>
<thead>
<tr>
<th>Stress treatment</th>
<th>Growth characteristics</th>
<th>Cuts</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
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<th>9th</th>
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<th>11th</th>
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<tr>
<td>Plant length (cm)</td>
<td>FC</td>
<td>58.4</td>
<td>57.2</td>
<td>56.7</td>
<td>64.2</td>
<td>69.2</td>
<td>63.9</td>
<td>58.8</td>
<td>64.8</td>
<td>70.3</td>
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<td>60.8</td>
<td>59.4</td>
<td>62.4</td>
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<tr>
<td></td>
<td>85 % FC</td>
<td>51.2</td>
<td>55.0</td>
<td>56.7</td>
<td>62.8</td>
<td>68.0</td>
<td>69.3</td>
<td>64.3</td>
<td>65.0</td>
<td>70.0</td>
<td>70.9</td>
<td>58.4</td>
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<tr>
<td></td>
<td>70% FC</td>
<td>52.4</td>
<td>57.8</td>
<td>60.7</td>
<td>61.6</td>
<td>63.3</td>
<td>70.7</td>
<td>63.1</td>
<td>68.2</td>
<td>66.9</td>
<td>67.9</td>
<td>56.7</td>
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<td>LSD P= 0.05</td>
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<td>0.21</td>
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<td>0.19</td>
<td>0.51</td>
<td>0.36</td>
<td>0.66</td>
<td>0.49</td>
<td>0.91</td>
<td>2.08</td>
<td>1.18</td>
<td>2.36</td>
<td>1.07</td>
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<td>Number of tillers</td>
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<td>6.30</td>
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<td>4.10</td>
<td>4.65</td>
<td>3.80</td>
<td>5.80</td>
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<tr>
<td></td>
<td>85 % FC</td>
<td>2.55</td>
<td>2.55</td>
<td>2.80</td>
<td>4.50</td>
<td>5.55</td>
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<tr>
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<td>70% FC</td>
<td>2.90</td>
<td>3.5</td>
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<td>5.70</td>
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<td>5.10</td>
<td>3.95</td>
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<tr>
<td>Fresh Leaves /stem (%)</td>
<td>FC</td>
<td>0.96</td>
<td>0.52</td>
<td>0.48</td>
<td>0.31</td>
<td>0.56</td>
<td>0.48</td>
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<tr>
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<td>85 % FC</td>
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<td>4.44</td>
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<td>1.78</td>
<td>1.18</td>
<td>2.36</td>
<td>1.07</td>
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</table>
As indicated by the results in table (2) stress treatments decreased fresh and dry yield compared with FC treatment. There is a lot of variability in the yield and ET relationship, caused by factors such as climate variation, pest damage, and harvest method and timing; however the relationship of yield to ET is consider linear which mean that decreasing irrigation water supply resulted in decreasing alfalfa hay (Lindemnayer et al., 2008). The study findings were comparable to those obtained by Saeed and El-Nadi (1997) who stated that maximum yield for six harvest of alfalfa were 15.3, 12.9 and 11.2 t/ha for the frequent, less-frequent and infrequent irrigation regimes respectively. They also concluded that alfalfa crop when grown under semi-arid conditions should be irrigated in small increments and frequently to attain high yield. The results also were comparable with the findings of Lazaridu and Noitsak is (2003) who published a reduction in the above ground biomass to one third of irrigated plants. Moreover the results were similar with those reported by Al-Naem (2008) who found that alfalfa dry yield could be severely affected under water stress irrigation management.

Increasing leave to ratio led to increase forage quality, (Abu-Suwar and Bakri, 2009). Results showed that the effect of investigated treatments on leave to stem ratio was not significant however, FC treatment increased leave to stem ratio compared with others treatments indicating that the forage quality may decrease under water stress conditions. Under water stress conditions leave size was decreased, consequently leave to stem ration was decreased. Similar results were found earlier by Phene (1995) and Weatherhead and Knox (1998).

The results of fresh and dry yield of the first cut presented in table (2) showed that the highest yield recorded in 70% FC followed by FC and 85% FC. The results of this cut were harvested before subjecting the experiment to stress treatments and all the treatment were at field capacity level.

**Effects of stress treatments and precise irrigation on water supply:**

The water supply for alfalfa under investigated treatments was different because water supply was controlled by fully automated systems. The system was run and controlled by WEM. The WEM was connected with two Moisture sensors measuring the soil water tension at 10 and 30 cm depths within the root zone. When the water tension in the root zone exceed the adjusted tension of WEM, the system permit irrigation water to flow until reach the required water tension as in FC treatment and at 85% FC and 70% FC for stress treatments respectively. The daily water supply was calculated from the gage of each treatment. Then the water supply for each cut including rainfall was calculated and presented in table (3) and Figure (1). The results showed that the highest water supply during the whole growing season was recorded in FC treatment. The water supply was gradually decreased in stress treatments where it was higher in 85% FC than in 70% FC (Fig. 1). The results also showed that the water supply was gradually increased in all treatments for each consecutive cut until reached its peak in the 7th cut, then it is gradually decreased to reach its minimum supply in 9th cut and continued with the same water supply up to 12th cut.

The results of seasonal water supply in mm (12 cuts) for investigated treatments were presented in Fig. (2). The results clearly indicated that the highest water supply was recorded in FC followed by 85% FC treatments while the least water supply obtained from 70% FC. The seasonal water supplies were 3725.3, 3247.5 and 2722.6 mm for FC, 85% FC and 70% FC, respectively.

The results showed that there was a gradual decrease in water supply by increasing stress. This is logic because in stress treatments the plants were not fully irrigated as in FC treatment. Increasing water supply
in each consecutive cut along the growing season up to the 7th cut and then decrease were due to the weather conditions. The air temperature is gradually increasing and relative humidity is decreasing from February (2nd cut) until reaching its maximum in mid of July (7th cut) then, again temperature decrease and relative humidity increase until January. The change in seasonal temperature and humidity resulted in the change of water supply of investigated treatments.

Fig. 1: Effect of water stress treatment on water supply of each cut for Alfalfa under precise irrigation practice.

Fig. 2: Effect of water stress treatments on total water supply for Alfalfa under precise irrigation practice

The results are similar to those found by Orloff et al. (2005) who found that seasonal water use is highest in midsummer and lower in spring and fall. They reported that spring and early summer cuttings are often higher in yield and forage quality than late summer or fall cuttings. Yield per cutting normally trails off in fall as temperature and day-length decline. Therefore, a high percentage of the total seasonal production occurs before midsummer. They also suggested that deficit irrigation scenario would be to adequately irrigate alfalfa in the spring until June or July, and then cease irrigation to conserve water. Waddell et al. (1999) and Onder et al. (2005) also reported that irrigation amount varied with weather conditions, irrigation methods and levels.

Effects of stress treatments on irrigation water use efficiency (IWUE):

The IWUE (t ha⁻¹ mm⁻¹), was defined as the ratio of the crop yield (t ha⁻¹) to irrigation water (mm) applied, including rain. While the WUE had been defined as the ratio of dry matter produced per unit area (t ha⁻¹) per unit of ET (mm). Under the current study the supplied water was based on the actual water consumption in the root zone where irrigation water was automatically supplied when needed. That means supplied water was equal to ET of alfalfa so that, the IWUE is the same as WUE. The results of IWUE or WUE were presented in table (3). The results showed that the highest IWUE obtained from 70% FC followed by 85% FC and the least IWUE recorded in FC for both fresh and dry yield in all cuts (12 cuts). The value of IWUE for FC ranged from 0.018 – 0.066 t ha⁻¹ mm⁻¹ for fresh yield and from 0.0043 – 0.018 t ha⁻¹ mm⁻¹ for dry yield. For 85% FC the IWUE were ranged from 0.016 – 0.077 t ha⁻¹ mm⁻¹ and from 0.0045 – 0.035 t ha⁻¹ mm⁻¹ for fresh and dry yield respectively. In 70% FC the IWUE were 0.017 – 0.086 t ha⁻¹ mm⁻¹ and 0.0049-0.028 t ha⁻¹ mm⁻¹ for fresh and dry yield respectively, table (3).

The results revealed that, increasing water stress increased IWUE. Water stress decreased losses via WEM by applying precise required irrigation water when and where needed. The results are comparable with those
reported by Al-Jamal et al. (2001) who said that IWUE can be increased by decreasing losses since the IWUE values affected by reducing the irrigation water lost to drainage, canopy interception, soil type, cultural and management practices. As shown in table (3) the least amount for water supply found in 70% FC followed by 85% FC and the largest supply of irrigation water was in FC treatment, (table 3 and Figs. 1,2).

| Characteristics          | Stress treatment | Cuts       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|--------------------------|------------------|------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Water supply for each cut (mm) | FC               | 310.4      | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 | 310.4 |
| 85 % FC                  | 268.5            | 203.7      | 223.2 | 244.4 | 397.9 | 503.3 | 251.5 | 160.1 | 235.6 | 150.0 | 150.3 | 270.6 |
| 70% FC                   | 237.6            | 179.6      | 187.2 | 200.8 | 203.2 | 208.5 | 208.2 | 203.1 | 213.4 | 193.6 | 121.5 | 140.4 |

IWUE for fresh yield (t ha⁻¹ mm⁻¹) |

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<tr>
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<tr>
<td>85 % FC</td>
<td>0.0514</td>
<td>0.0535</td>
<td>0.0392</td>
<td>0.0415</td>
<td>0.0213</td>
<td>0.0287</td>
<td>0.0166</td>
<td>0.0469</td>
<td>0.0706</td>
<td>0.0531</td>
<td>0.0747</td>
<td>0.0772</td>
<td>0.0479</td>
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<tr>
<td>70% FC</td>
<td>0.0696</td>
<td>0.0580</td>
<td>0.0412</td>
<td>0.0438</td>
<td>0.0247</td>
<td>0.0274</td>
<td>0.0187</td>
<td>0.0562</td>
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<td>0.0694</td>
<td>0.0773</td>
<td>0.0656</td>
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IWUE for dry yield (t ha⁻¹ mm⁻¹) |

<table>
<thead>
<tr>
<th>Stress treatment</th>
<th>Cuts</th>
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<tbody>
<tr>
<td>FC</td>
<td>0.0091</td>
<td>0.0101</td>
<td>0.0121</td>
<td>0.0066</td>
<td>0.0058</td>
<td>0.0067</td>
<td>0.0045</td>
<td>0.0099</td>
<td>0.0188</td>
<td>0.0146</td>
<td>0.0329</td>
<td>0.0354</td>
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<tr>
<td>85 % FC</td>
<td>0.0087</td>
<td>0.0113</td>
<td>0.0121</td>
<td>0.0066</td>
<td>0.0058</td>
<td>0.0067</td>
<td>0.0045</td>
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<tr>
<td>70% FC</td>
<td>0.0114</td>
<td>0.0170</td>
<td>0.0168</td>
<td>0.0055</td>
<td>0.0067</td>
<td>0.0054</td>
<td>0.0049</td>
<td>0.0117</td>
<td>0.0208</td>
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FC = Field Capacity

Increasing yields with minimal water supply sharply increase IWUE. This may be due to the ability of alfalfa plant to more effectively use water from the soil profile and also the ability of it to go to dormant during water stress resulting in higher IWUE, (Lindenmayer et al., 2008). Sammis and Wu (1986) and Al-Jamal et al. (2001) found that IWUE increased under soil moisture stress and by practising deficit irrigation. A sharp increase in water use efficiency obtained by deficit irrigation, (Dorji et al., 2005 and Ismail (2010). Shock et al. (2007) who investigated the effect of deficit irrigation for optimum alfalfa seed yield and quality, they concluded that seed weight increased with increasing ETc replacement level, but the largest increase occur from 20-60% ETc. They suggested that alfalfa seed production can be optimized with 50% ETc replacement using drip irrigation.

Water saving and yield reduction in relation to stress treatments:

The average water supply (mm) and the average dry hay yield ton/ha for each cut of the investigated treatments were presented in table (4). The water saving and yield reduction for stress treatments (85% FC and 70% FC) in percent were calculated in relation to FC treatment. The results indicated that by applying irrigation water in a rate of 85% FC and 70% FC, 13% and 27% of irrigation water can be saved, respectively. However, decreasing water supply below the field capacity led to decrease hay yield of alfalfa. The reductions in alfalfa yield were 12% and 21.7 % for 85% FC and 70% FC respectively (table 4).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Average water saving and yield reduction for each cut in relation to control (FC treatment).</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC</td>
<td>310.4</td>
</tr>
<tr>
<td>85% FC</td>
<td>270.6</td>
</tr>
<tr>
<td>70% FC</td>
<td>226.6</td>
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</tbody>
</table>

When average yield and water supplied for each cut basis are regressed, the relationship between water supply and yield reduction was linear, (Fig. 3). That means decreasing water supply increasing yield reduction. The results are comparable with the results obtained by Lindenmayer et al. (2008) who said that the relationship of yield to ET is linear. Moreover, Undersander (1987) reported that the relationship between yield and ET for individual hay cuttings across growing season depending on the cutting.

Soil moisture content distribution:

Water mark sensor readings during three months of the growing season were presented in Fig. 4 and 5. The sensors were buried at 15 and 45 cm depth in the root zone. The results showed that, the average soil water tension at 15 cm depth ranged from 10 -20 centibar (cb) in FC treatment, 10-40 cb in 85% FC and 30-60 cb in 70% FC treatments respectively. The least water tension (highest soil moisture content) obtained from FC followed by 85% FC and 70% FC respectively. Similar trend of distribution found at 45 cm depth (Fig. 5). The soil water tension was little lower than in 15 cm depth. The soil water tension at 45 cm depth were from 5-20 cb in FC and 85% FC respectively while it was from 30-40 in 70% FC and sometimes reached to 70 cb (Fig. 5).
The obtained results of soil water tension presented in figure 4 and 5 are in line with those reported by Shock et al., (2005) who said, 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, and irrigation system and  80 cb indicates dryness. The obtained results (figs. 4 and 5) indicated that the soil water content of FC treatment were almost at field capacity level while 85% FC treatments was near from field capacity and 70% FC was in between field capacity and dryness level.

At 45 cm depth the soil water tension was lower than at 15 cm however, it is gradually increased by increasing stress. The results may be due to presence of high density rooting system at 15 cm depth. Because of our subsurface drip irrigation was installed at 10 cm below soil surface, higher soil water content in that
root zone area was presented and resulted in high density of root growth. Presence high density root led to high soil moisture extraction and consequentially, high soil water tension at 15 cm depth compared with 45 cm. The results are in line with those found by Abdul-Jabbar et al. (1982) who reported that alfalfa root mass and yield were highest under high moisture level and by (Kramer, 1995 and Al-Omran et al., 2005) who reported that root growth extends in all directions and if it encounters an area high in moisture or minerals it grows and branches profusely because of the less resistance in the wet soil. Ismail and Ozawa (2007) reported that 60 to 75% of roots was presented in upper 20 cm soil profile. The results of water ccontented proved that WEM is an effective tool to precisely control deficit irrigation and succeeded to precisely supplied the require amount of irrigation water when needed.

Conclusion:

The findings of this study have potentially very important implication for decision makers and alfalfa producers. Decreasing water supply decreased fresh and dry yield of alfalfa however it increases IWUE and consequentially water saving. For each cut of alfalfa 13% and 27% of irrigation water can be saved from 85%FC and 70% FC respectively (table 4). The reduction of water supply resulted in yield reduction by 12% and 21.7% for 85% FC and 70% FC respectively. However, as water supply decreased IWUE increased indicating more efficient use of water by the crop. The results also proved that WEM is a practical tool to precisely supplied irrigation water and can be use effectively to control deficit irrigation. In conclusion, in a country with limited water resources like Saudi Arabia and faced by decreasing irrigation water supply, deficit irrigation could be a feasible irrigation technique to be used where the benefit from saving large amounts of water outweighs the decrease in total fresh and dry yields of alfalfa crop.

References


