Effects of Precision Irrigation on Productivity and Water Use Efficiency of Alfalfa under Different Irrigation Methods in Arid Climates

Mohammed H. Almarshadi and Saleh M. Ismail

Associate professors at Arid Land Agriculture Department, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Arabia

ABSTRACT

A field experiment comparing different irrigation methods (Sprinkler Irrigation “SPI”, surface drip “DI” and sub-surface drip “SDI) were precisely controlled for alfalfa productivity and water use efficiency. The experiment was conducted at the Agricultural Experimental Station of King Abdel-Aziz University. The design of the experiment was Randomized Complete Block Design (RCBD) with four replicates, consists of three irrigation methods. Water Electronics Module (WEM) technology was used to fully controlled the irrigation methods. The results revealed SDI increase growth parameters (plant length, number of tillers and leaf to stem ratio) compared with DI and SPI. The least water supply was recorded in SDI followed by DI and SPI respectively while the highest IWUE obtained from SDI followed by DI and the least IWUE was recorded in SPI. SDI and DI saved 35.7% and 29.2% of irrigation water compared with SPI. In spite of decreasing water supply under SDI and DI high dry yield was obtained. The increase in dry yield was 45% in SDI and 15.9% in DI compared with SPI. The results of experiment especially soil moisture data proved that WEM is a practical tool to precisely supplied irrigation water when needed and can be recommended for efficiently controlled different automated irrigation systems.

Key wards: Irrigation methods, precision irrigation, Alfalfa.

Introduction

Throughout the world, water is considered the most precious and heavily scrutinized natural resource, particularly in the arid lands. Alfalfa (Medicago sativa L) considers one of the most important forage crops in many counties as well as, Saudi Arabia due to its adaptability to different environments, excellent nutritional quality, and high forage yields. It consumes large amount of water regardless the scarcity of water which plays a critical role in the Kingdom's development plans. Because of its high water use, alfalfa is often in the crosshairs of regulators and environmentalists searching for new sources to satisfy the increasing urban demand and for environmental mitigation efforts (Orloff et al., 2005).

The use of precision farming for irrigation water management/scheduling known as precision irrigation, in order to apply water in the right place with the right amount at the right time, 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 believed that, improving irrigation system performance to applied water uniformly over the field had received and stills, a great attention in hands, 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. It is possible to take the advantages of some existing technologies to be adapted for precision irrigation, such as speed-control systems, which are still used for constant speed along the whole field, although it can be used for different speeds. 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.

When irrigation engineers designing an irrigation system, they try to maximize irrigation efficiency (IE) which, defined as the ratio of the volume of water that is taken up by the crop to the volume of irrigation water applied, (the American Society of Civil Engineers, ASCE, 1978). Drip irrigation has the potential to increase IE, because water can be applied in light and frequent amounts to meet crops Et needs. The IE, ranged from 80 to 91% when the crop was grown in fields using a surface drip system (Battikhi and Abu-hammad, 1994; Chimonides, 1995). Under sprinkler irrigation IE, ranged from 54 to 80% (Chimonides, 1995; Zalidis et al., 1997). Recently, subsurface drip irrigation is under evaluation to improve water use efficiency since water is getting more scarce and more valuable year by year (Onder et al., 2005).

Government policy makers are usually interested in achieving the greatest yield for a unit of water applied. Therefore, they are more interested in irrigation water use efficiency, IWUE (t ha⁻¹ mm⁻¹), 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. Previous research shows a higher IWUE for subsurface drip (from 0.0283 to 0.227 t ha⁻¹ mm⁻¹), surface drip (from 0.0235 to 0.127 t ha⁻¹ mm⁻¹) and sprinkler systems (from 0.0044 to 0.0659 t ha⁻¹ mm⁻¹) compared with furrow irrigation (from 0.0086 to 0.056 t ha⁻¹ mm⁻¹) (Sammis, 1980; Bogle et al., 1989; Lamm et al., 1995). Water use efficiency (WUE) has been defined as the ratio of total dry matter per unit of Et (Begg and Turner, 1976); as the ratio of dry matter produced per unit area (t ha⁻¹) per unit of Et (mm) (Jensen et al., 1981), and as the ratio of photosynthesis per unit of water transpired (Sinclair et al., 1984), consequently, care should be taken when comparing different WUE values.

In the current research we try to achieve the greatest yield per unit of water using very sophisticated technology called Water Electronic Module (WEM) to apply precision irrigation. The main objectives of this research were to: 1) investigate the WEM technology for implementing precision irrigation when and where needed under different irrigation method; 2) measure forage production of alfalfa under different irrigation methods when they precisely controlled; 3) calculate irrigation water use efficiency under different irrigation methods as affected by precision irrigation; 4) calculate water saving under DI and SDI compared with SPI as result of using precise irrigation.

Materials and methods

Experimental Location and Design:

The study was conducted during the period from December 2009 to December 2010, at Agriculture Experimental Station of King Abdulaziz University (KAU) located at Hada Alsham village, 110 km north east of Jeddah, KSA. The soil texture is sandy clay loam. The Climate of the area is arid with high temperatures during summer season. The design of the experiment was Randomized Complete Block Design (RCBD), consists of three irrigation methods and four replicates with block size of 2×3 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.

Irrigation System Installation:

Three irrigation methods namely: sprinkler (SPI), surface drip (DI) and subsurface drip irrigation (SDI) were investigated. In sprinkler irrigation 2045-PJ Maxi-Bird™ rotator was used. The inlet pressure on the system was 2 bars. With this pressure the radius of the rotator was 11 m with a maximum discharge of 0.68 m³/h. The design of the sprinkler system is based on the features of the rotator, where the distance between each adjacent sprinklers and lines was 11 m to give 100% 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/hr @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 uses 125 micron disk filter. The water source was two containers with a capacity of 6000 L for each. They always full of water via the main irrigation network. The lay-out of the surface drip irrigation was exactly the same as in subsurface drip except for the positions of dripper lines, where they installed on soil surface.
Automated Procedure:

All systems were automatically control 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. Under the current study the appropriate moisture level on the dial of the WEM was adjusted to keep the moisture of the soil under all irrigation systems at field capacity level.

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. The whole experimental area of the experiment were irrigated by sprinkler irrigation at the first 15 days of cultivation until the germination was completed, then the experiment was subjected to the treatments as explained previously. 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.

• **Leaf 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 period of the study.

• **Dry Yield:**
  
  For each irrigation method plants within an area of 0.5 m²from the center of each plot were cut, oven dried at 70 °C, 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.

• **Water Saving:**
  
  water saving in relation to SPI is calculated as follow:
**% of Water Saving**

\[
\% \text{ of Water Saving} = 100 - \left( \frac{\text{seasonal supply of SDI or DI in mm}}{\text{seasonal supply of SPI in mm}} \times 100 \right)
\]

**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 of Precise Irrigation and Methods on Growth Parameters:

The effects of investigated irrigation methods on growth parameters include plant length, number of tillers and fresh leave to stem ration were presented in table (1). The results indicated that SDI and DI significantly increased plant length in 6 out of the 12 cuts compared to SPI. The highest plant length obtained from cuts number 5 and 9 of SDI where the plant lengths were 69.2 and 69.3 cm, respectively. The plant length generally increased under SDI compared to DI however the increasing was significant in only 3 cuts out of the 12 which were cuts number 3, 5 and 10. SDI and DI significantly increased number of tillers in 3 out of 12 cuts compared to SPI.

Generally, the least number of tillers obtained from SPI except for cuts number 6 and 7 where number of tillers were higher than that in SDI and less than that in DI for cut number 6 and were the highest in cut number 7. SPI increased leave to stem ratio in most of cuts compared with SDI and DI however the increase was significant in only 1 cut out of 12 which was cut number 3 where the least fresh leave to stem ratio obtained from SDI (table 1).

The results showed that SDI was the most irrigation method increased plant length and number of tillers followed by DI while the least was found in SPI. The results are due to the fact that alfalfa is a large user of water. Depending on the location, alfalfa may use from 30 to 80 inch of water per acre (Henggeler, 1997 and Breazeale et al., 2000). Since our experiment was kept at field capacity by precisely applying the needed irrigation water at 7 a.m. every day, the loss of water by surface evaporation during the day-time was the highest in SPI followed by DI while there was no surface evaporation under SDI. That means the availability of water under SDI is higher than that in DI and SPI which resulted in high plant length and number of tillers. Henggeler, (1997) said that alfalfa would benefit more than most crops from SDI because of its heavy water use.

#### Effects of Precise Irrigation and Methods Fresh Yield, Dry Yield and Dry Leave to Stem Ratio:

The forage fresh yield of alfalfa varied significantly among the investigated irrigation methods in all cuts (1to 12). The results are presented in table (2). The results showed that the highest fresh yield was obtained from SDI followed by DI and the least fresh yield obtained from SPI. The forage productivity ranged from 16.9 to 7.72 ton/ha for SDI, 13.5 to 6.87 ton/ha for DI and from 4.6 to 9.44 ton/ha for SPI (table 2). The average increase of forage fresh yield under SDI was 18% and 61% compared with DI and SPI respectively. The DI increased the forage fresh yield by 36.8 % compared with SPI. The results of forage dry yield have similar trend as in forage fresh yield (table 2). The results indicated that the SDI increased the dry yield compare with DI and SPI. The highest dry yield obtained from SDI and varied significantly in 10 out of 12 cuts compared with SPI and in 6 out of 12 compared to DI. The production of dry yield ranged from 5.5 to 2.27 ton/ha for SDI, from 3.90 to 1.91 ton/ha for DI and from 3.90 to 1.67 ton/ha for SPI. The average increases obtained from SDI were 22% and 41.8% compared with DI and SPI respectively. The DI increased the dry yield by 16% compared with SPI (table 2). The results also showed that SPI Generally increased leave to stem ratio compared with DI and SDI, however the increases were not significant in 11 cuts out of the 12. Only cut number 1 showed significant increases in leave to stem ratio where it was 1.23, 0.81 and 0.89 in SPI, DI and SDI respectively (table 2).

As indicated by the results in table (2) SDI increased fresh and dry forage yield of alfalfa compared to DI and SPI. Large significant differences found between SDI compared with SPI however, the differences were less when comparing SDI with DI. These results are due to the fact that increasing available water in root zone area enhance growth parameters and increase yield production. SDI increased plant length and number of tillers compared to other irrigation methods (table 1). Due to the enhancement of growth parameters by SDI it is expected to be reflected in forage yield since at the end yield is the resultant of growth parameters. Similar results were reported by Patel et al., (1990) and Abu-Suwar and Bakri, (2009).
Alfalfa also would benefit more than most crops from SDI because of its heavy water use which is plenty as indicated by results, (Henggeler, 1997). Alam et al., (2009) reported that alfalfa needs plenty of water after each cutting to start re-growth. Subsurface drip irrigation (SDI) systems allow continuous irrigation right after harvest to encourage rapid re-growth and do not require irrigation suspension prior to harvest to allow for dry soil. According to studies done in California and Texas, SDI has shown increased alfalfa yield when compared to furrow irrigation.

Results show that the effect of investigated irrigation methods on leaf to stem ratio is not significant. But SPI increased leave to stem ratio compared with DI and SDI. Increasing leave to stem ratio led to increased forage quality, Abu-Suwar and Bakri, (2009). On the other hand Onder et al., (2005) reported that surface and sub-surface irrigation methods had no significant differences on yield parameters. Similar results were also reported earlier by Phene (1995) and Weatherhead and Knox (1998).

Effects of Precise Irrigation on Water Supply:

The water supply for alfalfa forage crop under investigated irrigation methods was different because water supply was controlled by fully automated systems. The system was run and controlled by Water Electronic Module (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 adjusted in WEM, which is the tension of soil moisture at field capacity. The daily water supply was collected from the gage of each irrigation system. Then the water supply for each cut including rainfall was calculated and presented in Fig. (1) and table (3). The results showed that during the first three cuts the water supply showed slight differences between irrigation systems. Starting from 4th cut to 12th the water supply for SPI was largely increased compared with DI and SDI. There were very small differences in water supply for SDI and DI except in 4th cut where the water supply of DI was higher than SDI and equal to SPI (Fig. 1).

The results of seasonal water supply in mm (12 cuts) for investigated irrigation methods were presented in Fig. (2). The results clearly indicated that the highest water supply was obtained from SPI followed by DI and the least water supply obtained from SDI. The seasonal water supplies were 5801, 4102 and 3725 for SPI, DI and SDI, respectively.

The result of water supply appeared that the difference among irrigation systems at the beginning of the growing season during the first three cuts were minimal (Fig. 1). The results are due to the fact that the weather in these two months at the location of the experiment was not hot but humid so that, evaporation was minimal in all investigated irrigation methods. In addition, the irrigation water was precisely applied from automated system. These two reasons resulted in small differences between irrigation systems (SPI, DI and SDI) as indicated in Fig. (1). Starting from 4th cut the water supply in SPI sharply increased compared to DI and SDI. The results were due to the gradual increase in temperature and gradual decrease in relative humidity.

Increasing air and soil temperature as well as decreasing humidity increased loss of water by evaporation in SPI resulted in the increased water supply compared with DI and SDI (Fig. 2). Since the evaporation is minimal in DI so that, there was very small differences compared with SDI which has no surface evaporation. Waddell et al., (1999) and Onder et al. (2005) reported that irrigation amount varied with irrigation methods and levels however the irrigation amount of DI and SDI were almost similar.

Effects of Precise Irrigation on Irrigation Water Use Efficiency (IWUE):

The IWUE (t ha⁻¹ mm⁻¹), was defined earlier in the article 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 was the same as WUE. The results of IWUE or WUE were presented in table (3). The results showed that the highest IWUE obtained from SDI followed by DI and the least IWUE recorded in SPI for both fresh and dry yield in all cuts (12 cuts). The value of IWUE for SDI ranged from 0.018 -0.064 t ha⁻¹ mm⁻¹ for fresh yield and from 0.0042 – 0.0275 t ha⁻¹ mm⁻¹ for dry yield. For DI the IWUE were ranged from 0.016 – 0.055 t ha⁻¹ mm⁻¹ and from 0.0035 – 0.021 t ha⁻¹ mm⁻¹ for fresh and dry yield respectively. In SPI the IWUE were 0.009 – 0.032 t ha⁻¹ mm⁻¹ and 0.0023-0.013 t ha⁻¹ mm⁻¹ for fresh and dry yield respectively, table (3).

The results revealed that, SDI gave the highest IWUE followed by DI and SPI for fresh and dry yield.
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. Decreasing losses by applying precise irrigation to add the required irrigation water when and where needed increase IWUE. As shown by the results in Table 2, the highest yield obtained from SDI followed by DI and SPI respectively. In the other hand the least amount for water supply found in SDI followed by DI and the largest supply of irrigation water was in SPI, (Fig 1, 2 and Table 3). Increasing yields with minimal water supply sharply increase IWUE resulted in higher IWUE in SDI followed by DI and SPI respectively. Sammis and Wu (1986) reported that IWUE increased under soil moisture stress. Previous research shows a higher IWUE for subsurface drip followed by surface drip, sprinkler systems and furrow irrigation respectively (Sammis, 1980; Bogle et al., 1989; Lamm et al., 1995). Ellis et al., (1986) has also shown higher IWUE values using surface drip compared with furrow irrigation.

Water Saving and Yield Production in Relation Sprinkler Irrigation:

The seasonal water supply (mm) and the total dry yield ton/ha for investigated irrigation systems as affected by precise irrigation were presented in Table 4. The water saving and increase in yield production for irrigation systems (SPI, DI and SDI) in percent were calculated in relation to SPI. The results indicated that by applying precise irrigation 29.2 and 35.7 of irrigation water can be saved DI and SDI compared with SPI, respectively. In spite of decreasing water supply in SDI and DI compared with SPI, high yield production was obtained from SDI and DI. SDI and DI increase yield production by 15.9% and 45% compared with SPI, (Table 4 and Fig. 3).

The results may be due to the high soil moisture content under SDI compared with DI and SPI. Irrigation water can be lost by surface evaporation and deep percolation from SPI and by evaporation for DI while under SPI there is now surface evaporation and the deep percolation is minimal resulted in high soil moisture content under SDI. Henggeler (1997) stated that alfalfa would benefit more than most crops from SDI because of its heavy water use. 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 it is possible to save 25 percent of total water diverted in the season by using SDI.

Soil Moisture Content Distribution:

Water mark sensor readings in the period of the first three months of growing season were presented in Fig. 4 and 5 respectively. 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 SPI and SDI. The soil water tension for DI also ranged from 10-20 however it reached 60 cb in a few days during the experiment (Fig. 4).

The least water tension (highest soil moisture content) obtained from SDI followed by SPI and DI respectively. Similar trend of distribution found at 45 cm depth although soil water tension was little higher than in 15 cm depth. The soil water tension at 45 cm depth during the period of 3/2/2010 to 13/4/2010, was 10 cb in SPI while it was from 10-40 cb and 10 -50 cb in SDI and DI respectively. Starting from 13 of April, soil water tension was from 0-10 cb in all investigated irrigation methods (Fig. 5).

The results of soil water tension presented in figure 4 and 5 indicated that the soil water content of SPI, SDI and DI were almost 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 SWT prior to irrigation, varying with the crop, soil texture, weather pattern, and irrigation system and 80 cb indicates dryness. That means the soil water content under the investigated irrigation method were kept the soil at field capacity during the time of the experiment especially at 15 cm depth. After 13 of April (Fig. 5) the soil water tension at 45 cm were at 0 – 10 cm. the decrease in soil water tension due to the increasing of irrigation frequency to be twice a day instead of one. The change in irrigation frequency was required to fairly maintain the soil moisture at field capacity due to the increase in temperature and decrease relative humidity at the location of the experiment, however the results indicated that increasing irrigation frequency was not required and irrigation once a day may be enough. Abdul-Jabbar et al (1982) reported that alfalfa root mass and yield were highest under high moisture level. Also they found that the largest percentage of root mass was found in the top 45 cm of soil profile. The results of water contented proved that water electronic module (WEM) succeeded to precisely supplied the require amount of irrigation water when needed.
Fig. 1: Effect of irrigation method on water supply of each cut for Alfalfa under precise irrigation practice.

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

Fig. 3: Seasonal water supply (SS) and yield production in relation SPI.
Fig. 4: Water tension distribution at 15 cm depth as affected by irrigation method and precise irrigation practice.

Fig. 5: Water tension distribution at 45 cm depth as affected by irrigation method and precise irrigation practice.

Table 1: Effect of irrigation methods on plant length, number of tillers and fresh leaf to stem ratio of alfalfa under precise irrigation practice.

<table>
<thead>
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<th>Growth characteristics</th>
<th>Irrigation method</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
<th>8th</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
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<tr>
<td>Plant length (cm)</td>
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<td>Fresh Leaves / stem (%)</td>
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<td>0.76</td>
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<td>0.84</td>
<td>0.85</td>
</tr>
<tr>
<td>LSD P &lt; 0.05</td>
<td></td>
<td>0.32</td>
<td>0.24</td>
<td>0.31</td>
<td>0.17</td>
<td>0.19</td>
<td>0.50</td>
<td>0.18</td>
<td>0.23</td>
<td>0.11</td>
<td>0.38</td>
<td>0.22</td>
<td>0.18</td>
</tr>
</tbody>
</table>

* SPI = sprinkler irrigation, DI = surface drip irrigation, and SDR = sub-surface drip irrigation.
* Means with different superscripts differ significantly (P<0.05) while same superscripts is not significant.

Table 2: Effect of irrigation methods on fresh yield, dry yield and dry leaf to stem ratio of alfalfa under precise irrigation practice.

<table>
<thead>
<tr>
<th>Yield components</th>
<th>Irrigation method</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
<th>8th</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh yield (t/ha)</td>
<td>SPI</td>
<td>8.00</td>
<td>4.66</td>
<td>4.97</td>
<td>8.31</td>
<td>7.30</td>
<td>6.03</td>
<td>7.17</td>
<td>9.12</td>
<td>7.37</td>
<td>9.30</td>
<td>9.44</td>
<td>8.66</td>
</tr>
<tr>
<td></td>
<td>DI</td>
<td>13.5</td>
<td>9.08</td>
<td>6.78</td>
<td>10.9</td>
<td>9.10</td>
<td>10.6</td>
<td>8.22</td>
<td>12.2</td>
<td>10.2</td>
<td>11.8</td>
<td>10.2</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>SDR</td>
<td>16.9</td>
<td>11.4</td>
<td>7.72</td>
<td>12.0</td>
<td>10.9</td>
<td>14.3</td>
<td>10.7</td>
<td>13.7</td>
<td>12.3</td>
<td>12.7</td>
<td>10.9</td>
<td>12.0</td>
</tr>
<tr>
<td>LSD P &lt; 0.05</td>
<td></td>
<td>3.14</td>
<td>2.90</td>
<td>0.91</td>
<td>0.68</td>
<td>1.30</td>
<td>4.23</td>
<td>1.07</td>
<td>1.56</td>
<td>1.52</td>
<td>1.31</td>
<td>0.86</td>
<td>0.98</td>
</tr>
<tr>
<td>Dry yield (t/ha)</td>
<td>SPI</td>
<td>1.67</td>
<td>2.33</td>
<td>2.13</td>
<td>1.57</td>
<td>3.82</td>
<td>1.68</td>
<td>1.41</td>
<td>2.03</td>
<td>2.38</td>
<td>3.18</td>
<td>3.9</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>DI</td>
<td>2.30</td>
<td>2.58</td>
<td>2.52</td>
<td>1.91</td>
<td>2.1</td>
<td>2.34</td>
<td>2.11</td>
<td>1.94</td>
<td>2.61</td>
<td>3.46</td>
<td>3.9</td>
<td>2.64</td>
</tr>
<tr>
<td></td>
<td>SDR</td>
<td>2.99</td>
<td>2.73</td>
<td>3.14</td>
<td>2.31</td>
<td>2.5</td>
<td>2.71</td>
<td>2.51</td>
<td>2.89</td>
<td>3.56</td>
<td>4.55</td>
<td>4.7</td>
<td>2.9</td>
</tr>
<tr>
<td>LSD P &lt; 0.05</td>
<td></td>
<td>0.56</td>
<td>0.56</td>
<td>1.00</td>
<td>0.52</td>
<td>0.52</td>
<td>0.59</td>
<td>0.49</td>
<td>0.36</td>
<td>0.35</td>
<td>0.87</td>
<td>1.57</td>
<td>0.96</td>
</tr>
<tr>
<td>Dry Leaves / stem (%)</td>
<td>SPI</td>
<td>1.23</td>
<td>0.67</td>
<td>0.63</td>
<td>0.36</td>
<td>0.43</td>
<td>0.42</td>
<td>0.39</td>
<td>0.61</td>
<td>0.68</td>
<td>0.56</td>
<td>0.48</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>DI</td>
<td>0.81</td>
<td>0.60</td>
<td>0.35</td>
<td>0.45</td>
<td>0.45</td>
<td>0.76</td>
<td>0.38</td>
<td>0.61</td>
<td>0.33</td>
<td>0.45</td>
<td>0.37</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>SDR</td>
<td>0.89</td>
<td>0.51</td>
<td>0.36</td>
<td>0.54</td>
<td>0.50</td>
<td>0.48</td>
<td>0.57</td>
<td>0.64</td>
<td>0.53</td>
<td>0.37</td>
<td>0.69</td>
<td>0.79</td>
</tr>
<tr>
<td>LSD P &lt; 0.05</td>
<td></td>
<td>0.36</td>
<td>0.31</td>
<td>0.14</td>
<td>0.34</td>
<td>0.21</td>
<td>0.25</td>
<td>0.27</td>
<td>0.18</td>
<td>0.14</td>
<td>0.11</td>
<td>0.28</td>
<td>0.12</td>
</tr>
</tbody>
</table>

* SPI = sprinkler irrigation, DI = surface drip irrigation, and SDR = sub-surface drip irrigation.
* Means with different superscripts differ significantly (P<0.05) while same superscripts is not significant.
Table 3: Effect of irrigation methods on irrigation water use efficiency (IWUE) of alfalfa under precise irrigation practice.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Irrigation method</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>
<th>8th</th>
<th>9th</th>
<th>10th</th>
<th>11th</th>
<th>12th</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water supply for each cut (mm)</td>
<td>SPI</td>
<td>527.4</td>
<td>249.1</td>
<td>281.8</td>
<td>381.5</td>
<td>561.0</td>
<td>489.9</td>
<td>608.2</td>
<td>275.1</td>
<td>199.3</td>
<td>296.9</td>
<td>185.5</td>
<td>226.6</td>
<td>341.8</td>
<td></td>
</tr>
<tr>
<td>IWUE for Fresh yield (t ha⁻¹ mm⁻¹)</td>
<td>SPI</td>
<td>0.0230</td>
<td>0.0188</td>
<td>0.0228</td>
<td>0.0356</td>
<td>0.0138</td>
<td>0.0116</td>
<td>0.0121</td>
<td>0.0142</td>
<td>0.0147</td>
<td>0.0145</td>
<td>0.0326</td>
<td>0.0172</td>
<td>0.0172</td>
<td></td>
</tr>
<tr>
<td>IWUE for Dry yield (t ha⁻¹ mm⁻¹)</td>
<td>SPI</td>
<td>0.0048</td>
<td>0.0054</td>
<td>0.0061</td>
<td>0.0047</td>
<td>0.0033</td>
<td>0.0028</td>
<td>0.0023</td>
<td>0.0032</td>
<td>0.0028</td>
<td>0.0048</td>
<td>0.0049</td>
<td>0.0135</td>
<td>0.0136</td>
<td>0.00527</td>
</tr>
</tbody>
</table>

SPI = sprinkler irrigation, DI = surface drip irrigation, and SDI = sub-surface drip irrigation.

Table 4: Water saving and increase in dry yield production in relation to SPI.

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Seasonal water supply (mm)</th>
<th>Total dry yield/ season(t/ha)</th>
<th>Water saving in relation to SPI(%)</th>
<th>Increase in yield production in relation to SPI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI</td>
<td>5361</td>
<td>31.67</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DI</td>
<td>4102</td>
<td>29.2</td>
<td>15.9</td>
<td>15.9</td>
</tr>
<tr>
<td>SDI</td>
<td>3725</td>
<td>35.7</td>
<td>45.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>

SPI = sprinkler irrigation, DI = surface drip irrigation, and SDI = sub-surface drip irrigation.

Conclusions:

The results indicated that plant growth parameters, fresh yield, dry yield, water supply and water saving significantly affected by precise irrigation under different irrigation methods. SDI increase growth parameters (plant length, number of tillers and leave to stem ratio) fresh and dry yield compared with DI and SPI. The least water supply was recorded in SDI followed by DI and SPI respectively while the highest IWUE obtained from SDI followed by DI and the least IWUE was recorded in SPI. In spite of decreasing water supply under SDI and DI high dry yield was obtained. The increase in dry yield was 45% in SDI and 15.9% in DI compared with SPI. The results of experiment especially soil moisture data proved that WEM is a practical tool to precisely supplied irrigation water when needed and can be recommended for efficient automated irrigation systems. In conclusion, large amount of yield can be produced and large amount of irrigation water can be saved when applying advance precise irrigation techniques such as WEM for different irrigation methods.

References


