Influence of Planting and Irrigation Management Methods on Maize Water Productivity Improvement in a Semi-arid Region

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Abstract: In West Asia and North Africa, farmers are facing limitations of water resources and need to increase crop production while applying less water. To investigate the methods of reducing irrigation water losses, this study was conducted at Saffiabad Agricultural Research Center of Dezful, Iran during 2007 and 2008. The experiment consisted of a randomized complete block design with strip-split plot arrangement of the treatments, in three replications. Main treatment included: (T1) planting on 75cm-wide ridges and full furrow irrigation (farmers’ practice, the control treatment), (T2) planting on 75cm-wide ridges and variable alternate furrow irrigation, (T3) double row planting on 75cm-wide ridges and full furrow irrigation, (T4) single row planting inside 75cm spaced furrows and converting furrows into ridges at 2-4 leaf stage, (T5) single row planting inside 75cm spaced furrows - fixed furrows and ridges and (T6) planting on 75cm-wide ridges using full drip irrigation. The three maize hybrids studied were Osak-602, Bo-666 and So-704 (secondary treatments). Measurements included the grain yield, biomass, irrigation water consumption, crop water productivity and irrigation water productivity. The results indicated that there were no significant differences in yield among the maize hybrids. Mean crop water productivity was 1.45 kg/m³. In T1, water loss occurred mainly as runoff. Treatment T5 resulted in 31% decrease in irrigation water, higher grain yield than T1, so T5 increase irrigation water productivity to values 45% higher than T1. Under our conditions, using drip irrigation increased irrigation water productivity by three fold.

Key words: Water productivity · Maize · Irrigation management · Planting pattern · Furrow irrigation

INTRODUCTION

Agriculture faces two major challenges in the 21st century: the increasing world population and their rising demands for water and food products and the consequent need for better management of the limited water resources [1]. Considering the current conditions, 7000-12586 km³ per year of accessible water resources are needed to produce the required food for the predicted 9.3 billion world population by 2050. Furthermore, new water resources of acceptable quality are scarce [2, 3]. The challenge of increasing crop yields despite the increasing water shortages means that yield per unit of applied water should be increased [4]. In 1997, Molden introduced the concept of water productivity (WP) as yield divided by the total volume of water consumed (irrigation + precipitations). In later studies, the numerator and the denominator of this ratio have been the subject of different interpretations [5].

\[
WP = \frac{Y}{I}
\]  

(1)

Where, Y, can be the harvestable yield, dry matter, grain, meat, milk, income, environmental benefits, economical profits, energy, food and other products and I, can be taken as the water consumed through evaporation, transpiration, evapotranspiration, applied irrigation water, or water delivered from the water source to the field.

Water resources are scarce in West Asia and North Africa and agricultural sectors share of these resources is decreasing in competition with the industrial and
household usages. This region has a Mediterranean type climate with most of the rain falling in autumn and winter months. Consequently, most of the agricultural products are grown under irrigation. Generally speaking, crop yield and irrigation efficiency of these regions are normally low and variable. For example, producing 1kg of wheat grain under fully irrigated conditions requires 1-2 m$^3$ of water [6] and for the same amount of grains on rain fed areas, 1-3m$^3$ of rainwater will be needed [7, 6]. Since water is a limiting factor in the agricultural development, improving irrigation water productivity is of the highest importance in meeting the increasing need for food in this part of the world [8].

Based on the review of 84 case studies performed during the past 25 years, Zwart and Bastiaanssen [9] reported that water productivity (WP) index for wheat, rice, cotton (seeds), cotton (bolls) and maize were 0.6-1.7, 0.6-1.6, 0.41-0.95, 0.14-0.33 and 1.1-2.7 kg/m$^3$, respectively. They attributed the changes in this index to factors such as climate, irrigation management and fertilizer application. An immediate result of this study was that a decrease in the amount of water used in irrigation (deficit irrigation) can lead to an increase in the WP index. They concluded that there was a great possibility for maintaining or increasing the WP index, or, in other words, obtaining greater yields by smaller amounts of water (a decrease of 20 to 40 percent).

Many factors contribute to WP including environmental conditions, cultural factors [10] and management measures [11, 12]. Improved irrigation water productivity (IWP) requires employment of knowledge and skills for reducing the water loss and increasing yield. Water losses can be reduced by appropriate planning and irrigation management through making use of efficient systems [4]. Improper irrigation management not only results in increased water losses, but also decreases crop yield [13, 14]. Irrigation management affects production costs and the amount of nutrients leaching off the surface and joining the underground waters [15].

Due to its diverse features, in particular the great ability to adapt to climate, maize is normally cultivated in 30 to 55 degrees north and south latitude. Regarding the planting acreage, maize is the third plant grown, standing after wheat and rice. Crop water productivity for maize farming was reported 1.5 kg/m$^3$ in China [16] and 1.5 kg/m$^3$ in India [17]. Studies on maize irrigation scheduling techniques in North Dakota using Lysimeter on small strips revealed that accurate irrigation management can significantly increase the amount of saved water [18, 19]. The steep slope of maize yield with respect to water usage in the plants shows a significant reduction in yield as a result of a decrease in the amount of water consumed by the plants (compared to the required amount under no-stress conditions) [20, 21, 22].

Imposing water stress is not an appropriate method for increasing crop water productivity (CWP). Improved irrigation water management with minimum water loss is an important and effective step toward optimum water use and increased irrigation water productivity (IWP) and yield [20].

In addition to irrigation management, one of the effective factors of water productivity improvement is the use of appropriate planting pattern aimed at the optimum use of water, light, nutrients and higher yield. As the distance between rows of maize plant decrease from 100 to 50 cm, grain yield increases linearly [23]. Shorter spacing between rows for special plants has some potential advantages. Firstly, due to this arrangement, the plants compete to a lesser degree for light, water and nutrients [24]. The arrangement also improves the rate of early growth for maize [25] and results in improved light absorption, radiation performance and grain yield [26]. Secondly, early closing of the canopy decreases the light transmitted into the canopy [27]. Reduced amount of sunlight received at the ground surface removes the potential weeds in particular for those which are less likely to grow in the shade [28]. Thirdly, early shadowing over the soil during the first days of a season reduces the amount of water lost through evaporation. This is in particular important for the soil surface moisture because retention of water allows the maize crop to have maximum level of photosynthesis and to increase the amount of crop consumed water as compared to the water evaporated from the soil surface [29]. Therefore, early growth of plant on narrow rows improves the level of protection for soil, reduces runoffs and soil erosion [30].

In some areas in the United States, in order to make use of soil moisture, sorghum is planted at the bottom of furrow using special equipment for planting [14].

The present study was conducted in Dezful Area, Iran, where maize is planted in rows with 75 cm spacing and irrigated using furrow method. The average evapotranspiration of maize for this type of planting is about 550-650 mm during the growing season (according to the findings of the present study); considering the irrigation efficiency of 30 percent [31], the amount of applied water would be 18000-22000 m$^3$/ha. This large amount of consumed water presents a challenge to the farmers of the region as one of the main factors limiting the acreages grown to maize.
Table 1: Growing-degree-day (GDD), number of days before physiologic maturation (NDM), thermal unit before maturation (TM) and Seeding rate (SR) of three maize hybrids (Late maturity) of this experiment

<table>
<thead>
<tr>
<th>Variety</th>
<th>GDD</th>
<th>NDM</th>
<th>TM</th>
<th>SR (seeds/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osk-602</td>
<td>1700</td>
<td>110</td>
<td>3752</td>
<td>75000</td>
</tr>
<tr>
<td>Be-666</td>
<td>1730</td>
<td>114</td>
<td>3767</td>
<td>75000</td>
</tr>
<tr>
<td>Sc-704</td>
<td>1786</td>
<td>120</td>
<td>3775</td>
<td>75000</td>
</tr>
</tbody>
</table>

The present study attempts to evaluate different planting and irrigation management methods in terms of increasing maize water productivity by using three late maturing maize genotypes and reducing water loss in the form of runoff and deep percolation.

MATERIALS AND METHODS

This study was performed in Safiabad Agricultural Research Center of Dezful, Iran (48° 26’ E, 32° 16’ N; 82.9 m above sea level) during the two cropping seasons of 2007 and 2008. This region has a semi-arid warm climate with mild winters and semi-forest vegetation. The average annual precipitation is 350 mm while the average annual evaporation is 2400 mm. Seventy percent of the precipitations occurs in the period from November to February and the rest falls in March and April. The soil, down to a depth of one meter, is silty clay loam with a bulk density of 1.68 g/cm³ and a groundwater level lower than 9 meters. Land slope is less than 1%. The soil average available water is 1.6 mm/cm of root depth. The average volumetric moisture at field capacity and wilting point is 37.7 and 21.9 percent, respectively.

The performance of three late maturing commercial maize hybrids, namely, Sc-704, Be-666 and Osk-602 (Table 1), was evaluated under different planting patterns using drip and surface irrigation systems in an experiment with complete randomized block design and strip-plot configuration with three replications. The main plot (horizontal) included six cropping and irrigation management treatments as follows:

T1: Planting on 75 cm ridges - full furrow irrigation (local farmers’ practice, control treatment).

T2: Planting on 75 cm ridges - variable alternate furrow irrigation.

T3: Double-row planting on 75 cm ridges - full furrow irrigation.

T4: Single-row planting in 75 cm furrows while converting furrows to ridges at 2-4 leaf stage - full furrow irrigation.

T5: Single-row planting in the bottom of 75 cm furrows - full furrow irrigation.

T6: Planting on 75 cm ridges-full drip irrigation.

The 75 cm furrows were created after seed bed preparation operations including: pre-plant irrigation in early July, mould board plowing at 30 cm depth, two perpendicular passes of disks, broadcasting of fertilizers and the final diskng operation. The length of planting rows and furrows were 126 m in east-west direction and longitudinal slope of 0.2 %. Each treatment included 7 furrows and 6 planting ridges. Each maize hybrid was planted in 14 m rows with a density of 75000 plants/ha. The required amounts of nitrogen, phosphate and potassium fertilizers were determined and applied based on soil testing results of Safiabad Agricultural Research Center laboratory. These amounts included 350 kg/ha of urea (one third at planting and the other two thirds as top dressing), 120 kg/ha of triple super-phosphate, 100 kg/ha of potassium sulfate and 50 kg/ha of zinc sulfate as basic applications.

All agricultural operations including fertilizer and herbicide applications and hand weeding were applied uniformly and simultaneously for all treatments. Dez irrigation network was used as water supply source for irrigation. In order to avoid water flow fluctuations and maintain a constant level of water in the upper ditch, two primary and secondary ditches were made with primary ditch head having an overflow output spillway. A WSC² valve was installed at the junction point of the upper and lower ditches to measure the inflow to each plot. Intake family (IF) parameters using soil conversation service (SCS) method as well as the most suitable discharge for each furrow were determined as 8.89 cm/hr and 0.5 l/s, respectively. The appropriate time to stop the irrigation was determined considering the depth of irrigation water and using the SCS recommended method based on the water advance time [32].

Daily crop evapotranspiration (ETd) was calculated using evaporation pan method, assuming no water limitation conditions and crop factors (Kc) were...
determined using the proposed table by FAO (Irrigation and Drainage Paper Series, No. 56) for different growth stages [33].

\[ \text{ET}_r = K_r \cdot \text{ET}_s \]  

Where,

\( \text{ET}_r \) : Evapotranspiration of reference crop (mm/day)
\( \text{ET}_s \) : Crop evapotranspiration under standard conditions (mm/day)

Climatic data including the required parameters to calculate the potential evapotranspiration were recorded at Sariabad Agricultural Weather Research Station, 200 m away from the study site.

During the growing season, time domains reflector (TRIME, TDR group) equipment were used for measurement of soil moisture for each treatment. Two 1.5m long tubes (5cm diameter) were installed in the first and the third 40m sections of the run for each treatment to measure the soil moisture at the depth of 20 cm. Moisture data were recorded during the growing season before the pre-plant irrigation, 4-6 leaf stage and other growth stages. A complete set of soil moisture data during the growing season in different treatments was recorded in 2008.

At harvest time, a 6m² sample was taken from the two middle rows (4m long) in each experimental plot for the measurement of yield components.

Duncan’s multi-domain method and MSTATC were used for statistical analysis of randomized blocks variance and comparison of the mean values for biomass, seed yield and water productivity.

Accumulative values of actual crop ET during the growing season (\( \text{ET}_a \)) for different treatments were calculated using the following equation [34]:

\[ (1-Y/Y_p) = K_r(1 \cdot \text{ET}_a/\text{ET}_s) \]  

Where,

\( \text{ET}_a \) : Maize evapotranspiration under no water-stress conditions (mm) which is calculated based on irrigation water amount, soil moisture and precipitations in treatment \( T_0 \) (drip irrigation).
\( Y_p \) : Potential maize yield (t/ha); the yield of drip-irrigated treatment is used here due to optimum soil moisture available to the plant during the growing season (Fig. 2).
\( K_r \) : Yield factor; this value is considered 1.25 for maize [34].
\( Y_s \) : Actual yield of irrigated treatments (t/ha).

Water loss for different treatments was calculated using the following empirical equation [20]:

\[ L = R + I - \text{ET}_s - \Delta S \]  

Where:

\( L \) : Water loss (mm)
\( R \) : Precipitations during the growing season (mm)
\( I \) : Total amount of irrigation water during the growing season (mm)
\( \Delta S \) : The difference between the amount of available water in the soil at germination and physiological maturity stages (mm)

The effects of different treatments on the CWP and IWP were evaluated based on the calculation of CWP and IWP as follows:

\[ \text{CWP} = 100 \cdot Y/Y_p \]  
\[ \text{IWP} = 100 \cdot Y/I \]  

RESULTS AND DISCUSSION

The Amount of Applied Irrigation Water: Amount of applied water and number of irrigations for each treatment in different months are presented in Table 2. The first irrigation was applied to provide the required moisture for seed germination in late July and early August. The surface irrigation was applied simultaneously for \( T_0 \) treatments with different irrigation times that were calculated based on SCS method. The last round of irrigation was applied before the full maturity in October. The drip irrigation applications started at the same time as surface irrigations.

The second irrigation was applied three days after the first irrigation, coinciding with seedling emergence in all the six treatments. After the second irrigation, the number of drip irrigations was about double that of the surface irrigation. The first top-dressing of urea fertilizer was applied during the 4-6 leaf stage and the second one at flowering and ear emergence stage. In order to prevent fertilizer losses due to runoff, irrigation was stopped before water front reached the end of the furrows. Fertilizers were applied as a solution in the drip-irrigated treatment. The depth of surface irrigation was 42 to 235 mm for \( T_0 \), \( T_5 \), \( T_3 \) and T4 and 31 to 151 mm for \( T_5 \). Comparison of water consumption for the two years of the experiment showed that most of the irrigation water losses in the control treatment were recorded during the early growing season. There was a 31% decrease in water consumption of \( T_5 \) compared to \( T_0 \) (control), while this decrease was 59% for drip irrigation treatment (\( T_0 \)).
Table 2: Amounts (mm) and number of irrigations for each treatment in different months for the two years of the experiment

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>Irr. Number</th>
<th>T5</th>
<th>Irr. Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Jul</td>
<td>199</td>
<td>213</td>
<td>177</td>
<td>143</td>
<td>78</td>
<td>1</td>
<td>77</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2007</td>
<td>Aug</td>
<td>617</td>
<td>551</td>
<td>651</td>
<td>282</td>
<td>196</td>
<td>5</td>
<td>160</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>2007</td>
<td>Sep</td>
<td>378</td>
<td>241</td>
<td>379</td>
<td>498</td>
<td>416</td>
<td>4</td>
<td>310</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Oct</td>
<td>252</td>
<td>149</td>
<td>248</td>
<td>300</td>
<td>282</td>
<td>3</td>
<td>154</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>Sum</td>
<td>1446</td>
<td>1154</td>
<td>1450</td>
<td>1223</td>
<td>972</td>
<td>13</td>
<td>700</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Aug</td>
<td>618</td>
<td>720</td>
<td>601</td>
<td>280</td>
<td>273</td>
<td>5</td>
<td>171</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Sep</td>
<td>596</td>
<td>352</td>
<td>590</td>
<td>629</td>
<td>539</td>
<td>5</td>
<td>244</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Oct</td>
<td>381</td>
<td>187</td>
<td>385</td>
<td>360</td>
<td>311</td>
<td>2</td>
<td>152</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Sum</td>
<td>1505</td>
<td>1259</td>
<td>1576</td>
<td>1269</td>
<td>1114</td>
<td>12</td>
<td>567</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Ave</td>
<td></td>
<td>1520</td>
<td>1206</td>
<td>1513</td>
<td>1246</td>
<td>1043</td>
<td>13</td>
<td>624</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Average dry matter yield in different treatments over the two years of study

<table>
<thead>
<tr>
<th>Year</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>Variety</th>
<th>Ossk602</th>
<th>B6666</th>
<th>Sc704</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>16.3a</td>
<td>13.2c</td>
<td>17.8ab</td>
<td>14.9bc</td>
<td>15.1bc</td>
<td>19.0a</td>
<td>19.0a</td>
<td>15.0 a</td>
<td>16.0 a</td>
<td>15.2 a</td>
</tr>
<tr>
<td>2008</td>
<td>21.8a</td>
<td>16.2b</td>
<td>20.2a</td>
<td>18.9ab</td>
<td>18.0ab</td>
<td>18.2ab</td>
<td>19.2 a</td>
<td>19.3 a</td>
<td>18.1 a</td>
<td></td>
</tr>
<tr>
<td>Ave</td>
<td>19.1a</td>
<td>14.7d</td>
<td>19.0a</td>
<td>16.9bc</td>
<td>16.5cd</td>
<td>18.6ab</td>
<td>18.1 a</td>
<td>17.6 a</td>
<td>16.7 a</td>
<td></td>
</tr>
</tbody>
</table>

*Dry matter yields with different letters within the same year were significantly different at a = 0.05

Table 4: Average maize grain yield for different treatments during the two years of experiment

<table>
<thead>
<tr>
<th>Year</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>Variety</th>
<th>Ossk602</th>
<th>B6666</th>
<th>Sc704</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>6.8c</td>
<td>6.6c</td>
<td>5.6ab</td>
<td>6.5c</td>
<td>7.7c</td>
<td>9.5a</td>
<td>8.2a</td>
<td>7.9a</td>
<td>7.1b</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>8.1a</td>
<td>5.6b</td>
<td>7.5a</td>
<td>8.3a</td>
<td>7.9a</td>
<td>8.6a</td>
<td>7.8a</td>
<td>7.7a</td>
<td>7.8a</td>
<td></td>
</tr>
<tr>
<td>Ave</td>
<td>7.4c</td>
<td>6.1d</td>
<td>8.4ab</td>
<td>7.6bc</td>
<td>7.8c</td>
<td>9.1a</td>
<td>8.0 a</td>
<td>7.8 a</td>
<td>7.4 a</td>
<td></td>
</tr>
</tbody>
</table>

Grain yields with different letters within the same year were significantly different for a = 0.05.

**Yield Results:** Table (3) shows the average dry matter yield and annual and biennial mean comparison results at 5% level of probability for different irrigation treatments. In the first year of the study, T3 and T5 performed better than the other treatments, respectively. The best performing treatments in the second year were treatments T3 and T5. The biennial average also showed the superiority of these treatments. As far as the dry matter is concerned, no significant difference was observed among the three hybrids. However, the Ossk602 hybrid showed better dry matter yield compared to the other hybrids under the same circumstances.

Table 4 shows the average maize seed yield for the two years of the experiment in different irrigation treatments as well as a comparison of annual means and the results of combined analysis as complete randomized blocks at 5% level of probability using Duncan’s multiple-range test. In the first year, sudden increase in the wind speed and evaporation (Fig. 1) in late August and early September and reduction in the minimum and maximum relative humidity resulted in environmental stresses. In surface irrigation treatments with planting rows in close proximity of the furrows and also in the drip irrigation treatment with optimum soil moisture, plants suffered less under those environmental stresses (Fig. 2), leading to T6, T3 and T5 to have the top performances, respectively. Also, yield results showed the relative instability of the commonly grown maize hybrid in the region (Sc704) under environmental stresses. However, in the second year of the experiment, with no major temperature fluctuations, all treatments, except T2, yielded similar amounts of grain.

The two-year averages of grain yield suggested a better performance by T5, T3, T5 and T6. Normalized yield for different treatments (the yield of each treatment divided by the yield of T0) (Y/Y0) is shown in Fig. 2. It can be seen that, despite their differences, T1 and T2 maintained relative yield stability in both years. In addition, among the surface irrigation treatments, the 2-year average of T3 was the highest while that of T2 was the least.
Fig. 1: Changes in evaporation (E) for different days of late August and early September in the two years of the study.

Fig. 2: Normalized yield ($Y_i/Y_s$) for different treatments in two years of study

Fig. 3: Average soil moisture before irrigation in the root zone of T_s plots in 2008

**Soil Moisture and Water Loss (L):** For T_s treatment soil moisture in the root zone at germination (Aug 8), the start (Aug 31) and the end (Sep 26) of the mid-season and at full maturity (Oct 20) and harvest (Nov 17) stages of maize are shown in Fig.3.
Table 5: Components of soil water balance (mm) for different treatments of the study in 2007 and 2008

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Year</th>
<th>I (mm)</th>
<th>d (mm)</th>
<th>Rain (mm)</th>
<th>8 (mm)</th>
<th>TW (mm)</th>
<th>ETc (mm)</th>
<th>ELs (mm)</th>
<th>L (mm)</th>
<th>I/WL</th>
<th>drO/L</th>
<th>TL/WL</th>
<th>CWP</th>
<th>IWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>2007</td>
<td>1446</td>
<td>487</td>
<td>0</td>
<td>54</td>
<td>1446</td>
<td>651</td>
<td>500</td>
<td>893</td>
<td>1.37</td>
<td>0.78</td>
<td>2.22</td>
<td>1.35</td>
<td>0.48</td>
</tr>
<tr>
<td>T2</td>
<td>2007</td>
<td>1154</td>
<td>485</td>
<td>0</td>
<td>76</td>
<td>1154</td>
<td>651</td>
<td>488</td>
<td>590</td>
<td>0.91</td>
<td>0.82</td>
<td>1.77</td>
<td>1.34</td>
<td>0.57</td>
</tr>
<tr>
<td>T3</td>
<td>2007</td>
<td>1459</td>
<td>604</td>
<td>0</td>
<td>21</td>
<td>1459</td>
<td>651</td>
<td>622</td>
<td>807</td>
<td>1.24</td>
<td>0.75</td>
<td>2.23</td>
<td>1.45</td>
<td>0.61</td>
</tr>
<tr>
<td>T4</td>
<td>2007</td>
<td>1223</td>
<td>683</td>
<td>0</td>
<td>34</td>
<td>1223</td>
<td>651</td>
<td>506</td>
<td>683</td>
<td>1.05</td>
<td>1.00</td>
<td>1.88</td>
<td>1.36</td>
<td>0.56</td>
</tr>
<tr>
<td>T5</td>
<td>2007</td>
<td>722</td>
<td>427</td>
<td>0</td>
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* I = inflow irrigation in units of mm
* d = runoff in units of mm
* All variables have units of mm, except for the ratios (L/EL, drO/L, TW/EL) that are unit less, CWP and IWP
* ETc = available soil water at crop emergence, available soil water at crop maturity
* TW = total water = ETa + L
* ETa = seasonal crop evapotranspiration assuming water is not limiting
* L = water losses by runoff, deep percolation and ineffective precipitation and irrigation
* CWP = crop water productivity in units of kg m⁻³
* IWP = Irrigation water productivity in units of kg m⁻³

Table (5) shows the components of water balance for different treatments in 2007-08. Treatment T6 had the lowest average amount of reserved water in soil profile compared to the other treatments during the growing season. Not all the figures have been measured; some of these data were obtained based on comparison and similarity of conditions during the two years of the study. The total used water included irrigation water, precipitation and changes in soil moisture. Evapotranspiration under no-water-stress conditions (ETc) was determined using water balance equation for T6 (drip irrigation), while the actual evapotranspiration (ETa) for different treatments was calculated using grain yield values (Equation 3). The difference between ETc and total water (TW) is due to the water loss (L) as a result of runoffs, deep percolation and other irrigation and precipitation losses. Due to the lack of data in 2007, soil moisture balance was determined based on certain assumptions about the soil behavior and changes in its moisture according to 2008 measurements, in particular the measured values at the beginning and end of the growing season. Results presented in Table 5 show the differences in water loss for different treatments. The negative value of water loss for T6 is the result of theoretical calculations and has no physical meaning. On the average, water loss for T6 is nearly half of that for T1 and T4. The amount of water losses in different treatments divided by the crop evapotranspiration under no water limitation (ETc) showed the ratio and the order of water losses in different planting and irrigation management treatments. Furrow irrigation and ridge planting method (especially for the control treatment) showed high levels of water loss that increased by an increase in the number of irrigations. Dividing runoffs (outflow) by the total irrigation water loss shows runoff component in the total loss. The average calculated values showed that a significant part of surface irrigation losses was in the form of runoff. It is to be noted that although the relative share of runoff in T6 was the highest, the absolute amount of runoff losses and, consequently, the total losses of water, in T6, was significantly lower than that of the other surface irrigation treatments.

**Crop Water Productivity (CWP):** The overall average CWP for all treatments over the two years of the study was 1.45 kg/m², which was in the range reported by other researchers [16, 17, 9]. CWP increased as ETc/ETa increased (Fig. 4). The figure shows that 28 percent decrease in ETc/ETa, ratio, i.e. from 100% to 72%, resulted in a 10 percent decrease in CWP. This indicates the possibility of applying a mild water stress on maize without great losses in grain yield. To increase CWP, one can use advanced irrigation methods for decreasing water losses and/or increase the yield by adopting proper agronomic practices including the use of high yielding varieties.
Fig. 4: Changes in ET<sub>r</sub>/ET<sub>c</sub> and CWP for maize. The maximum value of ET<sub>r</sub>/ET<sub>c</sub> is one.

Fig. 5: Changes in irrigation losses (L<sub>r</sub>) and IWP relative to the depth of irrigation for different treatments in the two years of the study.

**Irrigation Water Productivity (IWP):** Table 5 shows the IWP for treatments during 2 years of this study. In the case of drip irrigation, IWP was significantly higher (about 3 times) compared to the surface irrigation treatments. Treatment T<sub>5</sub> (surface irrigation and inside-furrow planting) had the highest IWP after drip irrigation. This management method caused a 40-51% increase in IWP compared to the local farmers' practice i.e. the control treatment (T<sub>c</sub>). Figure 5 shows IWP and irrigation water loss parameters fluctuations as a function of irrigation depth. An increase in the total irrigation water caused a subsequent increase in water losses and decreased IWP. The crossing point of these two graphs described the attributes of a surface irrigation management method in which: ET<sub>c</sub>, average irrigation efficiency, total amount of water consumption and IWP are 603 mm, 52%, 11,500 m<sup>3</sup>/ha and 0.65 kg/m<sup>3</sup>, respectively. Points with higher irrigation efficiency depend on T<sub>3</sub> and T<sub>5</sub> treatments.
CONCLUSION

In this study, the effects of planting and irrigation management methods were reduced in terms of irrigation water loss and IWP of 3 summer maize hybrids during 2007-2008 in south west of Iran (semi-arid region). Drip irrigation treatment was applied assuming the application of irrigation based on plant water requirements and the water balance components of this treatment were used to arrive at the actual crop evapotranspiration (ETc) in both years. ETc was calculated and recorded as 651 mm and 556 mm for the first and the second season of the study, respectively.

The farmers’ common planting and irrigation method (T1) required the highest amount of irrigation depth to meet the plant water requirements in the growing season compared to the other treatments and, as a result, had the highest water losses too.

Management factors [11, 12] are effective on optimization of CWP. Irrigation management improvement with minimum level of water loss is an important step towards the optimized water use, IWP and CWP improvement [4, 20, 18, 19].

Inside-furrow planting (T3) had less water losses compared to the common planting and irrigation method (T1) and, thus, had a higher grain yield than T1. The results of this study showed that there were no significant differences among maize hybrids for grain yield. It was also found that by the application of a planting and irrigation management method according to T5, it is possible to reduce the water consumption up to 31%. This method (T3) also caused a significant increase in IWP and CWP compared to T1. According to these results, with the present amount of water used by the farmers in Sari-Abad area, it is possible to increase the planting area of summer maize up to 30% by planting it inside 75 cm furrows. However, this method cannot be suggested for forage maize since harvest of complete maize forage is not possible in this method.

In the range of moisture stress of this study, by providing 75 percent of the crop water requirement, the predicted IWP will be 1.3 kg/m² of water consumed by the plant.

Variable alternate furrow irrigation method cannot be recommended due to high irrigation water consumption resulting from water influx from wet furrows into the neighboring dry furrows. However, the use of wider ridges (row planting on 150 cm wide ridges) can be evaluated.

Double row planting on 75 cm ridges (T3) had higher dry matter grain yield and IWP compared to the farmers’ practice (T1), but had less IWP than T5. The use of higher plant density for T3 in order to increase radiation use efficiency of the canopy and lower light penetration into lower canopy that would reduce weeds competition and increase yield [25-28] can be evaluated.

Application of drip irrigation system reduced water losses [4] and caused a threefold increase in IWP compared to surface irrigation methods. Of course, just based on economic analysis, this method can be recommended.

ACKNOWLEDGEMENT

This research was part of the PhD requirement of the Department of Irrigation, Science and Research Campus, Islamic Azad University, Tehran, Iran. The field experiments were conducted at Safiabad Agricultural Research Center. Partial funding for this project was provided by the Water and Food Challenge Program of CGIAR through International Center for Agricultural Research in Arid Areas (ICARDA) and Agricultural Engineering Research Institute, Iran.

REFERENCES


