REGULATED DEFICIT IRRIGATION SCHEDULING OF MAIZE CROP

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ABSTRACT

Despite of the fact, that irrigation scheduling is important tools for decision making process but only very few farmers understand and not yet utilized by the majority of farmers. Furthermore, limited irrigation scheduling information are utilized by farm managers and extensionists. A regulated deficit irrigation experiment was conducted to investigate the effect of different irrigation depths on yield of Maize crop by using pan evaporation method. Five irrigation treatments 0.50 Epan (T1), 0.75 Epan (T2), 1.00 Epan (T3), 1.25 Epan (T4) and one control treatment i.e. farmers practice (T0) with three replicates by using randomized complete block design were tested. The total irrigation depth applied to maize was 278, 132, 197, 263 and 328 mm for T0, T1, T2, T3 and T4 treatments respectively. Only three number of irrigation were applied due to the occurrence of heavy rainfall during the study period. The average actual MAD before first, second and third irrigation ranged between 0.24-0.44, 0.34-0.66 and 0.30-0.54 respectively. The variation in MAD was due to non-uniform frequency of irrigation. The average application efficiency was between 45-91, 37-46 and 43-75% during first, second and third irrigation respectively. The maize evapotranspiration (ETc) was 451 mm during the study period. Maximum yield of 2933 kg/ha was obtained when plots were irrigated according to 0.75 Epan. Statistical analysis showed that there was significant affect of irrigation depths on grain yield.

Key Words: Irrigation Scheduling, Pan-evaporation, Management allowed deficit application, Water use efficiency

INTRODUCTION

Due to the serious water shortages the great challenge for the coming decades is the task of increasing food production with less water, particularly in countries with limited water, land resources (FAO, 2002). Therefore, techniques are needed to increase the water use efficiency. Irrigation scheduling has conventionally aimed to achieve an optimum water supply for productivity, with soil water content being maintained close to field capacity. The increasing worldwide shortages of water and costs of irrigation are leading to an emphasis on developing methods of irrigation that minimize water use and maximize the water use efficiency (Hess, 1996). Irrigation scheduling is the decision of when and how much water to apply to a field in order to maximize profit. Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level, thus saves water and energy. It minimizes water-logging problems by reducing the drainage requirements and control root zone salinity problems through controlled leaching. It results in additional returns by using the saved water to irrigate non-cash crops that otherwise would not be irrigated during water-short periods. This requires knowledge on crop water requirements and yield responses to water, the constraints specific to each irrigation method the limitations relative to the irrigation water supply system and the financial and economic implications of the irrigation practice (Da Jager and Kennedy, 1996 and Van der Westhuizen et al. 1996). Environmental benefits of irrigation scheduling e.g. reduced losses of fertilizers resulting from a decrease in seepage increase in the soil (Mao, 1996); Nevertheless, in recent years there has been a wide range of proposed novel approaches to irrigation scheduling which have not yet been widely adopted; many of these are based on sensing the plant response to water deficits rather than sensing the soil moisture status directly (Jones, 1990). Research has made available a large number of tools (Hoffman et al., 1990) including procedures to compute crop water requirements, to simulate soil water balance, to estimate the impact of water deficits on yields and to estimate the economic returns of irrigation. Deficit (or regulated deficit) irrigation is one way of maximizing water use efficiency for higher yields per unit of irrigation water applied (English and Raja, 1996). The yield reduction will be insignificant compared with the benefits gained through diverting the saved water (Eck et al., 1987).
It is recognized, however, that the adoption of appropriate irrigation scheduling practices could lead to increased yields and greater profit for farmers, significant water savings, reduced environmental impact of irrigation and improved sustainability of irrigated agriculture. Consequently, there is a need to better identify the factors that could enhance the adoption of appropriate irrigation scheduling practices, favour the transfer of technology from research to farmer fields. Soil moisture measurement techniques have been the subject of many texts and reviews (Smith and Mullins, 2000; Dane and Topp, 2002) and detailed methods for estimating evapotranspiration and calculation of crop water requirements for different crops and different climates, as required in the water balance calculation, have been reviewed in detail by Allen et al. (1998). Maize response to irrigation and nitrogen rates was studied by Ali (1976), and he observed that decreasing of available soil moisture in the top 30-cm layer from 65 to 55, 40 and 25% gave grain yields of 3.72, 3.33, 3.03 and 2.14 t/ha respectively. Increasing the nitrogen rates from 0 to 60, 120 and 180 kg/ha gave yields of 1.89, 2.8, 3.56 and 3.97 t/ha respectively. Musick and Dusek (1980) studied the yield response of irrigation maize to water deficits, and concluded that the seasonal irrigation water requirement was 400 mm, grain yields were 9.52-10.85 t/ha and seasonal water use efficiencies were 12.5-14.6 kg/ha/mm. Doorenbos and Pruitt (1983) reported that the water requirements of maize for maximum production varied between 430-490 mm per season depending on climate and length of growing period.

Technique of pan evaporation for irrigation scheduling is extensively used by many researchers e.g. Pruitt and Jensen (1955), Stephan and Stewart (1963) and McIlory and Angus (1964). The usefulness of evaporation pan to predict soil moisture deficit in field and to estimate the crop water requirement need for weekly and long period is discussed in detail by Linacre and Till (1969) and Kalippa et al. (1974) observed that irrigation at the depletion of 65% of available soil moisture during the vegetative stage and 50% during the maturity stage gave the highest yields 2.15 t/ha with a total water consumption of 382 mm. Nadanam and Morachan (1974) studied the effect of soil moisture on the yield of maize and concluded that irrigation at 20, 40, 60 and 80% available soil moisture gave grain yields of 2.13, 3.0, 3.4 and 4.4 t/ha respectively. Maize an important Kharif cereal crop, cultivated through out the world, is of significant importance for countries like Pakistan, where rapid increase in population have already out stripped the available food supplies. Maize account for 4.8% of cropped area, with annual production of 1.3 million tones. The bulk (97%) of total production comes from two major provinces NWFP (57%) and Punjab (38%). The irrigation requirement of maize crop varies with soil type, and agro climatic conditions. Usually small quantity of irrigation water may be needed for maize crop in most part of the country because the best suitable time for maize sowing is 15 June to 15 July, the peak time of monsoon rainfall. Over irrigation lowers not only the quality and quantity of yield but also causes initiative steps towards waterlogging and salinity problems. However, the time and amount of irrigation water also play an important role in the production of maize crop in the arid and semi arid areas of the country.

Optimal crop production demands decision-making processes of irrigation scheduling such as number of irrigation and their frequency to meet the crop water requirement. Proper irrigation scheduling is essential for efficient use of water and crop production. Under scarce and costly water supplies it may sometimes be advantageous to stress the crop to some degree. The water stress may reduce the crop yield to some extent but it will remain economically feasible as long as the marginal benefit from reduced cost of water is equal or greater than marginal cost of reduced yield. Similarly, application efficiency is of also paramount importance in term of yield. It depends upon many factors i.e. soil topography, texture and structure, the vegetative cover, the frequency of irrigation and the depth of the root zone. The knowledge of water requirement of maize is important for planning water management practices at farm level. Therefore experiment was conducted with the objective to; assess the water need of maize crop throughout the growing season by pan-evaporation method, determine the irrigation interval and number of irrigation applied, compare actual management allowed deficit (MAD) with the desired MAD, to determine irrigation application efficiency (E_a) and water use efficiency of maize crop.

**MATERIALS AND METHODS**

**Experimental Design**

This study was conducted on maize crop at Jamra Agriculture Farm at Takht-i-Bhai. The experiment was based on Randomized Complete Block Design (RCBD) having 5-Treatments i.e. Irrigation depth applied according to 0.50, 0.75, 1.00 and 1.25 of pan-evaporation, T_0 as per farmer’s practices with 3 replicates (three blocks were formed i.e. A, B and C) (Table I). Based on experimental design total 15 plots with an average field size of 17 × 8m^2 were prepared. The inflow rate was measured with cutthroat flume of size 120cm × 75mm, installed at a few meters up stream from the inlet of the experimental plots. Flume readings and time was noted periodically until the flow cutoff. For the purpose of applying the measured quantity of irrigation water, each plot was irrigated independently.
Field Layout

The experimental field having size of 17m × 120m was ploughed twice and properly leveled before sowing to ensure uniform application of water. The leveled field was divided into 15 equal subplots each measuring size of 17m × 8m (Fig. 1). An irrigation channel ditch of one-meter widths was already existed on the sides of the field to ensure easy access of water to each plot. Maize variety Azam was sown with seed rate of 100 kg/ha in rows using a grain drill. Germination of maize variety started after 5 days. Di-ammonio phosphate and Urea were applied at a rate of 1.5 kg per sub plot by broad casting in the plots at the time of crop sowing. Weeding was done manually when required to save undue losses of nutrients and soil moisture.

Table I. The experimental design

<table>
<thead>
<tr>
<th>S. No</th>
<th>Variable</th>
<th>Level</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Irrigation depths (treatments)</td>
<td>5</td>
<td>Irrigation was applied according to 0.50, 0.75, 1.00 and 1.25 of pan-evaporation. One treatment i.e. T₀ was controlled and depth was provided as per farmer’s practices.</td>
</tr>
<tr>
<td>2</td>
<td>Replications</td>
<td>3</td>
<td>Three blocks were formed i.e. A, B and C.</td>
</tr>
<tr>
<td>3</td>
<td>Total number of experimental units 3 × 5 = 15 plots</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soil Physical Properties

The textural class of the soil was determined by hydrometer method using USDA soil texture classification. Soil samples were taken from three depths (0-25, 25-50, 50-100 cm). The dominant texture class of soil was clay loam for the entire experimental plots. Gravimetric method as described by Black et al (1965) was used to determine the moisture content of the soil. First sampling was done at the time of crop sowing and subsequent samplings were taken before and after each irrigation event. Similarly moisture samplings were also done after each substantial rainfall. The bulk density ranged 1.33 to 1.57 g cm⁻¹. Field capacity was determined at head, middle and tail of the experimental plots by ponding water on the soil surface of 1- m² plot area, saturated and covered with a plastic sheet for 24 hours. Moisture content on mass basis was determined until the difference comes to less than one unit among successive samplings.

Fig. 1. Layout of experimental plots
Potential evapotranspiration ($\text{ET}_0$) was determined from pan evaporation data. U. S. class A pan was installed near the research site to record daily pan evaporation. The pan evaporation method measures the evaporation from the open water surface, taking into account cumulative effect of radiation, wind, humidity and temperature.

The irrigation depth was calculated measuring the change in water level, correcting it for precipitation and determined the amount of water evaporated from pan. A rain gauge was also installed to record the rainfall data. Time required to obtain the desired depth of irrigation for each plot was calculated as suggested by Jensen (1980) and using following relation:

$$t = \frac{(A \times d_w)}{Q}$$

Where,
- $t$ = Time required to irrigate fields (sec)
- $A$ = Area of sub plot ($\text{m}^2$)
- $d_w$ = Depth of water applied according to E-pan (mm)
- $Q$ = Discharge ($\text{m}^3 \text{sec}^{-1}$)

Allen et al (1998) relationship between $\text{ET}_0$ and pan evaporation with, $K_c$ values based on percent growing season were use to determine $\text{ET}_c$.

$$\text{ET}_c = K_c \times K_p \times E_p$$

Where,
- $E_p$ = Pan evaporation (mm/day)
- $K_p$ = Pan co-efficient.

Soil Moisture Deficit (SMD) was calculated for each field at the middle, at three different depths i.e. 0-25, 25-50, 50-100 cm before each irrigation as suggested by Merriam and Keller (1978) using following equations. The difference in moisture content (volume basis) before each irrigation at field capacity from different depth upto the root zone gives the value of SMD.

$$d_{wi} = \frac{D_{rz} \times (\theta_{fc} - \theta_i)}{100}$$

Where,
- $d_{wi}$ = Depth of water needed in the ith layer (mm)
- $D_{rz}$ = ith depth of root zone (mm )
- $\theta_{fc}$ = Volume basis moisture content on field capacity (%)
- $\theta_i$ = Moisture content on volume basis in the ith layer (%)

The average depth of water needed to bring the field to field capacity was formed by adding the SMD needed in each layer i.e.

$$D_{wn} = \sum_{n=1}^{3} d_{wn}$$

Where,
- $D_{wn}$ = depth of water needed for the whole field in (mm)
- $Dw_1$ = water depth needed for 1st layer of rootzone (0-25 cm)
- $Dw_2$ = water depth needed for 2nd layer of rootzone (25-50 cm)
- $Dw_3$ = water depth needed for 3rd layer of rootzone (50-100 cm)

Management Allowable Depletion (MAD) is the degree to which volume of water in the soil is allowed to be depleted before the next irrigation to be applied. MAD is considered as the ratio of Readily Available Water (RAW) and Available Water (AW). The SMD values were taken as RAW. The desired Management Allowed Deficit (MAD) value of maize crop was taken 0.65 (Doorenbos and Pruitt, 1983).
MAD = \left\{ \frac{RAW}{AW} \right\} \tag{5}

Where,
\( MAD = \) Maximum Allowable Deficit (\%)
\( AW = \) Available Water (mm)
\( RAW = \) Readily Available Water (mm). The SMD values were taken as RAW

\[ AW = \frac{D_e \times (\theta_{fc} - \theta_{wp})}{100} \tag{6} \]

Where,
\( AW = \) Available water (mm)
\( D_e = \) Depth of rootzone (mm)
\( \theta_{fc} = \) Moisture content on volume basis at field capacity (\%)
\( \theta_{wp} = \) Permanent wilting point in %

Application efficiency (\( Ea \)) was determined from the soil moisture data based on the definition as the ratio depth of water store in the root zone to depth of water applied.

\[ Ea = \left( \frac{D_{ws}}{D_{wa}} \right) \times 100 \tag{7} \]

Where,
\( Ea = \) application efficiency (\%)
\( D_{ws} = \) Depth of water store (mm) and
\( D_{wa} = \) Depth of water applied (mm)

The crop was hand harvested when a visual inspection indicated that 95\% of the plant had reached to maturity. Grain yield was determined by harvesting one square meter area at head and tail section in each subplot. The yield of each subplot was separately threshed, weighed and converted into kg/ha. Water use efficiency (kg/m\(^3\)) of maize was calculated as ratio of crop yield (kg/ha) and total water depth applied (mm). The crop yield was obtained by grain yield estimation.

\[ Eu = \left( \frac{y}{D_a} \right) \tag{8} \]

Where,
\( Eu = \) Crop water use efficiency (kg/ha/mm)
\( y = \) Crop yield (kg/ha)
\( D_a = \) Total water depth applied (mm)

All the data was subjected to statistical analysis appropriate for randomized complete block design. The analysis of variance was carried out in order to determine whether the effect of treatments was significant or not (Steel and Torrie, 1980). Percent decrease or increase in yield under various treatments over farmer practices was also calculated and tabulated.

**RESULTS AND DISCUSSION**

**Maize Evapotranspiration**

Total ETc for maize crop calculated by pan evaporation method was 450 mm for the whole growing season. It was maximum 7.04 mm/day in month of August and was minimum as 2.14 mm/day in month of July (Fig. 2). Daily crop evapotranspiration from date of sowing to harvest indicate that crop evapotranspiration initially was low, increased gradually up to the month of August and decreased toward maturity. The amounts of seasonal water use were in the range as reported by Doorenbos and Pruitt (1983).
Irrigation Interval and Number of Irrigation Applied

During the whole growing season of maize crop only three number of irrigation was applied because of frequent and high amount of rainfall. The irrigation interval was also not uniform due to high range of precipitation. Total 383 mm of rainfall was recorded through out the study period. The maximum rainfall of 157 mm was recorded on 11th August, while the minimum of 2 mm was recorded on 19th July. First irrigation was given after a week of sowing of maize crop. The 2nd irrigation was applied after eight weeks; the gap in irrigation was due to high rainfall received during this period.

![Maize evapotranspiration at research site](image)

Fig. 2. Maize evapotranspiration at research site

Depth of Irrigation Water Applied

Total irrigation depth applied according to pan evaporation, in all three irrigation was 278, 132, 197, 263 and 328 mm for T₀, T₁, T₂, T₃ and T₄ respectively (Table II). Average seasonal irrigation demand of maize is 300-400 mm and normally requires 5-6 irrigations.

Table II. Number of irrigation and total depth of water applied under different treatments

<table>
<thead>
<tr>
<th>Number of Irrigation</th>
<th>Farmer’s practices</th>
<th>0.5 Eᵢ</th>
<th>0.75 Eᵢ</th>
<th>1.0 Eᵢ</th>
<th>1.25 Eᵢ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T₀</td>
<td>T₁</td>
<td>T₂</td>
<td>T₃</td>
<td>T₄</td>
</tr>
<tr>
<td>First</td>
<td>71.83</td>
<td>33.37</td>
<td>42.52</td>
<td>66.88</td>
<td>82.95</td>
</tr>
<tr>
<td>Second</td>
<td>127.56</td>
<td>66.57</td>
<td>99.25</td>
<td>132.34</td>
<td>163.03</td>
</tr>
<tr>
<td>Third</td>
<td>79.05</td>
<td>31.99</td>
<td>47.83</td>
<td>63.70</td>
<td>81.67</td>
</tr>
<tr>
<td>Total</td>
<td>278.44</td>
<td>131.93</td>
<td>196.6</td>
<td>262.92</td>
<td>327.65</td>
</tr>
</tbody>
</table>

Comparison of Actual with Desired MAD

The comparison of actual management allowed deficit with desired management allowed deficit before each irrigation is shown in Fig 3.
Before first irrigation all the plots (i.e.) $T_0$, $T_1$, $T_2$, $T_3$ and $T_4$ were of lower actual MAD as compared to their desired MAD about 38, 33, 48, 52 and 46% respectively. Before second irrigation all plots have lower actual average MAD as compared to the desired MAD about 11, 25, 29, 18 and 28% respectively. Before third irrigation also all the fields have lower actual average MAD as compared to their desired MAD about 31, 37, 25, 26 and 42% respectively. It is observed that 1\(^{st}\), 2\(^{nd}\) and 3\(^{rd}\) irrigation was not given on time and irrigation was applied to fields too early, before reaching their desired MAD level because of high evaporation rate and crop water extraction from the upper part of the root zone and soil moisture deficit was increased. Another reason was the under ground perforated pipes for drainage in two plots of block C installed by Mardan SCARP due to which the upper few cm of soil was dried earlier resulting in early irrigation by farmers. Similarly, the irrigation turn ($T_0$) was fixed and farmer was not able to irrigate their fields whenever he wanted. Therefore some parts of their fields remained un-irrigated as a result of which they again irrigate such fields on next turn of irrigation which caused early irrigation.

**Application Efficiency**

The application efficiency ($E_a$) of first irrigation ranged from 50% to 81%. The minimum $E_a$ was observed in $T_3$ treatment. Second irrigation application efficiency ranged from 38% to 64%. The minimum value of $E_a$ was observed in $T_4$ treatment while the maximum $E_a$ was observed in $T_1$ treatment. The application efficiency of third irrigation ranged from 56% to 78% and the minimum application efficiency was observed in treatment $T_4$ while the maximum application efficiency was observed in $T_1$ treatment, which means in all three irrigations the depth of water applied was much higher than the depth of water stored in the root zone (Fig: 4).
These results agree with the findings of Wolters and Beisavljevic (1991), reported that field application efficiency is influenced by factors such as soil type, irrigation application method. Very high values of the application efficiency are mostly related to arid condition and water shortage and small application of water results high application efficiency. Similar results were obtained by Awan and Ali (1988) who evaluated application efficiency at farmers’ field and reported that the application efficiency ranged from 34 to 95 percent.

**Grain Yield**

The statistical analysis of maize yield revealed that there was significant difference in different irrigation depths (Table III). The highest average yield of maize of 2993 kg/ha was obtained from T2 treatment, which were irrigated according to 0.75 of pan evaporation while the lowest yield of 1993 kg/ha was obtained from T0 treatment, which were irrigated according to farmer’s practice. The effect of different irrigation treatments on yield of maize crop indicates the significant difference in T0 and T2 treatments (Table III).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>Mean</th>
<th>Diff. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>1700</td>
<td>2150</td>
<td>2130</td>
<td>1993 C</td>
<td>-</td>
</tr>
<tr>
<td>T1</td>
<td>2390</td>
<td>2490</td>
<td>2080</td>
<td>2320 BC</td>
<td>16</td>
</tr>
<tr>
<td>T2</td>
<td>3210</td>
<td>2870</td>
<td>2900</td>
<td>2993 A</td>
<td>50</td>
</tr>
<tr>
<td>T3</td>
<td>2900</td>
<td>2290</td>
<td>2500</td>
<td>2563 AB</td>
<td>29</td>
</tr>
<tr>
<td>T4</td>
<td>2300</td>
<td>2220</td>
<td>2100</td>
<td>2207 BC</td>
<td>11</td>
</tr>
</tbody>
</table>

Mean followed by same letter are not significantly different.

@ 5% level of probability and LSD for treatment = 441.8

It also indicate that T1 plot has 16% higher yield than T0 plot, while T2, T3 and T4 treatment have 50, 29 and 11 % higher yield than T0 treatment respectively. In NWFP maize production was 1603 kg/ha (Development Statistics: 2007). Relatively high maize yield is reported at Chitral, Chitin, Swabi and Charsadda where the production per unit area was 2000 Kg/ha.

**Water Use Efficiency**

Crop water use efficiency was calculated (Oweis et al., 1998; Zhang et al., 1998) as ratio of the crop yield (kg/ha) and ETc is the actual evapotranspiration (mm). Water use efficiency of maize was determined for all the
treatments and replicates as presented in Fig. 5. The water use efficiency ranged from 0.6 kg/m$^3$ to 1.9 kg/m$^3$. The maximum average water use efficiency was obtained from T$_1$ treatment i.e. 1.8 kg/m$^3$. While the minimum average water use efficiency 0.7 kg/m$^3$ was observed in, both T$_0$ and T$_4$ treatment. These results indicate that the water use efficiency increased with the decreasing in irrigation depth applied.

![Fig 5. Water use efficiency under different irrigation treatments](image)

CONCLUSION

The total evapotranspiration of Maize was 451 mm for the whole growing season. The highest grain yield i.e. 2993 kg/ha of maize was obtained from T$_2$ treatment and lowest i.e.1993 kg/ha was obtained when farmer’s practices (To) were followed. All irrigations were applied before soil reached to the desired MAD. The application efficiency ranged between 50-81. The average application efficiency of 70% was obtained with treatment T$_1$ i.e. (0.5Epan). The yield per unit volume of irrigation water applied is most significant measure for evaluating the judicious use of water. The average water use efficiency of maize ranged from 0.7 to 1.8 kg/m$^3$. It is concluded from the study that optimum yield of maize can be obtained when crop is irrigated with a depth of 75% Epan.

REFERENCES


