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Water Use Efficiency of Maize as Affected By Irrigation Schedules and Nitrogen Rates

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ABSTRACT

A field study was conducted during 1997 and 1998 summer season to find out the effect of 4 irrigation schedules, based on actual evapotranspiration (ET), and 4 rates of nitrogen on maize. Averaged over the two seasons, the response of total dry matter (TDM) and I_3 (-8 bars) based on crop evapotranspiration was greater than control (I_1) or I_2 (-4 bars) irrigation schedule. The study showed that seasonal water requirements of the maize crop under irrigated conditions vary from 181 mm to 220 mm after due account of rainfall. Average response varied at 5.90 $gm^{-2}mm^{-1}$ and 2.37-3.01g $mm^{-2}mm^{-1}$ for TDM and grain yield, respectively.

INTRODUCTION

Irrigated agriculture is vital in meeting the food requirements for a rapidly expanding population. The main focus for enhancing water use efficiency (WUE) in irrigated cropping is to increase the output per unit of water and reallocate water thus saved to other priority areas. Irrigation scheduling can be an effective technique and improve WUE through increasing crop yield, especially in semi arid conditions. Water requirements vary with the type of crop and environmental conditions. Water used by crops is normally related to TDM or production of economic (grain) yield (Taylor *et al*., 1983). This led to the concept of WUE which was broadly defined as crop yield per unit of water used. WUE is a useful factor to determine for specific crops in order to provide information concerning seasonal crop water requirements (Brown, 1999).

Water is further required to provide constant turgor pressure that supports the plant and facilitates cell enlargement after cell division has been initiated. Hence, plant growth and survival depend on water availability. Thus irrigation improves the efficiency of fertilizer utilization by the crop. Increase in irrigation frequency increased N, P and K uptake by maize (Prasad & Prasad, 1988). Maximum grain yield and greater WUE were achieved when irrigating to 100% of field capacity (Mbagwu & Osuigwu, 1985). Highest grain yield was obtained with 120 kg K_2O ha^{-1} and irrigation at 25% depletion of available soil moisture (Patel *et al.*, 1985).

Increased application of nitrogen with adequate irrigation schedules gives faster rate of leaf expansion (Wright, 1982), increased leaf area index, leaf area duration, photosynthetic rate and increased radiation interception and radiation use efficiency (Muchow & Davis, 1988; Sinclair & Horie, 1989; Connor *et al.*, 1993).

Accurate information concerning WUE and seasonal crop water requirements may facilitate water savings in irrigation practice, improve crop management and increase crop production. The present study was, therefore, undertaken to examine the response of maize to irrigation schedules and nitrogen rates under the semi arid irrigated conditions.

MATERIALS AND METHODS

A field study was conducted on the Agronomic Research Area, University of Agriculture, Faisalabad (31°.26'N, 73°.06'E, 184.4m) during 1997 and 1998 summer seasons.

Experiment was laid out in a split plot design with four replications, randomizing irrigation schedules in the main plots and nitrogen levels in subplots. Irrigation treatments were selected to provide a wide range of soil moisture deficit during crop growth season.

Irrigation schedules were I_1 (control, weekly irrigation), I_2 (-4 bars), I_3 (-8 bars) and I_4 (-12 bars). Nitrogen rates were N_0 (control), N_1 (100 kg N ha^{-1}), N_2 (200 kg N ha^{-1}) and N_3 (300 kg N ha^{-1}). Plot size was 3 m x 5 m with four rows in each plot.

Maize cv. Golden was sown in 75 cm spaced rows on 10 August and 5 August during 1997 and 1998, respectively, using a dibble at 15 cm plant to plant distance. A basal dose of 100 kg P_2O_5 $ha^{-1}$and 100 kg K_2O ha^{-1} was applied. The whole P, K and half dose of N in the form of tri-super phosphate, potassium sulphate and urea, respectively was side-dressed at sowing. Remaining half of nitrogen was top-dressed with second irrigation. Irrigation was given according to specified irrigation schedule. Crop was kept free of weeds by hoeing on 9 September, 1997 and 24 August, 1998 to avoid weed-crop competition. Sunfuran was applied @ 20 kg ha^{-1} on 10 September, 1997 and 15 September, 1998 against borer control. All other agronomic practices were kept normal and uniform for all the treatments.

Final harvest was done on 21November, 1997 and 6 November, 1998 by harvesting an area of 3 x 4m. All plants in the respective plots were sun dried in the field for two days; thereafter tied into bundles and stalked for four weeks. Sub samples of 20 plants were randomly taken to determine. All the cobs were separated from the stalks and allowed to dry in sunshine for further few days before threshing. Then the grain yield was converted into kilograms per hectare.

Water use efficiency (WUE) was calculated based on total biomass or grain yield per unit crop water used. Actual evapotranspiration (synonym to consumptive use of water), was estimated by multiplying reference evapotranspiration (in effect, potential evapotranspiration) with appropriate value of a crop coefficient (Doorenbos & Pruitt, 1975) which usually corresponds closely with the green crop cover.

RESULTS AND DISCUSSION

Water Use. Table I shows the number and amount of irrigation (I) plus rainfall (R) during both the seasons. Table II presents the effects of treatments on cumulative crop evapotranspiration (ET) in both the seasons. The I_2 (-4 bars) irrigation schedule significantly increased cumulative crop ET over all other schedules in both the years. Similarly, I_3 (-8 bars) treatment were also superior in cumulative ET over I_1 (control) and I_4 (-12 bars) schedules in both the seasons. Minimum crop ET values were observed in I_1 (control) treatment. Averaged over the years, mean ET was 167 mm, 229 mm, 225 mm, and 280 mm in I_1, I_2, I_3 and I_4 treatments, respectively.

Table I. Amount of rainfall and irrigation applied to different treatments during the 1997-98

Dates		I_1(mm)		I_2(mm)		I_3(mm)		I_4(mm)	
1997	**1998**	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**
25.8.97	25.8.98	75	75	75	75	75	75	75	75
1.9.97	2.9.98	75	75	40	40	-	-	-	-
7.9.97	9.9.98	75	75	40	40	52.7	52.7	-	-
14.9.97	16.9.98	75	75	40	40	-	-	64.8	64.8
21.9.97	23.9.98	75	75	40	40	52.7	52.7	-	-
1.10.97	30.9.98	75	75	40	40	-	-	-	-
10.10.97	7.10.98	75	75	40	40	52.7	52.7	64.8	64.8
18.10.97	14.10.98	75	75	40	40	-	-	-	-
27.10.97	21.10.98	75	75	40	40	52.7	52.7	-	-
5.11.97	29.10.98	75	75	40	40	-	-	64.8	64.8
Rainfall	Rainfall	208	137	208	137	208	137	208	137
Irrigation	Irrigation	750	750	435	435	486	286	469	269
Total	Total	958	887	643	572	694	433.8	677	406.4

Increasing application of nitrogen levels significantly increased crop ET in both the seasons, and the response was either cubic (1997) or quadratic (1998) in nature (Table II). Averaged over the years, mean crop ET was 148 mm, 188 mm, 224 mm, and 242 mm in N_0, N_1, N_2 and N_3 treatments, respectively. Overall, mean crop ET was 181 mm in 1997 and 220 mm in 1998, respectively.

Interaction between irrigation schedules and nitrogen levels affecting cumulative crop ET was significant (Table III). In both seasons, increasing rate of nitrogen levels significantly enhanced cumulative crop ET than lower

Table II. Effect of irrigation schedules and nitrogen levels on cumulative crop ET, water use efficiency

Treatment	Cumulative ET(mm)		Water use efficiencies($gm^{-2}\ mm^{-1}$)			
			(TDM)		Grain yield	
Sowing date	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**
Irrigation schedule						
I_1 = Control	138.41 d	195.73 c	7.84 a	5.68 b	3.24 a	2.33^{NS}
I_2 = - 4 bars	212.25 a	245.89 a	7.26 b	6.21 a	2.87 c	2.40
I_3 = - 8 bars	208.14 b	241.08 b	7.35 b	6.00 ab	2.89 c	2.39
I_4 = -12 bars	164.97 c	195.46 c	7.36 b	5.70 b	3.03 b	2.36
LSD 5%	4.11	2.44	0.31	0.33	0.14	-
Nitroogen levels						
N_0 = Nil	133.52 d	162.50 d	7.69 a	6.07 a	3.08 a	2.29 c
N_1 = 100 kg ha^{-1}	167.43 c	208.17 c	7.25 b	5.59 b	2.89 b	2.19 d
N_2 = 200 kg ha^{-1}	203.80 b	243.59 b	7.68 a	6.21 a	3.16 a	2.63 a
N_3 = 300 kg ha^{-1}	219.02 a	264.91 a	7.18 b	5.73 b	2.90 b	2.36 b
LSD5%	2.65	2.73	0.19	0.31	0.11	0.07
Linear	**	**	**	NS	NS	**
Quadratic	**	**	NS	NS	NS	**
Cubic	**	NS	**	**	**	**
Mean	180.94	219.54	7.45	5.90	3.01	2.37

Means sharing different letters differ significantly at ($P \leq 0.05$)

Table III. The interaction between irrigation schedules and nitrogen levels affecting cumulative crop evapotranspiration (mm)

Treatments	1997	1998	1997	1998	1997	1998	1997	1998
		I_1		I_2		I_3		I_4
$N_{0\ =\ Nil}$	103.00 k	143.40 i	156.47 h	181.67gh	153.02h	117.43h	121.57j	143.47 i
N_1=100 kg ha^{-1}	129.33 i	186.88 fg	196.61 dc	231.65cd	191.91e	226.69d	151.84h	187.45 f
N_2=200 kg ha^{-1}	156.15 h	216.94 e	237.44 c	273.36b	235.07c	268.62 b	186.54f	215.44e
$N_{3\ =}$ 300 kg ha^{-1}	165.15 g	235.70 c	258.47 a	296.88a	252.53b	291.60 a	199.92d	235.47 c
	SX=1.85		LSD%=5.30			SX=1.91		LSD%=0.29

I_1 = control; I_2 = -4 bars; I_3 = -8 bars; I_4 = -12 bars levels of nitrogen application, and this response was significantly higher in I_2 (-8 bars) irrigation schedule as compared to other schedules. Lowest crop ET was given by N_0 (nil) treatment, irrespective of irrigation schedule.

Water use efficiency. Water use efficiency (WUE) for TDM or grain yield was calculated by dividing cumulative crop ET on a plot basis (Table II). The WUE was significantly but differentially affected by the irrigation schedules in both the seasons. In 1997, I_1 (control) treatment gave higher WUE as compared to all other irrigation schedules. In 1998, I_2 (-4bars) and I_3 (-8 bars) were superior in WUE than I_1 (control) or I_4 (-12 bars) treatments. Averaged over the years, WUE varied from 6.53 g m^{-2} mm^{-1} to 6.76 g m^{-2} mm^{-1}.

In both seasons, WUE was significantly higher in N_0 (nil) and N_2 (200 kg ha^{-1}) treatments over N_1 and N_3 nitrogen rates of application. But both of these rates were statistically at par in WUE in both the seasons. Overall, mean WUE was 7.45 g m^{-2} mm^{-1} in 1997 and 5.90 g m^{-2} mm^{-1} in 1998, respectively (Table II).

WUE for grain yield based on cumulative crop ET was also significantly higher in I_1 (control) than all other schedules in 1997. In 1998, differences in WUE for grain yield were non significant among all the schedules. Average response was ranged from 2.28 g m^{-2} mm^{-1} to 2.69 g m^{-2} mm^{-1} among different irrigation schedules.

In 1997, both N_0 (nil) and N_2 (200 kg ha^{-1}) gave higher WUE for grain yield than N_1 (100 kg ha^{-1}) or N_3 (300 kg ha^{-1}) treatments. In 1998, the N_2 (200 kg ha^{-1}) treatment gave significantly higher WUE than all other nitrogen application rates. The N_3 (300kg ha^{-1}) was also superior in WUE for grain yield over N_0 (nil) or N_1 (100 kg ha^{-1}) treatments. Averaged over the years, WUE was 2.68 g, 2.54 g, 2.89 g and 2.63 g m^{-2} mm^{-1} in N_0, N_1, N_2 and N_3 treatments, respectively. Overall, mean WUE was ranged at 3.01 g m^{-2} mm^{-1} in 1997 and 2.37 g m^{-2} mm^{-1} in 1998, respectively (Table II).

Relationship between seasonal TDM accumulation and cumulative crop ET was positive and linear in both the seasons, and the common regression accounted for 92.95% variability in TDM yield (Fig. 1). The slope of the common line (a measure of WUE) indicated that for each mm of water 7.19 g m^{-2} was produced. The relationship between grain yield to cumulative ET was also positive and linear; the common regression line gave the response of grain yield at 1.81 g m^{-2} mm^{-1} (Fig. 2). Significant increases in water use varying from 351 mm to 644 mm among different irrigation levels were reported by others (Stone *et al.*, 1996). These authors also reported values of WUE (based on yield divided by crop water use) ranging from 8.32 g m^{-2} mm^{-1} to 15.72 g m^{-2} mm^{-1} among various irrigation levels. Such wide range differences in WUE are caused by factors such as climate, irrigation schedules and length of growing season.

Fig. 1. Relationship between TDM and cumulative evapotranspiration for the pooled data

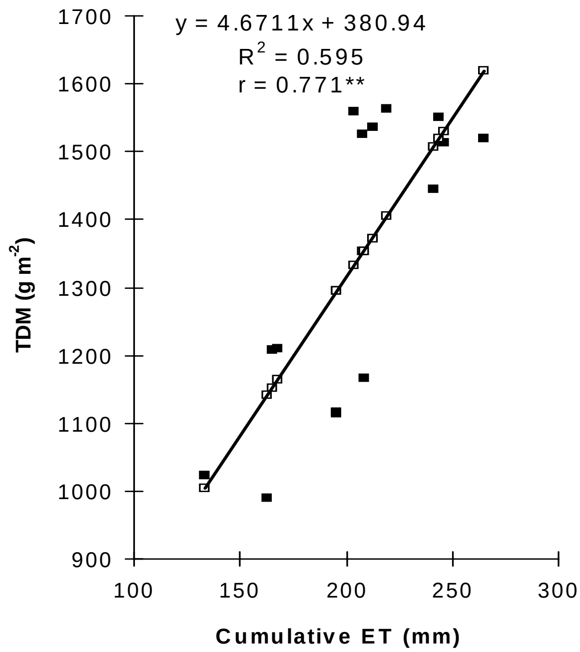
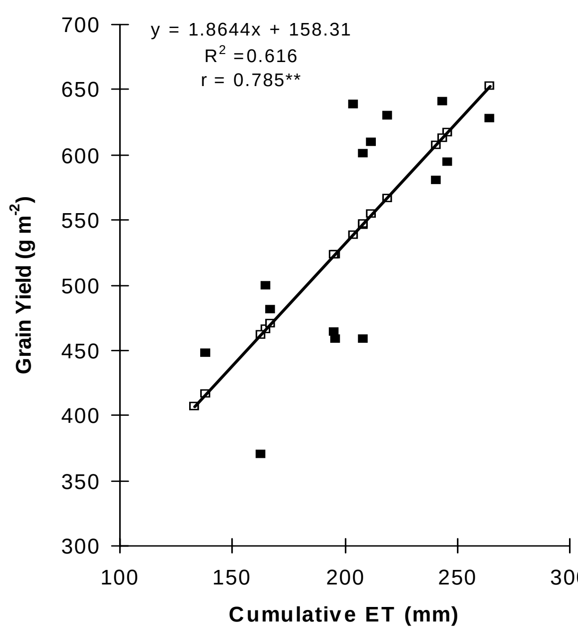


Fig. 2. Relationship between grain yield and cumulative evapotranspiration for the pooled data



CONCLUSION

In conclusion, scheduling of irrigation based on leaf water potential appears to be feasible for maize crop. It allows considerable water saving upto 42% (I_1 vs I_2) compared to farmers practice. It is therefore, recommended as a general guideline for the farmers to irrigate their crops under semi arid conditions.

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