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Influence of drought on water use efficiency in wheat in semi-arid regions of Punjab

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Abstract

Drought imposed study on wheat in semiarid regions of Punjab was under taken to see the effects of cultivars and irrigation regimes on water use efficiencies calculated for total water applied and crop evapotranspiration. Four irrigation i.e. l_0 = control, l_1 = irrigation up to stem elongation, l_2 = irrigation from stem elongation to maturity and l_3 = full irrigation treatments based on soil moisture deficit were applied to each cultivar. Irrigation treatments were managed to induce a range of drought from full irrigation to nil irrigation from emergence to physiological maturity. Relationship between grain yield and ET was observed and concluded that for each mm of crop ET 3.27 g m^{-2} TDM was produced. Inqlab-91 increased yield by 10.7% over MH-97. Fully irrigated crop produced 93.18% higher yield over control treatment. In treatments where drought was imposed before or later Anthesis, the primary cause of reduced efficiencies was a decrease in intercepted light which ultimately reduced its efficiency into economic part.

Key words: Drought, water use efficiency, yield, wheat

Introduction

Crop plants require adequate water if they are to grow at an optimum rate. Water requirements vary with the type of crop and environmental conditions. Water used by crops is normally related to total dry matter production or economic yield. This led to the concept of water use efficiency (WUE) broadly defined as crop yield per unit of water use. Water use efficiency is a useful factor to determine for specific crops in order to provide information concerning seasonal crop water requirements. The climate or weather of a region or locality has a great influence on WUE linked to crop transpiration particularly via vapor pressure deficit (VPD). Tanner and Sinclair (1983) reviewed in detail the various approaches for improving efficiency of water use. Accurate information concerning WUE and seasonal crop water requirement may facilitate water savings in irrigation practice, improve crop management and increase crop production. Water stress experienced by a wheat crop during growth is known to have cumulative effects expressed as a reduction in total biomass compared to the well watered potential (Legg *et al*., 1979). Better performance of the crop depends upon availability of water during Tillering, Anthesis and Grain formation stages. Water stress at anthesis reduces pollination and thus less grains spike^{-1} which results in the reduction of grain yield (Nazir *et al*., 1987). Adequate water at or after anthesis period not only allows the plant to increase photosynthetic rate but also increases grain filling duration (Zhang *et al*., 1998), thus enhancing grain size and ultimately cause higher grain yield (Gallagher and Biscoe, 1978).

Water use efficiency can be based either on evapotranspiration (ET_{WUE}) or on crop transpiration (T_{WUE}). The latter being a more appropriate measure of crop performance. These two WUEs may be based on either total dry matter production or grain yield, and when used the yield base should be clearly stated (Tanner and Sinclair, 1983). In agronomic practice, crop transpiration is not commonly estimated directly under field conditions. Instead, evapotranspiration is most frequent measure. The present study was, therefore, undertaken to examine the effects of water stress on water use efficiencies for TDM and grain yield of various wheat cultivars. Differences in yield and biomass were compared in terms of water use efficiency on the basis of irrigation applied and crop evapotranspiration.

Materials and Methods

Field experiment was conducted at the Agronomic Research Area, University of Agriculture, Faisalabad during the growing season 2002-03. The experiment was laid out in a Randomized Complete Blocked Design with three replications having split plot arrangement. Two cultivars InqiIab-91 and MH-97 and four irrigation levels (l_0 = control, l_1 = stress after tillering, l_2 = stress after heading and l_3 = full irrigation) were used as a medium of trial. Cultivars were randomly assigned to the main plots and irrigation levels to the sub-plots. All other cultural operations were kept uniform except irrigation levels for the growth season. The amount of water applied was equal to the differences between potential evapotranspiration (PET) and rainfall plus irrigation in the previous week. The calculations assumed the soil to be at field capacity after establishment irrigation applied to all the treatments. Moisture stress was imposed by withholding irrigation in the early, middle, and late stages of crop development and was continued for varying lengths of time. Maximum potential soil moisture deficit (D_{max}) was used as a measure of drought severity for each treatment, (French and Legg, 1979).

Irrigation was applied when cumulative potential soil moisture deficit (PSMD) becomes more than 50% in the respective treatment. Measured quantity of water was

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applied by manual labor (with fountain bucket). At any time the amount of water applied was equal to the differences between potential evapotranspiration (PET) and rainfall plus irrigation in the previous week. Daily PET values were calculated by FAO computer program 'CROPWAT' based on Penman-Monteith formula (Smith, 1992).

Calculations of amount of water per plot are shown as under

Calculation of amount of water

Plot area	= .20 m x 10 m = 12 m^2
Depth of irrigation	= 25 mm = 0.025 m
Volume of water required	= 12 m^2 x 0.025 m = 0.30 m^3
Quantity required for 1 m^3 in liters	= 1000 L
Required for 25 mm depth of water	= 0.30 x 1000 = 300 L
Fountain diameter (d	= 24 cm
Radius (r) = 12 cm	= 0.12 m
Length of fountain	= 26 cm = 0.26 m
Area (πr^2)	= 3.14 x 0.12^2 = 0.045 m^2
Volume = Area x length	= 0.0452 x 0.26 = 0.011 m^3
Volume required	= 0.30 cm^3

Number of fountain buckets required for 25 mm water application per plot = 0.30/.011 = 27.27 i.e. 27 fountain buckets were used for 25 mm water per plot.

Results and Discussion

Response of water use to total dry matter (TDM) accumulation

Figure 1 shows the potential soil moisture deficit (PSMD) for the irrigated and non-irrigated treatments. The values of maximum PSMD for I_0 (control), I_1 (Irrigation up to stem elongation), I_2 (Irrigation from stem elongation to maturity) and I_3 (full irrigation) were 206.8 mm, 136 mm, 206.8 mm and 92.08 mm respectively. Irrigated crop plants significantly enhanced both TDM and grain yield. Many workers have shown a strong relationship between crop yield and PSMD using Penman drought response model. Inqilab-91 gave higher WUE of 7.47 g m^{-2} mm^{-1} as compared to MH-97 (6.67 g m^{-2} mm^{-1}) for TDM. The response of TDM accumulation to water received (I+R) was significant and varied among different irrigation levels. Irrigated crop plants showed significantly higher response of TDM to water applied over control (nil) irrigation treatment. Similarly, crop plants irrigated up to stem elongation (I_1) reduced TDM accumulation to water applied as compared to I_2 and I_3 treatments (Table 2).

Grain yield response to water use

Data presented in Table 1 show a similar pattern of grain yield response to that of TDM. Inqilab-91 gave higher

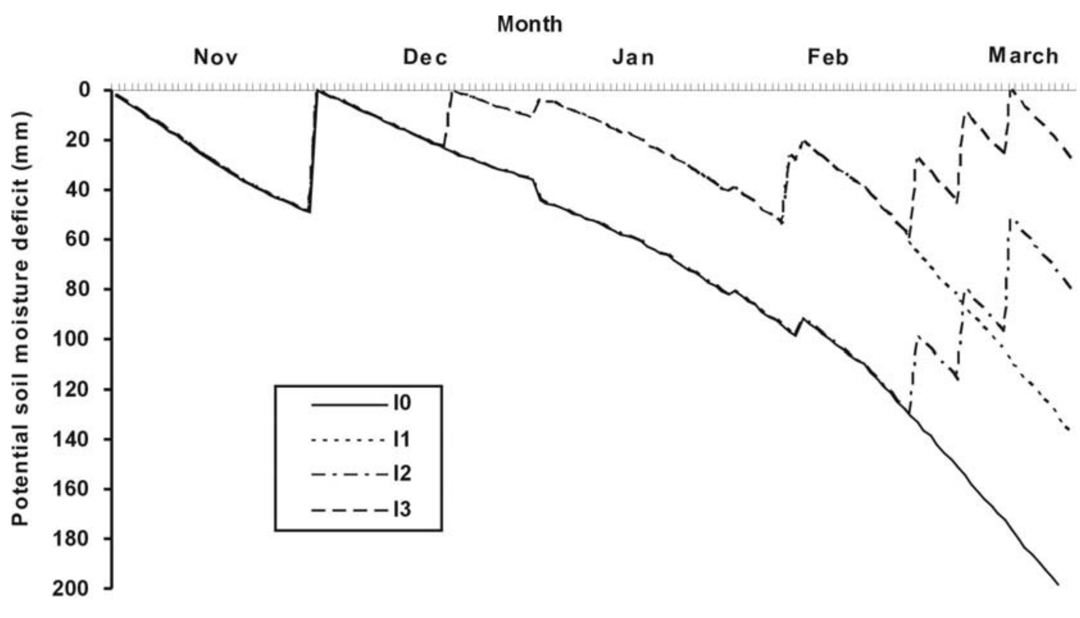

Figure 1: Daily changes in potential soil moisture deficit during crop season

Measurements were recorded on biomass accumulation and grain yield to calculate water use efficiencies on the basis of total water applied and crop evapotranspiration. Data for each trait were subjected to analysis of variance (Steel and Torrie, 1984) and was tested against 0.05 level of probability.

WUE for grain yield (2.15 g m^{-2} m m^{-1}) than MH-97 in the season. As far as irrigation is concerned unirrigated (I_0) control gave significantly higher response of grain yield than irrigated crop plants. WUE response was 1.32 $gm^{-2}mm^{-1}$, 1.88 $gm^{-2}mm^{-1}$, 2.29 $gm^{-2}mm^{-1}$ and 2.51 $gm^{-2}mm^{-1}$ in I_0, I_1, I_2 and I_3 treatments respectively.

Table 1. Number and amount of irrigation during crop season (mm).

Dates	Irrigation amount (mm)			
	I_0	I_1	I_2	I_3
24.11.2002	75.0	75.0	75.0	75.0
16.12.2002	-	30.0	-	30.0
25.02.2003	-	30.0	-	30.0
04.03.2003	-	-	35.0	35.0
17.03.2003	-	-	40.0	40.0
23.03.2003	-	-	50.0	50.0
Rainfall	22.8	22.8	22.8	22.0
Total	97.8	157.8	222.8	282.8

Interaction between cultivar and irrigation levels affecting the response of grain yield to water received was significant (Table 2). Cultivar 1nqilab-91 significantly enhanced water use efficiency for grain yield (2.75 $gm^{-2}mm^{-1}$) at full irrigation and less grain yield of 1.29 gm^{-2} was produced by MH-97. Similar results have been reported by Rafiq, 2004; Day *et al*., 1978; Cortazar *et al*., 1995.

Table 2. Effect of cultivar and irrigation levels on water use efficiency for grain yield and TDM base on total water (irrigation + rainfall) applied (g m^{-2} mm^{-1}).

Treatment	Total dry matter	Grain yield
Cultivar		
Inqulab-91	7.47 a*	2.15 a
MH-97	6.67 b	1.85 b
$S\bar{X}$	0.078	0.023
LSD 5%	0.47	0.14
Irrigation levels		
I_0	4.49 d	1.32 d
I_1	7.18 c	1.88 c
I_2	8.06 b	2.29 b
I_3	8.54 a	2.51 a
$S\bar{X}$	0.149	0.036
LSD 5%	0.46	0.11
Contrast		
I_0 vs (I_1+I_2+I_3)	**	**
I_1 vs (I_2+I_3)	**	**
I_2 vs I_3	**	*
Interaction	NS	**
Mean	7.07	1.99

*Means sharing different letters differ significantly at P < (0.05)
**Significant at 5% and 1%, respectively
NS: Non-significant
I_0 = Control
I_1 = Irrigation upto stem elongation
I_2 = Irrigation from stem elongation to maturity
I_3 = Full irrigation

Table 3. Interaction between cultivar and irrigation affecting water use efficiency for grain yield based on total water (irrigation + rainfall applied (g m^{-2} mm^{-1}).

Irrigation	Inqalab-91	MH-97
I_0	1.35 f	1.29 f
I_1	1.99 d	1.76 e
I_2	2.51 b	2.06 d
I_3	2.75 a	2.27 c
	$S\bar{X}$ = 0.047	LSD 5% = 0.14

Means sharing different letters differ significantly at P < (0.05)
I_0 = Zero irrigation
I_1 = Irrigation upto stem elongation
I_2 = Irrigation from stem elongation to maturity
I_3 = Full irrigation

Table 4. Effect of cultivar and irrigation levels on water use efficiency for yield and TDM base on crop evapotranspiration (g m^{-2} mm^{-1}).

Treatment	Total dry matter	Grain yield
Cultivar		
Inqulab-91	5.99 a*	1.72 a
MH-97	5.44 b	1.51 b
$S\bar{X}$	0.058	0.023
LSD 5%	0.25	0.14
Irrigation levels		
I_0	4.07 c	1.19 d
I_1	5.67 b	1.48 c
I_2	6.35 a	1.80 b
I_3	6.76 a	1.99 a
$S\bar{X}$	0.15	0.025
LSD 5%	0.46	0.08
Contrast		
I_0 vs (I_1+I_2+I_3)	**	**
I_1 vs (I_2+I_3)	**	**
I_2 vs I_3	NS	**
Interaction	NS	**
Mean	5.71	1.62

*Means sharing different letters differ significantly at P < (0.05)
**Significant at 5% and 1%, respectively
NS: Non-significant
I_0 = Control
I_1 = Irrigation upto stem elongation
I_2 = Irrigation from stem elongation to maturity
I_3 = Full irrigation

WUE for TDM based on crop evapotranspiration

Table 4 shows non-significant differences among treatment means of cultivars on crop evapotranspiration (ET) during the season. However, Inqilab-91 used water

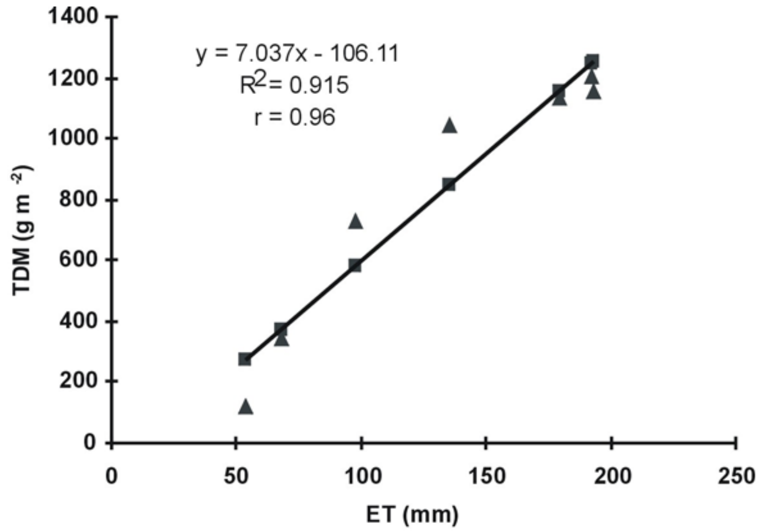

Figure 2. Relationship between TDM and accumulated crop evapotranspiration

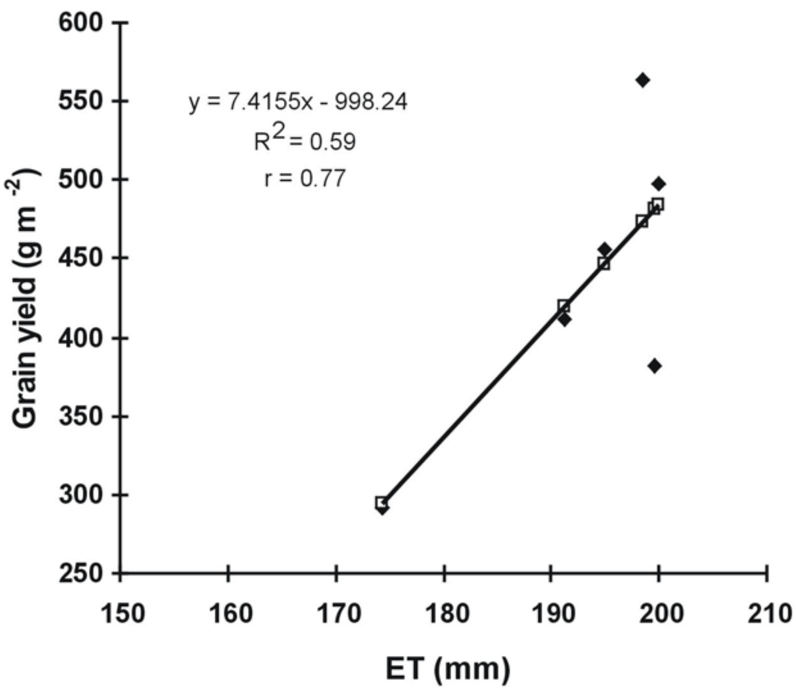

Figure 3. Relationship between grain yield and accumulated crop evapotranspiration

efficiently in producing TDM than MH-97. Relationship between TDM and $Crop_{ET}$ was linear and common regression accounted for 92% variability in the data (Figure 2).

WUE for grain yield based on crop evapotranspiration

A similar trend in WUE for grain yield based on crop ET was noted (Table 4). Irrigation treatments significantly enhanced crop ET over control (nil) treatment. Crop ET for different irrigation levels was 153, 178, 180 and 178 mm in I_0, I_1, I_2 and I_3 treatments, respectively and corresponding responses of WUE were 4.07, 5.67, 6.35 and 6.76 g m^{-2} m m^{-1} of water transpired. These results are in confirmation with with Sun et al., 2006 who concluded that WUE increased from zero to full irrigation in semi-arid regions. The relationship between grain yield and cumulative crop ET was positive (Figure 3), and the common regression accounted for 59% variance in the data.

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