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Influence of Water Stress on Growth, Yield and Radiation Use Efficiency of Various Wheat Cultivars

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ABSTRACT

Effects of water stress on growth, yield and radiation use efficiency (RUE) of different wheat cultivars were studied during 1998-2000 at the Agronomic Research Area, University of Agriculture, Faisalabad. Four or five irrigation treatments, based on soil moisture deficit, were applied to each cultivar in the two seasons. Irrigation treatments were designed to induce a range of drought treatments from full irrigation to no irrigation between emergence and harvest. Leaf area index, radiation interception and biomass accumulation were measured throughout the growing season. In both seasons there was a highly significant positive relationship between cumulative intercepted PAR and biomass production. The RUE of wheat ranged from 1.99 to 2.71g DM MJ^{-1}intercepted PAR in both the seasons. Results showed that the highest yields were obtained from fully irrigated treatments; yield variations among treatments were caused by affecting both the amount of intercepted PAR and RUE. Drought imposed throughout or after emergence early in the season depressed RUE significantly by 29.7 to 32.8% (1998-1999) and 10.9-15.5% (1999-2000) compared with the fully irrigation treatment. In treatments where drought was imposed later in the growth (before anthesis or later), the primary cause of reduced biomass production was a decrease in the RUE and to a lesser extent in the amount of intercepted PAR, mostly associated with low photosynthesis rate. The response of cultivars to radiation interception was slight and significant only during 1999-2000. Final grain or biomass yield was sensitive to drought timing, especially to maximum potential soil moisture deficit for the early than the later drought treatments.

Key Words: Drought; Radiation use efficiency; Yield; Wheat; Pakistan

INTRODUCTION

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). Decreased growth rate is caused primarily by reduction in radiation use efficiency (RUE) when drought was imposed at various growth stages such as tillering, booting, earing, anthesis and grain development stage (Jamieson *et al*., 1995). Better performance of the crop depends upon availability of water during these stages. Water stress at anthesis reduces pollination and thus less number of grains is formed per spike 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 photosynthesis rate but also gives plant extra time to translocate the carbohydrates to grains (Zhang *et al*., 1998), thus enhancing grain size and ultimately cause higher grain yield (Gallagher & Biscoe, 1978).

Grain yield of many crops is closely related to their total biomass production rather than harvest index (Monteith & Scott, 1982). It is, therefore, necessary to understand the process of dry weight production under high water deficits in order to understand yield differences among various irrigation regimes. The mechanisms involve changes in the crop's ability to intercept solar radiation and efficiency of its use or time available for both. As photosynthesis process is controlled by the amount of radiation intercepted and efficient use of light is attributed to the leaf area of the crop which is more or less controlled by temperature and water. Efficient water supply during early growing season increases leaf area of the crop, enabling it to intercept more of the incoming radiation. According to Jamieson *et al*. (1995) drought at tillering stage has shown a linear decrease in RUE of a cereal crop and drought at the middle or late period of growing season does not have effect on RUE. High temperature after anthesis coupled with drought generally decrease kernel number, reproductive duration and grain yield (Gibson & Pauslsen, 1994).

The present study was, therefore, undertaken to examine the effects of water stress on biomass production and grain yield of various wheat cultivars. Differences in yield were compared in terms of intercepted PAR and its efficiency of use into dry matter.

MATERIALS AND METHODS

Two field experiments were conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, (31.25^{o} N, 73.09^{o} E, 184.4 m) during 1998-1999 and 1999-2000. Both experiments were laid out in a split plot design with three replications. During season 1, the treatments were four cultivars (InqiIab-91, Punjab-96, Kohistan-97, MH-97) and four irrigation levels (l_1 = control, l_2 = stress after tillering, l_3 = stress after earing, l_4 = fully irrigated). In season 2, treatments were three cultivars (Inqilab-91, Punjab-96, MH-97) and five irrigation levels (I_1 = control, I_2 = stress after tillering, I_3 = stress after earing, I_4 = stress before earing, I_5 = fully irrigated). Cultivars were the main plots and irrigation levels were the subplots. Each subplot was 1.20m x 5.0m.

In each season the crop was sown manually with the help of a single row hand drill @ 100 kg seed ha^{-1} in early November. Half doze of nitrogen (N) and full doze of phosphorus (P) @ 120-100 NP kg ha^{-1} was worked out in the soil during seed bed preparation while remaining half of the N was applied with first (establishment) irrigation. All other cultural operations were kept uniform except irrigation levels in both the seasons.

Measured quantity of water was applied by manual labour (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. The calculations assumed the soil to be at field capacity after establishment irrigation being 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. Drought was considered to start on 24 November 1998 and 1 December 1999 after the pre-drought (establishment) irrigation. Maximum potential soil moisture deficit (D_{max}) was used as a measure of drought severity for each treatment (French & Legg, 1979).

Data on various growth and yield attributes were recorded by using standard procedures. All the data were analysed statistically using analysis of variance technique and the significance of treatment means was tested using least significance difference (LSD) test at 5% probability (Steel & Torrie, 1984).

RESULTS AND DISCUSSION

Leaf area index. Water stress of various durations caused large variations in the development of leaf area index (LAI) throughout the season (Fig. 1). Water stress influenced LAI significantly during mid to late season growth and not in the early part of growth. From mid February onward l_1 (control) treatment reduced LAI as compared to irrigated treatments until final harvest. Similarly drought imposed after tillering (l_2) also significantly reduced LAI than all other treatments where drought was partial (l_3, l_4) or no drought at all (l_5). Maximum LAI varied from 5.49 to 6.63 among different treatments on 97 DAS (15 February), thereafter it declined to < 1.0 on 30 March harvest (Fig. 1). Cortazar *et al.* (1995) also reported that drought reduced LAI in wheat.

Biomass accumulation. At final harvest, total biomass also differed significantly among different cultivars (Tables I, II). Maximum biomass was accumulated by cv. Inqilab-91 at 11.86 t ha^{-1} in 1998 / 99 and 15.14 t ha^{-1}in 1999 / 2000. The cv. MH-97 gave the lowest (10.49 t – 13.94 t ha^{-1}) biomass accumulation in two seasons.

Biomass accumulation differed significantly among various treatments during the seasons (Fig. 2). In droughted treatments (l_1, l_2) biomass accumulation was substantially lower than irrigated treatments. The l_1 (moisture stress throughout the season) decreased biomass by 8.81% as compared to crops with partial or no drought treatments (l_2 +---l_5). Differences in biomass accumulation between l_2 vs (l_3 + ---l_5) or l_3 vs (l_4+---l_5) were non significant up to early February, and then drought significantly reduced biomass until final harvest. Biomass accumulation at final harvest ranged from 8.59t to 13.78 t ha^{-1} (1998-99) and 13.64 t to 15.41 t ha^{-1} (1999-2000) among various irrigation treatments respectively (Tables I, II). Many workers reported similar values of 9.5 to 15.0 t ha^{-1} under variable management in wheat (Hussain *et al*., 1997; Wajid *et al.*, 2002 a,b).

Drought showed a significant effect on maximum biomass production (Fig. 3). Simple linear regression showed that drought reduced biomass production by 2.73 g m^{-2} mm^{-1} (R^2 = 0.935) in 1998-1999 and 1.19 g m^{-2} mm^{-1} (R^2 = 0.946) in 1999 / 2000 seasons. Both Day *et al*. (1978) and Jamieson *et al*. (1995) reported similar pattern of reduction (1.03 to 2.0 g m^{-2} mm^{-1}) in biomass during mid to later drought; early drought, however, reduced biomass production 4.21 g m^{-2} mm^{-1}.

Radiation interception. The fraction of radiation intercepted by different treatments followed the pattern of LAI curves (Fig. 4). Light transmission was stable and reached at its maximum value of 90% when LAI values were greater than 5.0 in I_5 treatment. By contrast, it reached at a value of about 80% in I_1 (control) or I_2 (stress at Tillering) treatments when LAI values were 4-5. The amount of accumulated intercepted PAR differed significantly by about 8-10% among various drought treatments (Tables I, II). Maximum cumulative intercepted photosynthetically active radiation (PAR) ranged from 430 to 470 MJ m^{-2} in 1998 / 99 and 847 to 916 MJ m^{-2} in 1999 / 2000, respectively (Tables I, II).

Radiation use efficiency. Radiation use efficiency (RUE) for individual treatments was obtained from regression of biomass accumulation on intercepted PAR (Table III). For all treatments accumulated biomass was closely related with accumulated intercepted PAR, and the regression lines gave RUE (slope) of 2.71 g MJ^{-1} in 1998-99 and 1.99 g MJ^{-1} in 1999-2000 (Fig. 5). Variations in maximum measured biomass attained by treatments could be explained by the variation in PAR intercepted. According to Monteith (1977) total biomass production in a range of field crops including wheat is proportional to the amount of intercepted PAR. The fraction of radiation intercepted by crops increases hyperbolically with LAI, and reaches to more than 90% when LAI becomes 4-6, irrespective of climate to ensure maximum growth rate (Monteith & Elston, 1983).Many workers have reported similar values of RUE in wheat

Fig. 1. Changes in Leaf Area Index with time for different irrigation treatments

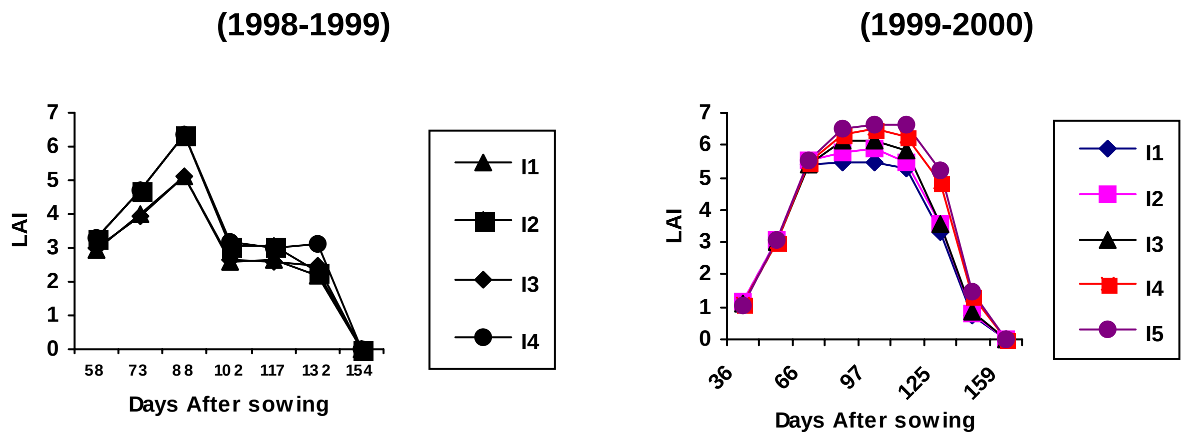


Fig. 2. Changes in Total Dry Matter accumulation with time for different irrigation treatments

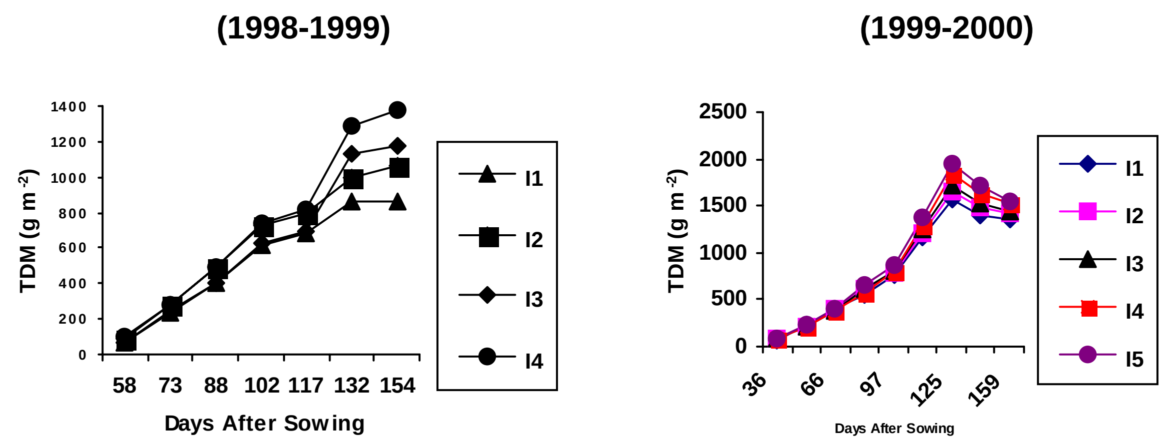


Fig. 3. Changes in Fraction of Intercepted Radiation with time for different irrigation treatments

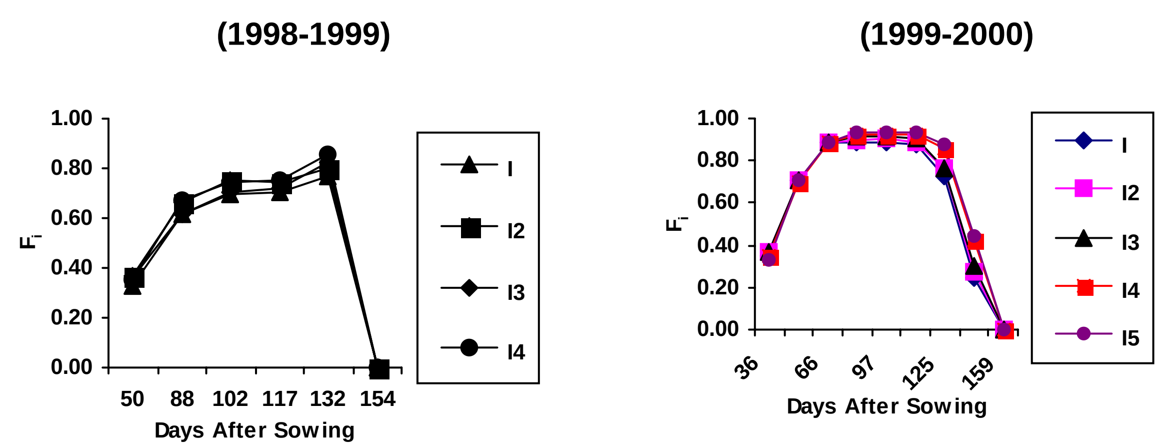


Fig. 4. Relationship between maximum biomass and maximum potential soil moisture deficit (Dmax)

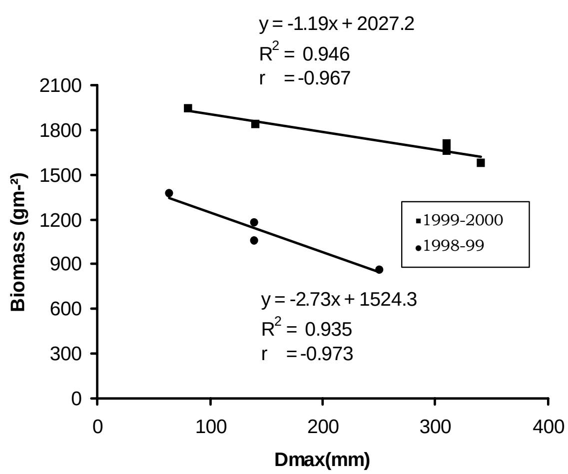


Fig. 5 Relationship between biomass accumulation and intercepted PAR accumulation

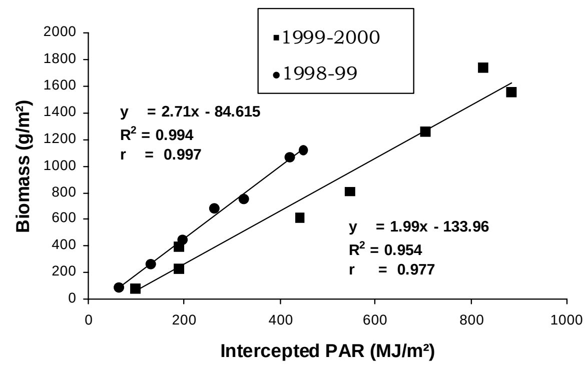
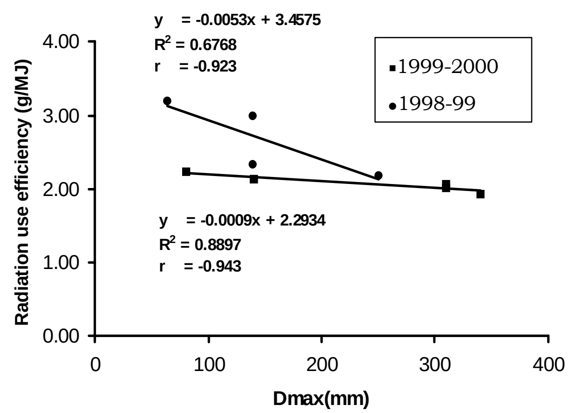


Fig. 6. Relationship between radiation use efficiency and maximum potential soil moisture deficit (Dmax)



ranging from 1.62 g MJ^{-1} to 2.38 g MJ^{-1} intercepted PAR (Kiniry *et al.*, 1989; Yunusa *et al.*, 1993; Jamieson *et. al.*, 1995). Water stress caused significant reduction in maximum biomass production by changes in the amount of intercepted PAR (Table II). However, results also showed that the reductions caused by changes in RUE were substantially larger than those changes in interception. The RUE (slopes) of the drought treatments were significantly lower than the value for the irrigated treatments (Table III). There was a strong negative linear relationship between RUE and maximum potential soil moisture deficit (Fig. 6). In 1998 / 1999, reductions caused in RUE by drought were 46.12 % in I_1, 37.34 % in I_2 and 7.02 % in I_3 compared with unstressed crop (I_4). Equivalent reductions in RUE by water stress were 15.54% in I_1, 10.94% in I_2, 8.25% in I_3 and 4.21% in I_4 treatments compared with the unstressed crop (I_5) during 1999 / 2000.

Results showed that early moisture stress did cause substantial reductions in RUE, and these persisted throughout the life of the crop. This also implies that only early drought is involved in significant diminishing production through decreasing photosynthesis per unit leaf area. Jamieson *et al.* (1995), working in New Zealand, also reported similar effects of drought on RUE in barley.

Grain yield. Cultivar differences in grain yield were significant only during 1999-2000 when cv. Inqilab-91 gave the maximum grain yield, followed by cv. Punjab-96 and cv. MH-97 (Table II). As harvest index varied little among cultivars, grain yield was mainly determined by the total biomass production. Differences in grain responses of these cultivars appear to be a direct consequence of the factors which enhance compensation of yield components among various genotypes. Many workers have reported similar yield level varying from 3.0t to 6.0t ha^{-1} among various genotypes of wheat (Hussain *et al.*, 1997; Wajid *et al.*, 2002 b).

The major determinant of grain production was total biomass, therefore drought induced reduction in grain yield followed trends similar to those of total biomass (Tables I, II). Differences in grain yield between treatments were largely attributed to changes in both mean seed weight and seed number. Both components were equally influenced by moisture stress (Sajjad, 2001).

CONCLUSION

There was a linear relationship between total biomass production and cumulative intercepted PAR. High yields thus require agronomic techniques that produce both a high level of radiation interception and a high rate of conversion of intercepted PAR to grain. Reductions in RUE under adverse moisture conditions could possibly be avoided by an improved rooting habit of wheat cultivars. Further increases in yield are most likely to come from techniques which promote earlier leaf expansion.

Table I. Effect of cultivars and irrigation levels on grain yield, total biomass and harvest index during 1998-1999

Treatments	Grain yield (t ha^{-1})	Biomass (t ha^{-1})	Harvest index	Intercepted PAR (MJ m^{-2})	Radiation use efficiency (g DM MJ^{-1})
Cultivars					
C1 (Inqilab-91)	3.55 NS	11.86 a	0.30 NS	460 NS	2.67 a
C2 (Punjab-96)	3.29	11.14 b	0.30	455	2.44 b
C3 (Kohistan-97)	3.41	11.32 b	0.31	433	2.58 a
C4 (MH-97)	3.25	10.49 c	0.32	452	2.28 c
LSD 5%	-	0.51	-	-	0.11
Irrigation					
l_1 (Control)	2.80 c	8.59 d	0.33 a	430 d	1.91 d
L_2 (Stress after tillering)	3.25 b	10.63 c	0.31 ab	458 b	2.36 c
L_3 (Stress after earing)	3.53 b	11.81 b	0.30 b	442 c	2.63 b
l_4 (Fully irrigated)	3.93 a	13.78 a	0.29 b	470 a	3.06 a
LSD 5%	0.30	0.33	0.03	9	0.13
Contrasts					
l_1 vs (l_2+---l_4)	**	**	**	**	**
l_2 vs (l_3+---l_4)	**	**	NS	NS	**
l_3 vs l_4	*	**	NS	**	**
Mean	3.38	11.20	0.30	450	2.49

Figures in the same column with different letters differ significantly by LSD at ($P \leq 0.05$)

*, ** = Significant at 5% and 1% probability

NS = Non significant

Table II. Effect of cultivars and irrigation levels on grain yield, total biomass and harvest index during 1999-2000

Treatments	Grain yield (t ha^{-1})	Biomass (t ha^{-1})	Harvest index	Intercepted PAR (MJ m^{-2})	Radiation use efficiency (g DM MJ^{-1})
Cultivars					
C1 (Inqilab-91)	5.76 a	15.14 a	0.38 a	898 a	1.69 NS
C2 (Punjab-96)	5.37 b	14.74 a	0.36 b	903 a	1.63
C3 (MH-97)	4.95 c	13.94 b	0.35 b	850 b	1.64
LSD 5%	0.35	0.70	0.01	14	
Irrigation					
l_1 (Control)	5.07 c	13.64 c	0.37 NS	847 c	1.61 c
l_2 (Stress after tillering)	5.26 b	14.27 b	0.37	867 b	1.65 b
l_3 (Stress after earing)	5.24 b	14.44 b	0.36	876 b	1.50 b
l_4 (Stress before anthesis)	5.57 a	15.27 a	0.37	912 a	1.67 ab
l_5 (Fully irrigated)	5.66 a	15.41 a	0.37	916 a	1.68 a
LSD 5%	0.10	0.21	-	10.3	0.33
Contrasts					
l_1 vs (l_2+---l_5)	**	**	NS	**	**
l_2 vs (l_3+---l_5)	**	**	NS	**	NS
l_3 vs (l_4 + l_5)	**	**	NS	**	*
l_4 vs l_5	NS	NS	NS	NS	NS
Mean	5.36	14.61	0.37	884(68%)	1.65

Figures in the same column with different letters differ significantly by LSD at ($P \leq 0.05$)

*, ** = Significant at 5% and 1% probability

NS = Non-significant

Table III. Regression analysis of biomass accumulation on intercepted PAR

Treatment	Slope	Intercept (g MJ^{-1})	R^2 (g m^{-2})
		1998–1999	
l1 (Control)	2.19 ± 0.16	-18.53	0.974
l2 (Stress after tillering)	2.33 ± 0.16	-20.25	0.977
l3 (Stress after earing)	2.99 ± 0.18	-142.49	0.983
l4 (Fully irrigated)	3.20 ± 0.16	-152.27	0.988
Mean	2.65 ± 0.10	-86.74	0.994
		1999–2000	
Treatment	**Slope**	**Intercept (g MJ^{-1})**	**R^2 (g m^{-2})**
l1 (Control)	1.93 ± 0.15	-166.68 ± 109.41	0.967
l2 (Stress after tillering)	2.01 ± 0.15	-190.20 ± 113.44	0.968
l3 (Stress after earing)	2.06 ± 0.16	-200.71 ± 116.10	0.969
l4 (Stress before earing)	2.14 ± 0.19	-219.02 ± 148.71	0.957
l4 (Fully irrigated)	2.23 ± 0.18	-202.86 ± 149.45	0.961
Mean	1.99 ± 0.18	-134.17 ± 144.49	0.954

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