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GROWTH AND RADIATION USE EFFICIENCY OF WHEAT AS AFFECTED BY DIFFERENT IRRIGATION LEVELS AND PHOSPHORUS APPLICATION METHODS

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ABSTRACT

Effects of five irrigation treatments (I_1 = control (no irrigation), I_2 = two irrigations (crown root and booting stage), I_3 = three irrigations (crown root, booting and grain development), I_4 = four irrigations (crown root, booting , anthesis and grain development), and I_5 = five irrigations (crown root, booting, earing, anthesis and grain development) and three phosphorus application methods (P_1 = side dressing, 3 inches side the seed , P_2 = broadcasting at the time of seedbed preparation and P_3 = top dressing after first irrigation) on growth, light interception and light use efficiency of wheat were studied through field experiments conducted at experimental area of the Central Cotton Research Institute (CCRI), Multan, (30.12 ^{o}N, 71.28 ^{o}E, 123 m) during growing seasons of 2006-07 and 2007-08. Full irrigation treatments (I_4 and I_5) captured 510-488 MJ m^{-2} between 20 DAS and 120 DAS, by that time crop had achieved maximum biomass. In addition to light interception, treatments also affected radiation use efficiency (RUE). During both the seasons, highly significant linear relationship between cumulative intercepted photosynthetically active radiation (PAR) and biomass production was observed. Radiation use efficiency (RUE) of wheat ranged from 1.81-1.88 g MJ^{-1}. Results revealed the highest grain yield (> 5 t ha^{-1}) obtained from fully irrigated treatments (I_4) while yield variations among irrigation levels were caused by affecting both the amount of intercepted PAR and RUE. Based on these results, application of four irrigations at crown root, booting, anthesis and grain development could be considered for improving RUE in spring wheat under a relatively hotter environment.

Keywords: Leaf area index, Pakistan, total dry matter accumulation, wheat.

INTRODUCTION

Crop growth and yield is considered to be a function of photosynthetically active radiation (PAR) intercepted and its utilization efficiency into dry matter and is significantly influenced by plant moisture stress (Monteith 1977). A number of workers have found close correlation between crop growth and yield and radiation interception (Gregory *et al*., 1992; Hussain *et al*., 2002; Wajid *et al*., 2007; Quanqi *et al*., 2008; Li *et al*., 2009; Miranzadeh *et al*., 2011; Ahmad *et al*., 2012).

Availability of soil moisture influences many aspects of crop growth and yield (Begg and Turner 1976). High yields of cereals and other crops were associated with larger values of leaf area duration (LAD) under better management of irrigation (Thorne 1974). Better performance of crop depends on availability of irrigation water, especially at various growth stages. Jamieson *et al*. (1995) concluded that non-availability of water at early stages of crop growth showed reduction both in the amount of intercepted PAR and RUE. Adequate water at or after anthesis not only allowed the plant to increase photosynthesis rate but more importantly gave the plant extra time to translocate the carbohydrates to grains (Zhang *et al*., 1998), thus enhanced grain size and ultimately resulted higher grain yield.

The effect of radiation on yield formation in irrigated and fertilized spring wheat was quantified, focusing on the crop growth and partitioning during the spike growth period, critical for the determination of number of grains (Abbate *et al*., 1997). Significant differences were observed in RUE when maize crop was sown under phosphorus deficiency. Measurements of post-anthesis RUE reduced in all cultivars that confirmed that the sink size may exert a great effect in post-anthesis RUE through reducing the leaf photosynthetic rates during grain filling (Acreche *et al*., 2009). The objective of this research was to study the effects of irrigation regimes and phosphorus application methods on growth, light interception and light use efficiency of wheat under irrigated arid environment.

MATERIALS AND METHODS

Interactive effects of irrigation regimes and phosphorus application methods on growth, light interception and light use efficiency of wheat were studied through field experiments conducted at experimental area of the CCRI, Multan, (30.12 ^{o}N, 71.28

°E, 123 m) during growing seasons of 2006-07 and 2007-08. The experiments were laid out in a randomized complete block design (RCBD) with split plot arrangement keeping moisture regimes in main plots and P application methods in sub-plots. Main plots had five irrigation regimes (I_1, I_2, I_3, I_4, I_5) and sub-plots were composed of 3 phosphorus application methods (P_1 = side dressing, 3 inches side the seed, P_2 = broadcasting at the time of seedbed preparation and P_3 = top dressing immediately after first irrigation). Each experiment consisted of three replications with a plot size of 2.4 m x 8.0 m, having 12 rows and each row 20 cm apart. The experimental site was ploughed twice and harrowed once for seedbed preparation. Before sowing, 120 kg N and 100 kg P ha^{-1} was applied and incorporated into the soil manually as per treatments. The sowing date was 20th and 24th November in 2006 and 2007, respectively. Weeds were controlled, early in the season, by hand weeding. The crop was harvested manually on 30th and 25th April in 2007 and 2008, respectively. Details of different husbandry practices were described in a companion paper by Ali *et al*. (2012). All measurements relating to growth and yield were the same in both the years. Fresh weight of components fractions of plant i.e. leaf, stem and ear (when appeared) was determined. An appropriate sub-sample of each fraction was taken to dry in an oven to a constant weight at 75-80°C. From measurements of leaf area and dry weight, following growth parameters were determined. Leaf area index (LAI) was calculated as the ratio of leaf area to land area (Watson, 1947).

Radiation interception and radiation use efficiency: The fraction of intercepted radiation (Fi) was calculated from measurements of LAI using the exponential equation as suggested by Monteith and Elston (1983). [Fi = 1-exp (-k x LAI); where k is the extinction co-efficient for total solar radiation. The k value of 0.45 was used for wheat as described by Jamieson *et al*. (1995)]. The amount of intercepted radiation (Sa) was determined by multiplying Fi with incident PAR (Sa) during the season {Sa = Fi x Si}. Radiation use efficiency for TDM (RUE_{TDM}) and grain yield (RUE_{GY}) were calculated as the ratio of total biomass and grain yield to cumulative intercepted PAR ($\sum$ Sa).

All the data collected were statistically analyzed as a split plot design, using analysis of variance to calculate main and interaction effects. Differences among treatment means were compared using least significant difference (LSD) at $P \leq 0.05$ probabilities (Steel *et al*., 1997).

Weather: The average temperatures for the growing cycle were lowered from November to January; thereafter they increased to a maximum value of 29.5°C (2006-07) and 26.1°C (2007-08). The rainfall recorded for the growing seasons shows that the second season (2007-08) was drier than the first (2006-07). Low rainfall in the second season, along with relatively warmer temperatures, increased the potential soil moisture deficit early in the season (Table 1), exceeding 354 mm in March during 2007-08. Total potential soil moisture deficit 260.9 mm and 391.1 mm in season 1and 2, respectively at the end of March compared with about 282.2 mm and 295.3 mm in the first and second season at that time. Radiation levels were generally close to the long term means during both the seasons.

RESULTS

Biomass accumulation: Generally, total dry matter (TDM) accumulation of various treatments continued to increase up till 120 DAS, and thereafter DM slightly increased or leveled off in all the treatments until final harvest (Fig. 1). Irrigated crop plants significantly increased biomass compared to control (I_1) treatment in both the seasons. Differences between I_2 (two irrigations) and I_3 (three irrigations) were also significant during both the years. Accumulation of biomass between I_4 (four irrigations) and I_5 (five irrigations) was not significantly affected during the seasons (Fig. 1a, b). The average TDM at final harvest was 415, 530, 809, 1072 and 1085 g m^{-2} for I_1, I_2, I_3, I_4 and I_5 treatments,, respectively during 2006-07, although trend of TDM accumulation was similar during 2007-08 yet treatments produced 3.85%, 1.88%, 4.56%, 1.86% and 3.875 less TDM than 2006-07 (Table 1).

The P_1 (side dressing) treatment accumulated higher TDM than P_2 (broadcast) and P_3 (top dressing) throughout the seasons (Fig. 1c, d). Differences between the P_2 and P_3 application methods were also significant when P_2 treatment enhanced biomass accumulation over P_3 treatment. Peak biomass accumulation reached at 120 DAS in all the treatments during both the years; thereafter, it slightly increased or leveled off towards the final harvest. At final harvest, average biomass accumulation, during 2006-07, was 840, 778 and 729 g m^{-2} in P_1, P_2 and P_3 treatments, respectively. While, in 2007-08, treatments produced 2.97%, 3.08% and 3.56% less TDM, respectively (Table 1).

Leaf area index: During both the seasons, irrigation significantly influenced LAI at all the harvest dates (Fig. 2a, b). Among various irrigation levels, differences in LAI development were also significant throughout the seasons. Differences in LAI between I_4 and I_5 treatments were, however, non-significant during both the years. Maximum LAI reached at 80 DAS in all the treatments and it varied 1.66 in I_1, 2.17 in I_2, 3.22 in I_3, 4.34 in I_4 and 4.26 in I_5 during 2006-07. However, during 2007-08 treatment produced maximum LAI 2.41%, 3.68%, 3.11%, 3.46% and 3.99% less than the previous year (Table 1). Thereafter, LAI declined in all the irrigation levels and reached its minimum values at final harvests.

The effect of P application methods on LAI during both the seasons are shown in Fig. 2c, d. Generally differences among P application methods for LAI development were significant throughout the seasons and maximum LAI reached at 80 DAS which ranged 2.74 to 3.40 in 2006-07 and 2.64 to 3.29 (2007-08); thereafter LAI in all the P application methods sharply declined to a value less than 2.0 towards the physiological maturity.

Incident and intercepted radiation: During 2006-07, total incident PAR was 875 MJ m^{-2} of which 414 MJ m^{-2} (47.3%) was intercepted and equivalent values, in 2007-08, for the incident PAR was 878 MJ m^{-2} of which 44.8% (393 MJ m^{-2}) was intercepted (Table 1). During both the seasons irrigated crop plants significantly increased the cumulative intercepted PAR over control or partially irrigated treatments. Differences in accumulated intercepted PAR between I_4 and I_5 treatments were non-significant during 2006-07 but significant during 2007-08. During 2006-07, mean values of intercepted PAR were 279, 338, 435, 510 and 508 MJ m^{-2} for I_1, I_2, I_3, I_4 and I_5, respectively. However, during 2007-08 respective treatments intercepted 5.38%, 5.62%, 5.06%, 4.31% and 4.72% less intercepted PAR, respectively (Table 1).

The effect of different P application methods on intercepted PAR was also significant (Table 1). Treatment P_1 (side dressing) resulted higher interception of PAR compared with P_2 (broadcasting) and P_3 (top dressing) treatments. The P_2 treatment also enhanced intercepted PAR over P_1 treatment during both the seasons. The average amount of intercepted PAR in 2006-07 was 435, 423, and 384 MJ m^{-2} for P_1, P_2 and P_3, respectively. However, during 2007-08 treatments intercepted PAR 4.83%, 4.72% and 5.47% less than previous year, respectively.

Radiation use efficiency: During both the seasons, I_4 and I_5 irrigated treatments significantly enhanced RUE for TDM over control (I_1) or partially irrigated treatments (I_2, I_3) (Table 1). Differences in RUE between I_4 and I_5 treatments were non-significant in either year. The average RUE, in 2006-07, was 1.49, 1.57, 1.86, 2.10 and 2.14 g MJ^{-1} in I_1, I_2, I_3, I_4 and I_5 treatments, respectively. However, during 2007-08 treatments average RUE was 1.97%, 3.68%, 0.53%, 2.77% and 0.47% higher than the previous year, respectively.

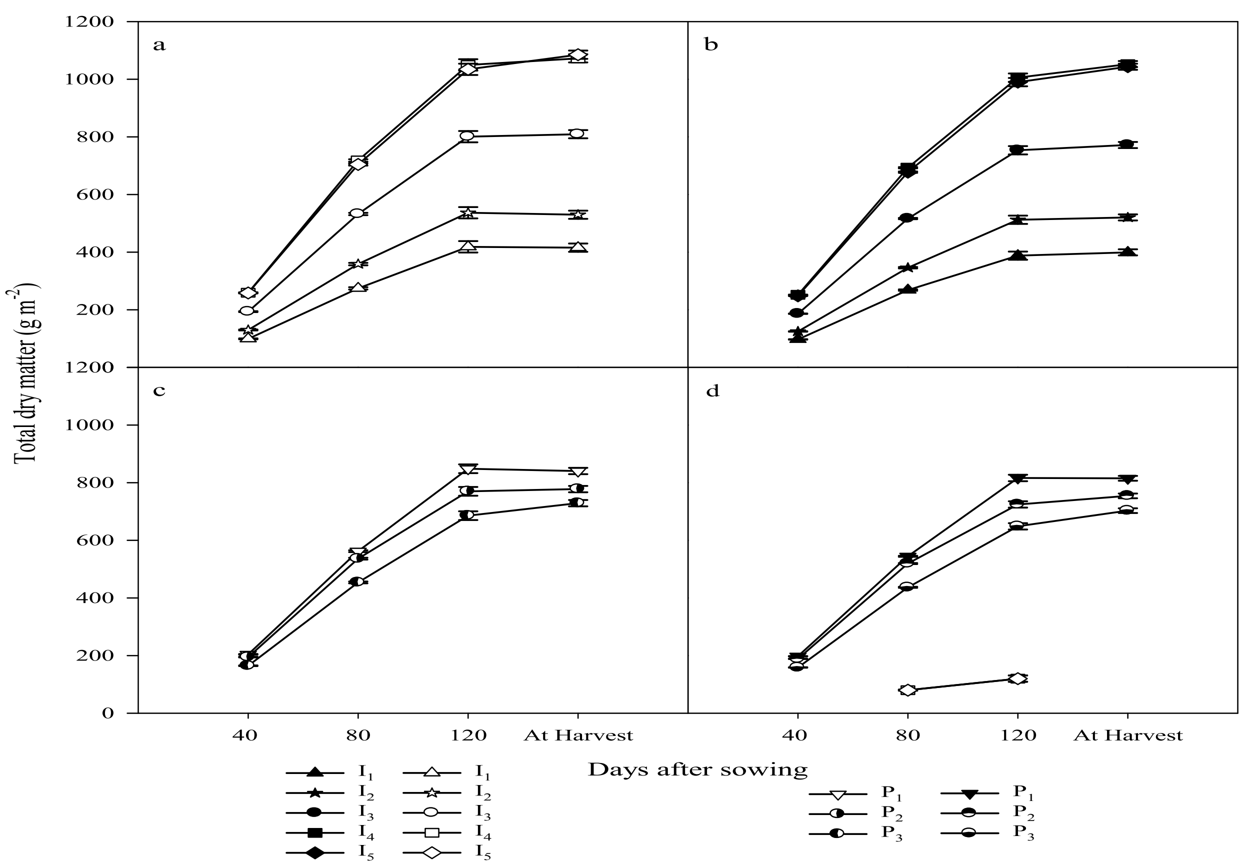

Fig. 1. Total dry matter of wheat as affected by irrigation regimes and phosphorus application methods during 2006-07 (a and c) and 2007-08 (b and d).

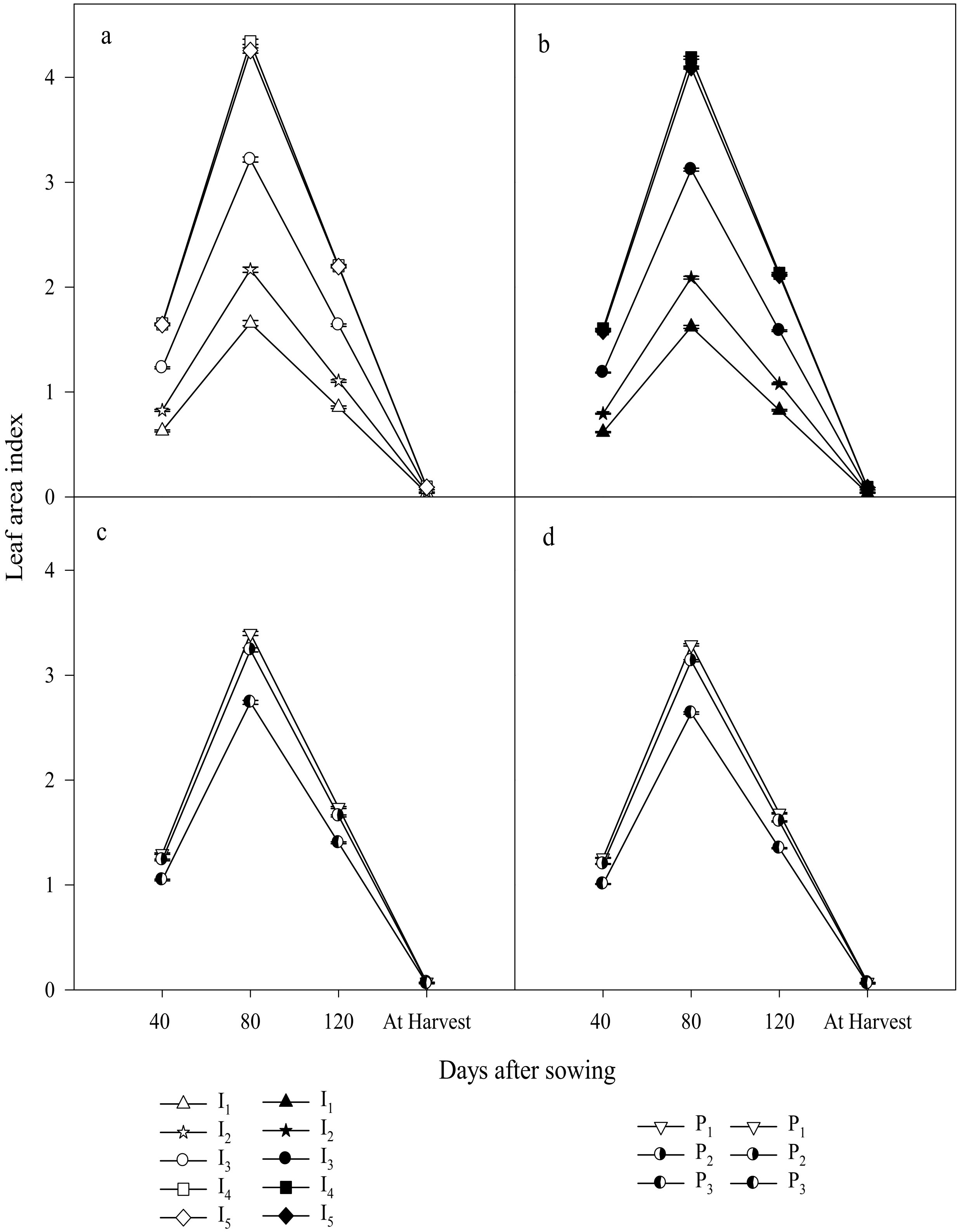

Fig. 2. Leaf area index of wheat as affected by irrigation regimes and phosphorus application methods during 2006-07 (a and c) and 2007-08 (b and d).

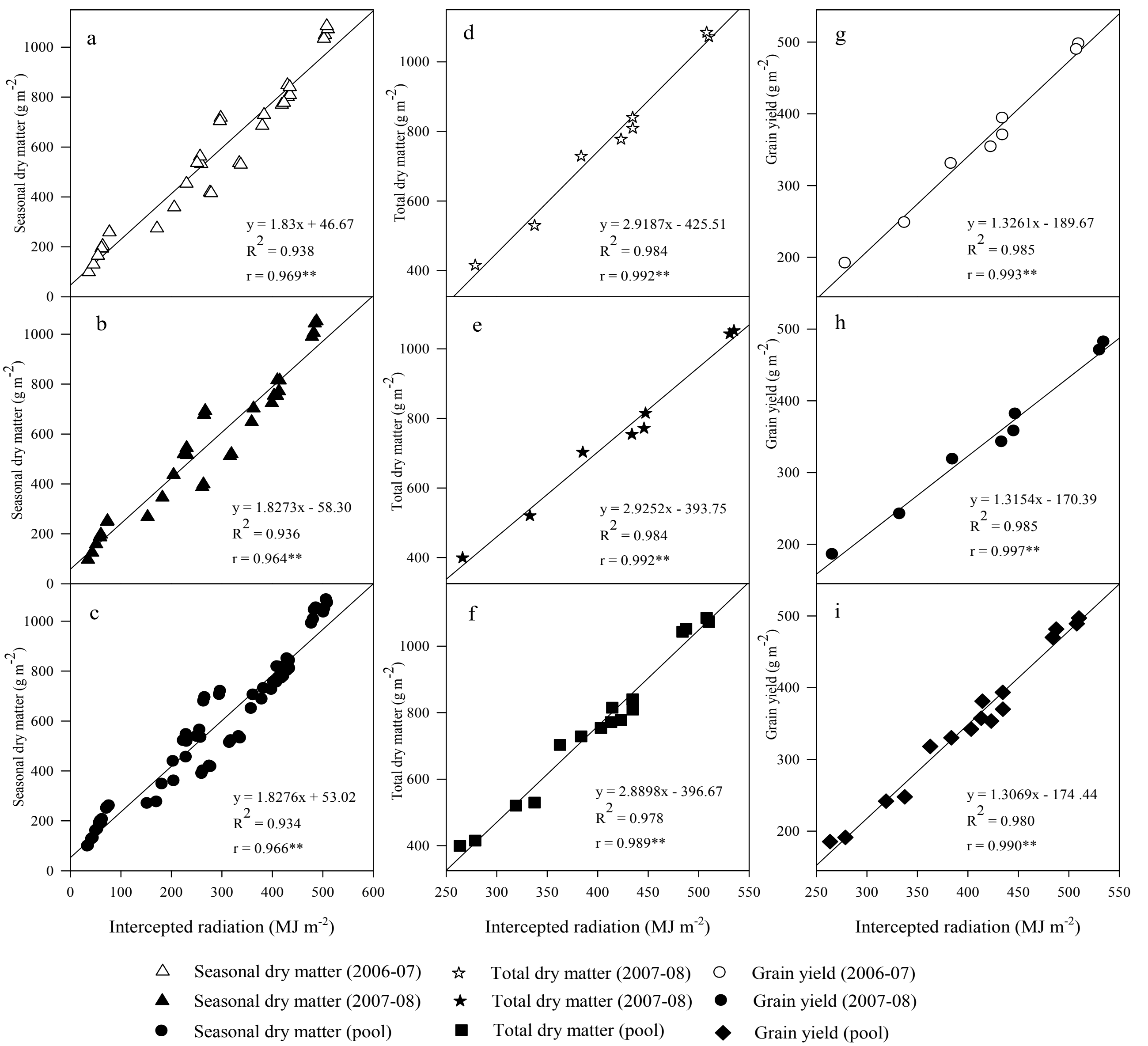

Fig. 3. Relationship between seasonal dry matter and intercepted radiation (a, b and c), final dry matter and intercepted radiation (d, e and f) and grain yield and intercepted radiation (g, h and i) of wheat at Multan, Pakistan.

The effect of P application methods on RUE for TDM was also significant in both years. Treatment P_1 (side dressing) and P_3 (top dressing) resulted in higher RUE compared with P_2 application method. The average RUE was 1.87 g MJ $^{-1}$ in P_1, 1.78 g MJ $^{-1}$ in P_2 and 1.84 g MJ $^{-1}$ in P_3 during 2006-07. While, treatments RUE was 1.57%, 1.65% and 2.12% higher during the year 2007-08, respectively (Table 1).

Seasonal TDM accumulation was strongly and linearly related with the accumulated intercepted PAR during both the seasons (Fig. 3a, b). The common regression accounted for 96.6% variability in the pooled data (Fig. 3c), and gave a value of 1.83 g MJ^{-1}. Final TDM production was also positively and linearly related with the final cumulative intercepted PAR (Fig. 3d, e), and the regression gave a value of 2.89 g MJ^{-1} (Fig. 3f). Table 1 presents the effect of treatments on RUE for grain yield. During both seasons increasing irrigation levels (I_4, I_5) significantly enhanced RUE for grain yield over control (I_1) or partially irrigated treatments (I_2, I_3). Differences in RUE between I_4 and I_5 treatments were slight but significant during both the years. The average RUE was 0.69, 0.73, 0.85, 0.97 and 0.96 g MJ^{-1} in I_1, I_2, I_3, I_4 and I_5 treatments, respectively in 2006-07. However, during 2007-08 treatments average RUE was 1.43%, 3.92%, 1.16%, 2.02% and 1.03% higher than the previous year, respectively. Treatment P_1 significantly increased RUE for grain yield over P_2 treatment during both the seasons. Similarly, P_3 treatment was superior in RUE for grain yield than P_2 treatment in either year. The average RUE for grain yield in 2006-07 was 0.88, 0.81 and 0.84 g MJ^{-1} in P_1, P_2 and P_3 treatments, respectively. While, during 2007-08 treatments performance with respect to RUE was 1.12%, 1.22% and 1.86% higher than the previous year, respectively (Table 1). Grain yield and accumulated intercepted PAR was also positively and linearly related during both the seasons (Fig. 3g, h). The common regression accounted for 99.0% variability in pooled data, and gave a value of 1.31 g MJ^{-1} of grain (Fig. 3i).

Table 1. Effect of irrigation levels and methods of phosphorus application on growth, yield and radiation use efficiency of spring wheat

Treatments	TDM (t ha^{-1})		Grain yield (t ha^{-1})		Intercepted PAR (MJ m^{-2})		RUE for TDM (g MJ^{-1})		RUE for grain yield (g MJ^{-1})	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Irrigation levels										
I_1	4.15	3.99	1.91	1.85	278.72	263.53	1.49	1.52	0.69	0.70
I_2	5.30	5.20	2.48	2.42	337.56	319.05	1.57	1.63	0.73	0.76
I_3	8.09	7.72	3.70	3.57	434.78	413.28	1.86	1.87	0.85	0.86
I_4	10.72	10.52	4.97	4.82	510.03	487.54	2.10	2.16	0.97	0.99
I_5	10.85	10.43	4.89	4.70	507.92	484.08	2.14	2.15	0.96	0.97
LSD 5%	0.14	0.11	0.03	0.007	2.63	0.45	0.04	0.04	0.003	0.002
P application methods										
P_1	8.40	8.15	3.93	3.81	434.56	414.48	1.87	1.91	0.88	0.89
P_2	7.78	7.54	3.53	3.42	423.18	403.28	1.78	1.81	0.81	0.82
P_3	7.29	7.02	3.30	3.18	383.66	362.73	1.84	1.88	0.84	0.85
LSD 5%	0.11	0.08	0.021	0.005	2.04	0.32	0.03	0.03	0.002	0.002
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	7.82	7.57	3.55	3.47	413.80	393.50	1.83	1.97	0.84	0.85

NS = non-significant.

DISCUSSION

The higher TDM yield from the fully irrigated (I_4, I_5) crops compared with the un-irrigated (I_0) plants was associated with 83.8% greater interception of PAR and 42.8% larger RUE, during the two seasons. On average, 46% of the incident PAR during the growing seasons was intercepted by the crops, which is similar to the average value of about 40% estimated for a range of arable crops in Britain by Monteith (1977) and in Pakistan by Hussain *et al*. (2004), Ahmad *et al*. (2008, 2009 and 2012). Crop yield in terms of TDM was strongly related to cumulative PAR up to the time when maximum TDM was attained. Different crops have been found to be closely correlated with cumulative radiation intercepted by their foliage e.g. barley (Legg *et al*., 1979), wheat (Hussain *et al*., 2004; Albrizio and Steduto, 2005; Ahmad *et al*., 2012) and rice (Ahmad *et al*., 2008, 2009). The RUE varied with respect to drought. Reduction in RUE of about 25% in barley due to drought had also been reported (Legg *et al*., 1979). Full irrigation treatments (I_4, I_5) and P_1 (side placement) method increased TDM and grain yield by increasing the crop growth rate. Early in the season the increased CGR from irrigation was associated with an increase in the amount of radiation intercepted, RUE being stable. However, later increases in both TDM and grain yield were associated with similar percentage increase in both intercepted PAR and RUE. During anthesis and late season moisture stress, less grain could be found and leaf senescence might be the main reason for both lower TDM and grain yield (Wajid *et al*., 2007; Ahmad *et al*., 2008; Aown *et al*., 2012). For improving TDM production in dry-land conditions, interception of PAR or RUE should be enhanced by increasing LAI at earlier growth stages (Kalimullah *et al*., 2012). In this study, crop yield was positively related to interception of PAR (Fig. 3a-f), a finding in agreement with the results reported by others (Abbate *et al*., 1997; Li *et al*., 2006, 2009; Wajid *et al*., 2007; Miranzadeh *et al*., 2011). In conclusion, results showed that differences between treatments for LAI, TDM, intercepted PAR and RUE were significant. During both years I_4 treatment and P_1 application method gave the highest TDM production and RUE. It appeared that RUE was dependent on LAI and TDM yield increased with irrigation application at various developmental stages.

Conclusion: It is, therefore, recommended that application of phosphorus by side dressing (P_1) and irrigation during various growth stages should be considered for improving RUE and grain yield under dry-land conditions. The future studies should consider pre- and post-anthesis RUE separately because of the many physiological changes occur during these phases of development.

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