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WATER AND RADIATION USE EFFICIENCIES OF TRANSPLANTED RICE (*ORYZA SATIVA* L.) AT DIFFERENT PLANT DENSITIES AND IRRIGATION REGIMES UNDER SEMI-ARID ENVIRONMENT

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Abstract

Growth and yield of rice (*Oryza sativa* L.), in response to plant densities and irrigation (optimum to stress) were analyzed in terms of interception and utilization of photo- synthetically active radiation (PAR) and water use efficiency (WUE). The amount of PAR intercepted and cumulative evapotranspiration (ET) by each treatment was estimated from the measured leaf area index. The relationships between total dry matter, grain yield and accumulated intercepted PAR and cumulative ET were linear. Yield differences among the treatments were attributed to the amount of PAR intercepted and water transpired their efficiencies of utilization or both. The fraction of intercepted radiation and WUE was significantly affected by the plant densities and various irrigation regimes, while, radiation utilization efficiency (RUE) and water use efficiency (WUE) for TDM varied from 1.15 g MJ^{-1} to 1.36 g MJ^{-1} and 22.6 kg ha^{-1} mm^{-1} to 24.3 kg ha^{-1} mm^{-1} during both the seasons.

Introduction

Crop yield has been reported to be strongly dependent on irrigation i.e. quantity of water, especially in arid climates (Sharma & Prasad 1984; Wajid, 2004). Water stress affects crop phenology, leaf area development ultimately resulting in low yield (McKenzie & Hill 1990). The quantity of irrigation water needed for the crop depends upon climate, crop and soil characteristics. The water requirement can be altered by changing the irrigation schedule and method of crop establishment (Kim *et al.,* 1992). Lack of proper water management is probably one of the most serious constraints to greater rice yield (Sharma & Sarkar 1994).

Efficient use of water or water use efficiency in rice production is of critical importance in view of projected boost in rice production to meet the growing population (Ahmad *et al*., 2005a). Previous studies have demonstrated that grain yield increases proportionally with water supply and is particularly high under flooded irrigation (Sharma 1987). Heenan & Thompson (1984) found that delaying flooding until two weeks before panicle initiation reduced water use by 30 % without incurring any significant loss in yield in rice crop.

The amount of solar radiation intercepted by a crop is a major determinant of the total dry matter (TDM) produced (Biscoe & Gallagher, 1977). Therefore analysis of crop growth should consider TDM as a product of the amount of photosynthetically active radiation (PAR) intercepted by the crop, multiple by an efficiency factor (Monteith, 1977, & Gallagher & Biscoe 1978). Such analysis suggests that radiation utilization efficiency is a conservative quantity (Monteith & Elston 1983), whilst the amount of radiation intercepted is the variable that determines the crop yield. At present, very few studies with rice have analyzed crop performance in terms of radiation interception and utilization.

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Density dependent effects on yield are due to the competition between the adjacent plants for the necessary resources (Donald, 1963). Excessive crowding may deprive adjacent plants of adequate supplies from these growth factors as well as actual space for growth. Plant population exerts a strong influence on the rice growth and grain yield, because of its competitive effects, both on the vegetative and reproductive development (Ahmad, 2006). Hue *et al*., (2000) reported that photosynthetic characters of rice are affected by plant population. Grain yield increases linearly with population until some competitive effects become apparent (Ahmad *et al*., 2005b).

Most of the Pakistani lands, in particular and Asian lands in general, are semi-arid. No report describing the simultaneous relationship between radiation interception, cumulative ET and yield of transplanted rice has been presented so far. This study examines the relationship between radiation interception, WUE and yield of transplanted rice sown at different plant densities and irrigation management regimes (optimum to stress) under semi-arid environmental conditions. This work might serve as a milestone towards crop growth modeling for breeders and water saving towards national cause to produce more and more crops under supply of available water as well as for the farmers by improving the crop yield leading to strengthening the economy of country.

Materials and Methods

Two field experiments were established to asses the response of rice (*Oryza sativa* L., cv: Basmati-385) to plant densities and irrigation regimes. The site of experiment was sandy clay loam in texture. Both the experiments were designed as randomized complete block design with three replications. During both the crop seasons treatments were: three plant densities i.e. (D_1 = 16 plants m^{-2}, D_2 = 32 plants m^{-2} and D_3 = 48 plants m^{-2}) and five irrigation regimes i.e. (I_1 = 62.5 cm, I_2 = 77.5 cm, I_3 = 92.5 cm, I_4 = 107.5 cm and I_5 = 122.5 cm). In each season, the wet land preparation (puddling) method was used for preparing the paddock for transplanting. Thirty days old seedlings were transplanted normally in the puddle field in standing water at 22.5 cm × 22.5 cm plant to plant and row to row distance. The experiments were fertilized @ 150-67-67 kg NPK ha^{-1} during both the seasons. All the P, K and half of nitrogen in the form of single super phosphate (SSP), potassium sulphate and urea were applied to all the plots at the time of puddling before transplanting in both the seasons.

Sampling: A total of seven harvests including final were made at two weeks interval in each season. A randomly selected area of 45 cm × 45 cm was harvested from each plot avoiding border effect. The plants were divided into leaves, stem and grains (when present). Fresh weights were recorded separately. Sub-samples of 100-200g of green leaves and branches were oven dried to a constant weight, at 75-80 ºC for determining the dry weight. A sub sample of 50-100 g of green leaves was taken and leaf area was measured with an electronic area meter (Licor, model 3100). The leaf area index (LAI) was calculated as the ratio of total leaf area to land area (Watson, 1947).

Estimation of radiation: The fraction of intercepted radiation (Fi) was estimated from LAI using the exponential attenuation equation suggested by Monteith & Elston (1983).

$$Fi = 1 - \exp(-K \times LAI)$$

where K is extinction co-efficient for total solar radiation Monteith (1977). The co-efficient is equal to 0.306. The PAR was assumed to be equal to one half of the total incident radiation Szeich (1974). Multiplying these totals by the appropriate estimates of Fi gave an estimate of the amount of radiation intercepted by a crop canopy (Sa):

$$Sa = Fi \times Si$$

where Si is the total amount of incident PAR. The radiation utilization efficiency of TDM was defined as;

$$RUE_{TDM} = TDM/\Sigma Sa$$

A seasonal value of ΣSa was also estimated from the regression of TDM on accumulated intercepted PAR (Hussain & Field, 1993; Hussain *et al*., 1998). This analysis was extended to calculate the efficiency of seed yield (e SY).

Estimation of water use efficiency: Water use efficiency (WUE) was calculated as TDM or grain yield per unit crop water used. Actual crop evapotranspiration (ET) (synonym consumptive use of water), was estimated by multiplying potential evapotranspiration with appropriate value of a crop coefficient Doorenbos & Pruitt (1977) which usually corresponds closely with the green crop cover. Daily Penman's potential evapotranspiration (PET) was calculated by using standard programme of "CROPWAT" developed by FAO (Anon., 1992). WUE for TDM and grain yield was calculated as under.

$$WUE_{TDM} = TDM/\Sigma ET$$
$$WUE_{GY} = TDM/\Sigma ET$$

Statistics analysis: Data analysis was carried out using the analysis of variance function of the "MSTATC" Anon., (1991) statistical computer package. Differences among the treatments means were determined using the LSD test when more than two means were found to be significant Steel & Torrie (1984).

Results

Intercepted radiation and radiation use efficiency: During season 1, the total amount of incident PAR received during the growing season was 1958 MJ m^{-2}, of which only 52.8 % was intercepted (Table 1). In season 2, the equivalent figure for the incident PAR was 1974 MJ m^{-2}, of which only 45.5 % was intercepted (Table 2).

The amount of PAR intercepted differed significantly between plant densities. The plant density of (32 plants m^{-2}) resulted in the interception of more radiation than other plant densities during both the seasons. The mean values of accumulated intercepted PAR were 1027.31, 1043.03 and 1035.86 MJ m^{-2} in 16 plants m^{-2}, 32 plants m^{-2} and 48 plants m^{-2}, respectively (Table 1). Equivalent figures for season 2 were 884.99, 899.19 and 892.51 MJ m^{-2}, respectively.

Generally higher irrigation regimes, in both seasons, intercepted significantly more PAR compared to lower levels of irrigation (Tables 1 and 2). The average values in Season 1, for accumulated PAR were 990.57, 1019.55, 1037.83, 1059.32 and 1069.71 MJ m^{-2} for I_1, I_2, I_3, I_4 and I_5 respectively. Equivalent values for season 2 were 851.52, 877.69, 894.29, 914.07 and 923.60, respectively.

Table 1. Water and radiation use efficiencies as affected by plant density and irrigation regimes during season 1.

Treatment	Total intercepted PAR (MJ m^{-2})	TDM (M g ha^{-1})	Grain yield (M g ha^{-1})	RUE_{TDM} (g MJ^{-1})	RUE_{GY} (g MJ^{-1})	WUE_{TDM} (kg ha^{-1} mm^{-1})	WUE_{GY} (kg ha^{-1} mm^{-1})	Cumulative ET (mm)
'lant density								
D_1	1027	13.11	3.96	1.28	0.385	23.1	7.29	545
D_2	1043	13.64	4.24	1.31	0.405	22.6	7.33	579
D_3	1036	13.30	4.10	1.28	0.395	22.6	7.27	563
LSD 5%	11.25	36.49	0.16	0.02	0.007	0.06	0.02	23.73
gation regimes								
I_1	991	12.07	3.50	1.22	0.353	24.4	7.42	472
I_2	1020	12.80	3.80	1.26	0.372	23.1	7.18	528
I_3	1038	13.48	4.15	1.30	0.401	22.7	7.32	566
I_4	1059	14.13	4.49	1.33	0.422	22.0	7.34	611
I_5	1070	14.27	4.57	1.33	0.426	21.5	7.21	633
LSD 5%	14.52	47.10	0.20	0.03	0.009	0.07	0.03	30.63

Table 2 Water and radiation use efficiencies as affected by plant density and irrigation regimes during season 2.

Treatment	Total intercepted PAR (MJ m^{-2})	TDM (M g ha^{-1})	Grain yield (M g ha^{-1})	RUE_{TDM} (g MJ^{-1})	RUE_{GY} (g MJ^{-1})	WUE_{TDM} (kg ha^{-1} mm^{-1})	WUE_{GY} (kg ha^{-1} mm^{-1})	Cumulative ET (mm)
'lant density								
D_1	885	13.52	4.19	1.53	0.471	24.3	7.87	535
D_2	899	14.07	4.48	1.56	0.497	23.6	7.83	572
D_3	893	13.71	4.32	1.54	0.481	23.7	7.81	555
LSD 5%	10.26	37.68	0.16	0.03	0.007	0.07	0.02	26.13
gation regimes								
I_1	852	12.44	3.70	1.46	0.434	26.1	8.11	456
I_2	878	13.20	4.00	1.50	0.456	24.3	7.74	518
I_3	894	13.90	4.38	1.56	0.491	23.8	7.86	559
I_4	914	14.57	4.73	1.59	0.516	22.9	7.82	607
I_5	924	14.73	4.82	1.59	0.521	22.3	7.66	631
LSD 5%	13.25	48.64	0.21	0.04	0.009	0.09	0.03	33.74

The accumulated intercepted PAR was linearly related to final TDM yield; for all treatments in both the seasons (Fig. 1). Plant density significantly affects the radiation utilization efficiency for TDM and grain during both the seasons. Overall mean RUE for TDM and grain yield was 1.29 g MJ^{-1} and 0.39 g MJ^{-1}, respectively. Equivalent figures for season 2 were 1.54 and 0.48, respectively.

Regression of seed yield for all the treatments in season 2 on cumulative PAR was also linearly related (Fig. 2). There were significant differences in the radiation utilization efficiency for TDM among various irrigation regimes in both the seasons (Tables 1 and 2). RUE for TDM during season 1 was 1.22, 1.26, 1.30, 1.33, 1.33 g MJ^{-1} for I_1, I_2, I_3, I_4 and I_5, respectively and equivalent values for season 2 were 1.46, 1.50, 1.56, 1.59 and 1.59 g MJ^{-1}, respectively. RUE for grain yield during season 1 was 0.35, 0.37, 0.40, 0.42, 0.42 g MJ^{-1} for I_1, I_2, I_3, I_4 and I_5, respectively. Equivalent values for season 2 were 0.43, 0.45, 0.49, 0.51 and 0.52 g MJ^{-1}, respectively.

Water use and water use efficiency: During season 1, the total amount of cumulative evapotranspiration (ET) was 562.04 mm. In season 2, the equivalent figure for the ET was 544.20 mm.

In both the seasons the D_2 and D_3 densities significantly increased crop ET over D_1. Differences in cumulative crop ET between D_2 and D_3 were statistically at par. The mean values of cumulative crop ET were 544.50, 578.53 and 563.10 mm in 16 plants m^{-2}, 32 plants m^{-2} and 48 plants m^{-2}, respectively (Table 1). Equivalent figures for season 2 were 535.13, 572.38 and 555.09 mm, respectively.

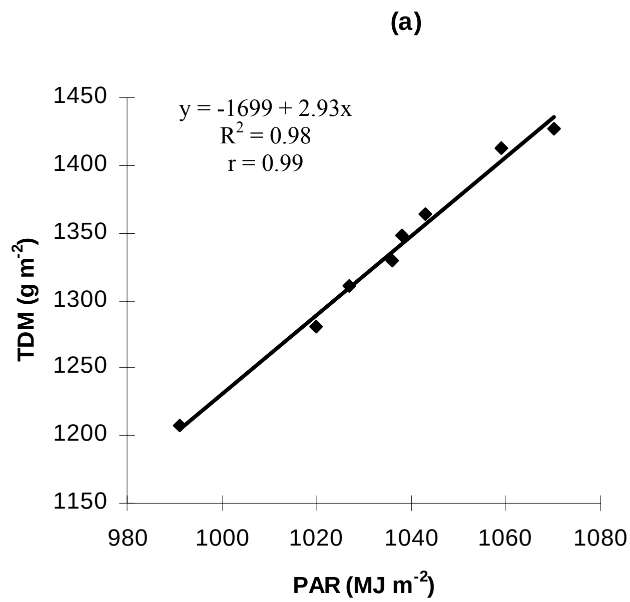
Generally higher irrigation regimes, in both seasons, evapotranspiration significantly more water compared to lower levels of water depths (Tables 1 and 2). The average values in Season 1, for cumulative crop ET were 471.99, 528.22, 566.16, 610.70 and 633.14 mm for I_1, I_2, I_3, I_4 and I_5 respectively. Equivalent values for season 2 were 455.80, 517.76, 559.01, 607.03 and 631.39 mm, respectively.

Plant density did not significantly affect the WUE for TDM and grain during both the seasons. Overall mean WUE for TDM and grain yield were 22.8 kg ha^{-1} mm^{-1} and 7.30 kg ha^{-1} mm^{-1} respectively. Equivalent figures for season 2 were 23.9 and 7.80 kg ha^{-1} mm^{-1}, respectively.

There were significant differences in the WUE for TDM among various irrigation regimes in both the seasons (Tables 1 and 2). WUE for TDM during season 1 was 24.4, 23.1, 22.7, 22.0, 21.5 kg ha^{-1} mm^{-1} for I_1, I_2, I_3, I_4 and I_5 respectively and equivalent values for season 2 were 26.1, 24.3, 23.8, 22.9 and 22.3 kg ha^{-1} mm^{-1}, respectively. WUE for grain yield during season 1 was 7.42, 7.18, 7.32, 7.34, and 7.21 kg ha^{-1} mm^{-1} for I_1, I_2, I_3, I_4 and I_5 respectively. Equivalent values for season 2 were 8.11, 7.74, 7.86, 7.82 and 7.66 kg ha^{-1} mm^{-1}, respectively.

Discussion

Radiation use efficiency: Significant differences were found in the amount of PAR absorbed (Tables 1 and 2) between treatments up to final harvest. During season 1, crop absorbed 52.8% PAR; whilst in season 2, equivalent figure was 45.2%. This was probably due to the climatic conditions and performance of crop under these conditions. Over the seasons, similar values of interception in rice were reported by Jamil (1999). Our results showed that the magnitude of this response was greater with the plant density of 32 plants m^{-2} (D_2).



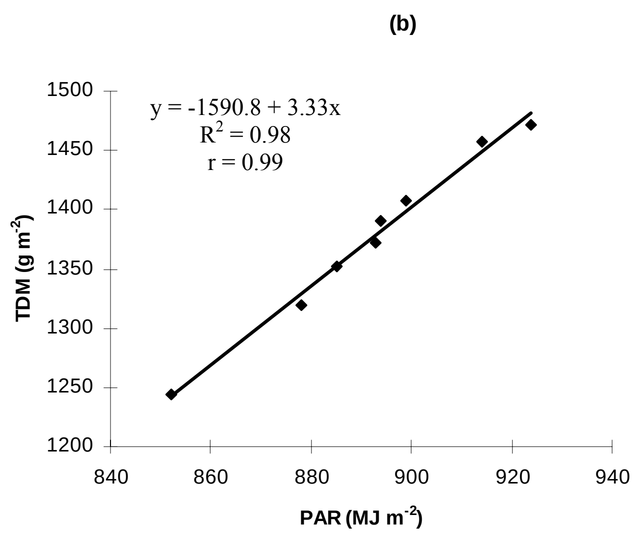


Fig. 1. Relationship between final TDM and cumulative intercepted PAR during (a) season 1 and (b) season 2.

These values are almost at par than the average values reported by Monteith (1977) for different arable crops.

Our study demonstrated a linear relationship between yield (TDM, seed yield) and accumulated PAR (Figs. 1 and 2) and regression gave a slope of 2.93 g (season 1) and 3.33 g (season 2) was produced for each MJ of intercepted PAR. Kiniry *et al*., (1989) reported RUE of 2.2 g MJ^{-1} of intercepted PAR for a non-stressed rice crop.

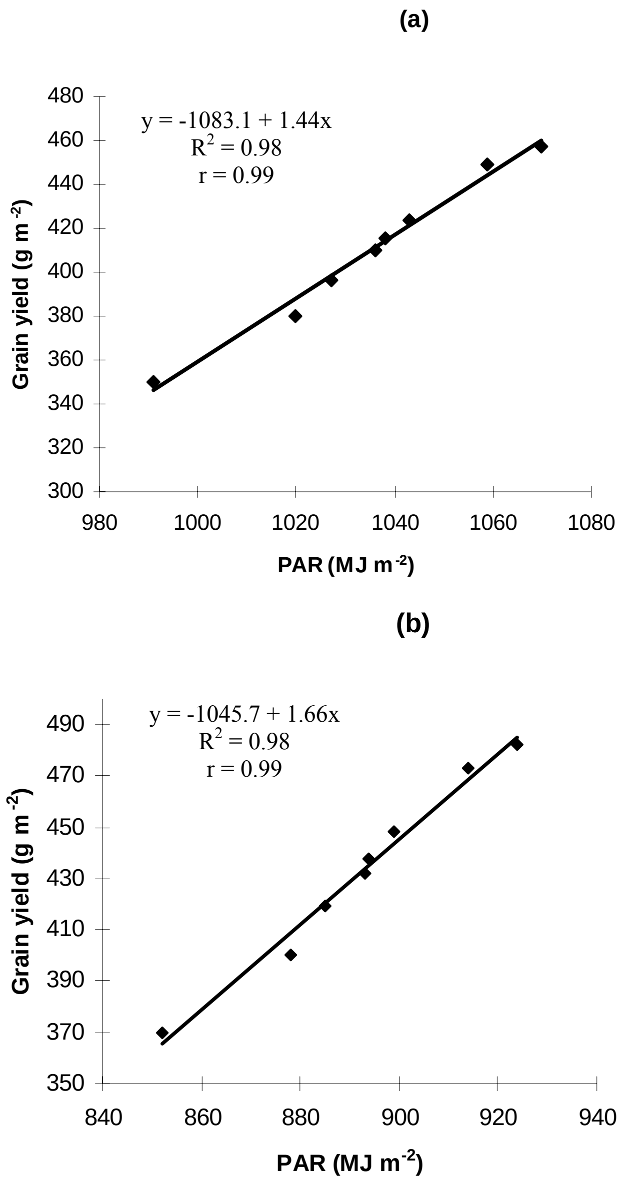


Fig. 2. Relationship between grain yield and cumulative intercepted PAR (a) season 1 and (b) season 2.

Few differences were found in the values of RUE for TDM between the treatments of plant population during both the crop seasons, whilst in irrigation regimes when the values were significantly higher at higher levels of irrigation as compared to lower levels of irrigation.

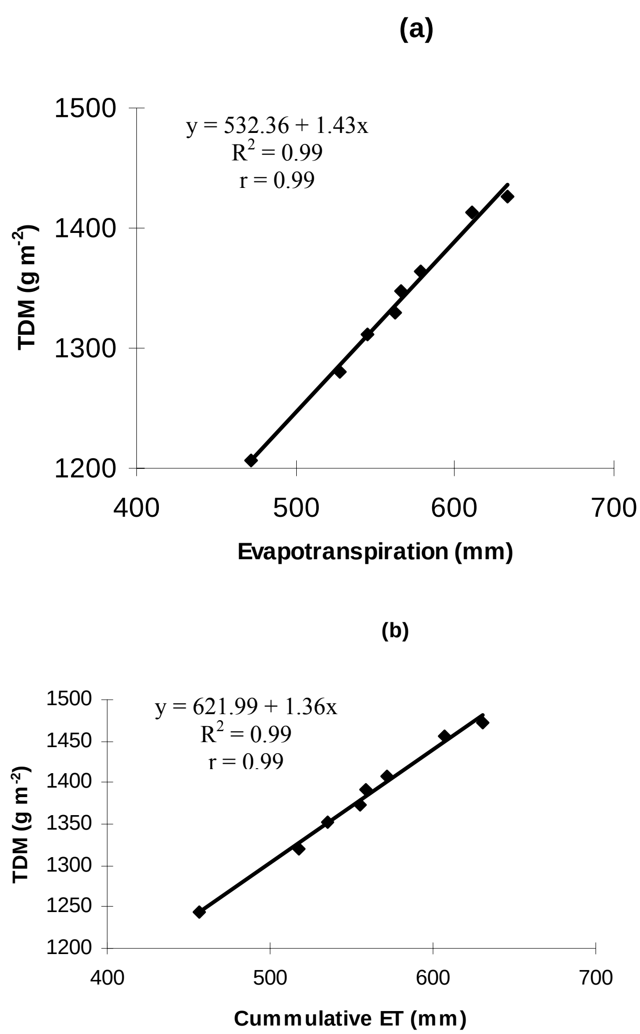
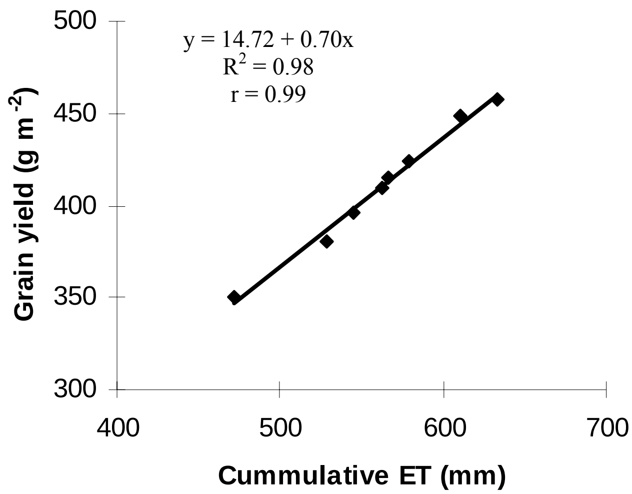


Fig. 3. Relationship between final TDM and cumulative ET during (a) season 1 and (b) season 2.

Water use efficiency: Significant differences were found in the amount of water evapotranspired (Tables 1 and 2) between treatments up to final harvest. During season 1, crop ET was 562.04; whilst in season 2, equivalent figure was 544.20. This was probably due to the temporal variations in climatic conditions and the performance of crop under these conditions. Our results showed that the magnitude of this response was greater with the plant density of 32 plants m^{-2} (D_2). These values of WUE are almost similar with the average values reported by Sarangi & Lenka (2000); Jun & Hirasawa (2001) for rice crop.

Our study demonstrated a linear relationship between yield (TDM, seed yield) and crop ET (Figs. 3 and 4) and regression gave a slope of 1.43 (season 1) and 1.36 (season 2) was produced for each mm of water evapotranspiration.

(a)



(b)

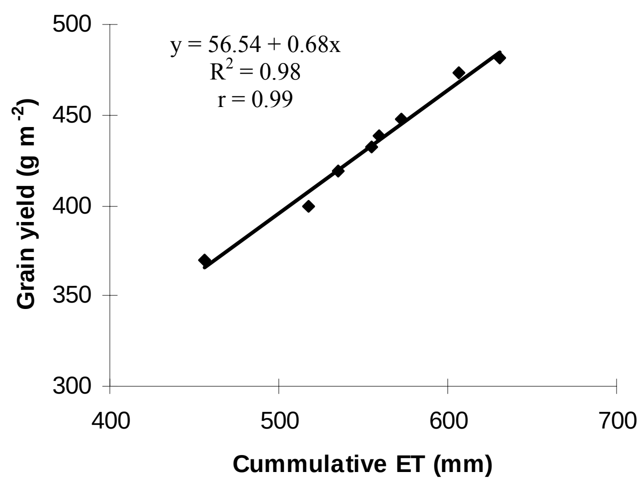


Fig. 4. Relationship between grain yield and cumulative ET during (a) season 1 and (b) season 2.

Few differences were found in the values of WUE for TDM and grain yield among the treatments of plant population during both the crop seasons, whilst in irrigation regimes when the values were significantly higher at higher levels of irrigation as compared to lower levels of irrigation.

Conclusion

Treatments affected crop yield by changing the ability of the canopies to intercept radiation and evapotranspiration due to the changes in the water and PAR utilization efficiencies. Considering growth and yield in terms of the amount of radiation, crops absorb and water transpired, the efficiency with which they convert it, DM and seed yield may be physiologically and analytically more relevant than traditional growth analysis techniques.

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