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Yield, water and radiation use efficiency of wheat (*Triticum aestivum* L.) as influenced by irrigation levels in a semi-arid environment

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ABSTRACT

Field experiment was conducted during the *rabi* 2009-10 and 2010-11 on a sandy loam soil of New Delhi to study the effect of irrigation levels on yield, water and radiation use efficiency of wheat (*Triticum aestivum* L.) cultivars. The treatments comprised of two wheat cultivars (PBW 502 and DBW 17) and three irrigation levels (I_1: irrigation at CRI, I_2: irrigations at CRI and flowering and I_4: irrigations at CRI, tillering, flowering and grain formation stage) laid out in factorial randomized block design (RBD). The results showed that the cultivar DBW 17 (3320 kg/ha) registered significantly higher yield compared to PBW 502 (2980 kg/ha). The grain yield with I_4 treatment (4004 kg/ha) was significantly higher than that of I_2 (3330 kg/ha), which in turn significantly out yielded I_1 treatment (2116 kg/ha). The water and radiation use efficiency (WUE) were significantly lower in I_1 treatment (8.39 kg/ha/mm, 1.79 g/MJ) compared to the I_2 treatment (10.61 kg/ha/mm, 1.99 g/MJ). I_2 and I_4 treatments were at par with respect to WUE. Among the irrigation treatments, the highest RUE was obtained with I_4 (2.23 g/MJ).

Keywords: Wheat, Evapotranspiration, Water use efficiency, Radiation use efficiency

INTRODUCTION

Wheat is the second most important cereal crop in India after rice covering an area of about 28 million hectare and production of 40 million tones. It is mainly grown in semiarid and arid tracts of India during winter season which normally remains dry. For optimum production, it requires supplemental irrigations. Wheat in arid and semiarid region of India faces severe competition from domestic and industrial sectors for water making it imperative to develop ways and means to increase water use efficiency of wheat (Kijne *et al.*, 2003). Besides moisture, dry matter production depends up on the amount of solar radiation intercepted by a crop and the net primary production is linearly related with intercepted photosynthetically active radiation (Monteith, 1977). The solar radiation in the western and north-western parts of India, which covers large area under wheat, is highly variable and occasionally limited during winter season (Pradhan *et al.*, 2014a). The variation in solar radiation and radiation interception affects radiation use efficiency (conversion efficiency of intercepted radiation energy into dry matter) of wheat crop. Radiation use efficiency (RUE) is affected by LAI and crop geometry (Plenet *et al.,* 2000). Crop management practices may thus influence the RUE. Limited evidence is available about the effect of different irrigation levels on the water and radiation use efficiency of wheat in these areas. The present experiment was, therefore, conducted to study the effect of different levels of irrigation on yield, water and radiation use efficiency of two wheat cultivars.

MATERIALS AND METHODS

Field experiment was conducted during winter 2009-10 and 2010-11 at the Research Farm of the Indian Agricultural Research Institute, New Delhi, India (77°89'N, 28°37'E, 228.7m asl) on sandy loam (Typic Haplustept) with wheat (*Triticum aestivum*) as the test crop. The climate of the region is semi-arid with warm summer and mild winter. The experiment was laid out in a factorial Randomized Block Design (RBD) with 6 treatments comprising two cultivars (V_1: PBW 502 and V_2: DBW 17) and three irrigation levels (I_1: irrigation at CRI stage, I_2: irrigations at CRI and flowering stages and I_4: irrigation at CRI, tillering, flowering and grain formation stages) in three replications. The net plot size was 5×5 m. The test varieties were sown in the 3rd week of November at a seed rate of 100 kg/ha and row spacing of 22.5 cm and harvested in 2nd week of April in both years of study. Nitrogen @ 120 kg/ha was applied in the form of urea in three splits: 50% at sowing, 25 % at crown root initiation stage and 25% at flowering stage. Phosphorous (60 kg P_2O_5/ha as single super phosphate) and potassium (60 kg K_2O/ha as muriate of potash) were applied at sowing.

Soil moisture content in 0-120 cm profile was determined gravimetrically at regular intervals during the crop growth period to study the distribution and redistribution of the soil water in the profile. Seasonal evapotranspiration (ET) was computed using the field water balance equation as given below:

$$ET = (P + I + C) - (R + D + \Delta S) \ldots\ldots (1)$$

Where P is the precipitation, I is the irrigation, C is the capillary rise, R is the runoff, D is the deep percolation and ΔS is change in profile soil moisture - all expressed in mm. The ground water table depth was very low (8-10 m) and hence C was assumed negligible. There was no runoff (R) from the field plots as they were bunded to a sufficient height (40 cm height) and also no case of bund overflow was observed during the period of study. D was considered negligible beyond 120 cm because of negligible changes in the soil moisture storage beyond this soil depth.

Thus, Eq. (1) simplifies to,

$$ET = (P + I) - (\Delta S) \ldots\ldots\ldots\ldots\ldots (2)$$

Precipitation data (P) was collected from the meteorological observatory of IARI, which is located at a distance of about 50 m from the experimental plot. Irrigation amount (I) was measured by Parshall Flume. Changes in soil moisture content (ΔS) were calculated by the difference in the soil moisture content measured gravimetrically at sowing and harvest.

Water use efficiency (WUE) was computed by dividing grain yield with seasonal evapotranspiration.

The incoming and outgoing photosynthetically active radiation (PAR) values were measured periodically at the top and bottom of the wheat canopy on clear days between 1100 and 1200 hrs IST throughout the crop season using line quantum sensor LI-191SA (LICOR Inc., Lincoln, NE, USA). The intercepted photosynthetically active radiation (IPAR) for a particular day was computed as the difference between PAR at the top and bottom of canopy. The fraction intercepted photosynthetically active radiation (fIPAR) for a particular day was computed as the ratio between IPAR and total incident PAR for that particular day. The radiation use efficiency (RUE) was calculated by dividing total aboveground biomass (g/m^2) with the total IPAR (TIPAR, MJ/m^2) for the whole crop duration (Pradhan *et al*., 2014b and Pandey *et al*., 2004).

Normalized difference vegetation index (NDVI) was calculated as follows (Raun *et al.,* 2001):

$$NDVI = \frac{(R_{780} - R_{670})}{(R_{780} + R_{670})} \ldots (3)$$

Where R and the subscript numbers indicate the light reflectance at the specific wavelength (in nm). The reflectance at different wavelengths (350 nm to 2500 nm) were measured by hand held ASD Field Spectroradiometer (Analytical Spectral Devices Inc., Boulder, CO, USA). The data were statistically analyzed using analysis of variance (ANOVA) as applicable to RBD design (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Soil moisture dynamics and seasonal evapotranspiration

The effect of irrigation levels on soil moisture storage (Fig. 1) was significant and that of cultivars was non-significant. The peaks in the soil moisture profile (0-120 cm) corresponds to either irrigation or rainfall events. Soil moisture increased with the increase in number of irrigations. During later crop growth stages, soil moisture storage in I_1 treatment was below the permanent wilting point (PWP) due to absence of irrigation, crop water extraction and more evaporation from bare field due to lower canopy coverage as seen by lowest NDVI (Fig. 3).

The seasonal evapotranspiration (ET) under different treatments varied between 233 mm and 330 mm (mean 283 mm) in 2009-10 and between 265 mm and 468 mm (mean 354 mm) in 2010-11 (data not given). The increased ET in 2010-11 could be attributed to the higher amount of rainfall and water extraction from the profile. Averaged over both the years and irrigation levels, the cultivars showed similar ET values. However, averaged over the years and cultivars, the I_1 and I_2 treatment showed 37% and 22% lower ET compared to I_4 treatment. Lower water input and lower biomass production in I_1 and I_2 treatments resulted in lower ET compared to I_4 treatment.

The evapo-transpiration production function (ETPF), the relation between ET and wheat grain yield for the study period 2009-11(y= 14.169ET-1359.3, $R^2 = 0.77$) was linear and significant (P<0.01). Bandyopadhyay *et al.* (2010) and Pradhan *et al.* (2014b) also observed linear ETPF for wheat. The ETPF showed that about 77 % variation in grain yield of wheat could be explained by ET. The intercept of ETPF was less than zero indicating scope of increasing WUE with increase in ET (Liu *et al*., 2002).

Fractional intercepted PAR (fIPAR) and Total seasonal intercepted PAR (TIPAR)

The differences in cultivars for seasonal profile of fractional intercepted PAR (fIPAR) were non-significant but between different irrigation treatments were significant in both years of study (Fig. 2). The fIPAR increased from sowing to flowering stage due to crop development and increase in canopy coverage and decreased during subsequent growth period till maturity due to crop ageing and leaf senescence. Pradhan *et al.* (2014b) also observed similar pattern of fIPAR throughout the crop growth cycle of wheat. The highest fIPAR was observed in I_4 treatments followed by I_2 and I_1 treatments. It could be attributed to the higher canopy coverage in I_4 treatment compared to the I_2 and I_1 treatments the fact supported by higher NDVI (Fig. 3).

The total seasonal intercepted PAR (TIPAR) varied between 377 and 515 MJ/m^2 (mean 455 MJ/m^2) in 2009-10 and between 456 and 581 MJ/m^2 (mean 528 MJ/m^2) in 2010-11 (data not shown). The higher TIPAR in 2010-11 crop growth period was due to better crop development and canopy coverage than the year 2009-10. Irrigation treatments I_1 and I_2 showed 23% and 6% lower TIPAR compared to the I_4 treatment. It was due to better crop growth and more chlorophyll formation as indicated by crop greenness for extended period under I_4 treatment compared to I_2 and I_1 treatments. Cultivar PBW 502 showed 2% higher TIPAR compared to DBW 17. Pooled over the years, a significant and positive relationship was observed between TIPAR and aboveground biomass yield (y= 39.458TIPAR – 9353.1, $R^2 = 0.86$). This relationship showed that 86% variation in grain yield could be explained by the variation in TIPAR. Similar relationship has been observed by Pandey *et al.* (2004) and Pradhan *et al.* (2014b) for wheat. This indicated that increased interception of radiation is one of the major driving forces of crop biomass production.

Wheat grain and aboveground biomass yield

The grain yield of wheat varied from 1820 (V_1I_1) to 3080 (V_1I_4) kg/ha with a mean of 2365 kg/ha in 2009-10 and from 2060 (V_1I_1) to 5615 (V_2I_4) kg/ha with a mean of 3935 kg/ha in 2010-11. Similarly the biomass yield varied between 5000 and 10500 kg/ha (mean 8000 kg/ha) in 2009-10 and between 9000 and 15000 kg/ha (mean 12042 kg/ha) in 2010-11. The grain and aboveground biomass yields were 40% and 34%, respectively lower in 2009-10 compared to the year 2010-11. The night temperature during reproductive period of the crop was 0.1 to 7.4 ^oC higher for 22 days in 2009-10 compared to the year 2010-11. The cultivars did not differ (P<0.05) for grain yield in 2009-10 (Table 1), whereas in 2010-11, DBW 17 (4340 kg/ha) registered significantly higher grain yield than PBW 502 (3530 kg/ha). Pooled over the years, both the cultivars were statistically at par with respect to grain yield. Contrary to the grain yield, cultivars significantly differed for aboveground biomass yield in 2009-10 but not in 2010-11 (Table 1). The pooled aboveground biomass yields of

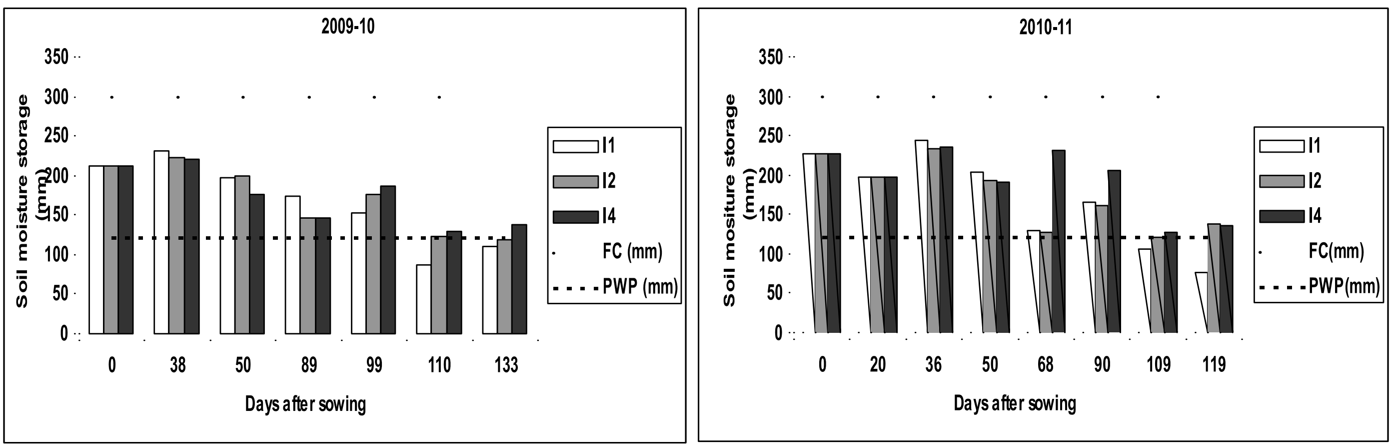

Fig. 1: Temporal variation of soil moisture storage in irrigation treatments for the year 2009-10 and the bars of the 2010-11 graphs are drifted.

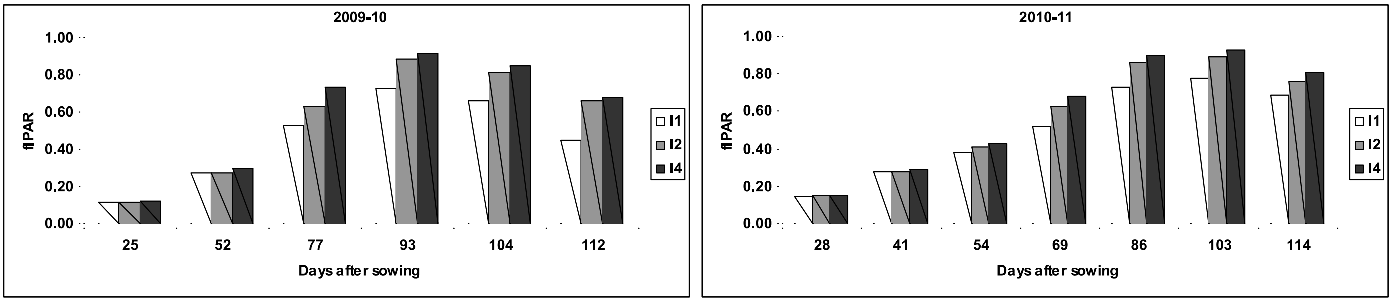

Fig. 2: Temporal variation of fractional intercepted PAR (fIPAR) under different irrigations during the bars of the 2009-10 and 2010-11 are drifted.

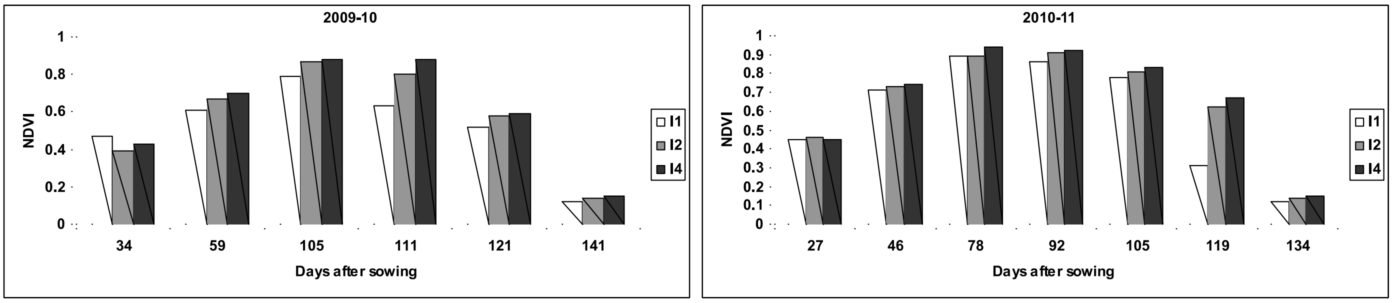

Fig. 3: Temporal variation of NDVI due to different irrigations during the bars of the 2009-10 and 2010-11 graphs are drifted.

cultivars were also statistically similar.

The grain yield of wheat increased with increase in number of irrigations in both years (Table 1). In 2009-10, the differences in grain yield between all irrigation treatments were significant whereas in 2010-11, I_4 (4983 kg/ha) and I_2 (4300 kg/ha) treatments were statistically at par but resulted in significantly higher grain yield than I_1 (1710 kg/ha), Pooled grain yield with I_4 (4004 kg/ha) was significantly higher than I_2 (3330 kg/ha) and I_1 (2116 kg/ha).

The aboveground biomass yield also increased significantly with increasing number of irrigations in both years except the difference between I_2 and I_1 in 2010-11 (Table 1). Mean biomass yield recorded with I_4 (12250 kg/ha) was significantly higher than I_2 (10156 kg/ha) which was in turn significantly higher yield than I_1 (7656 kg/ha). The increased grain and biomass yield with the increased levels of irrigation can be attributed to better water and nutrient availability, greater canopy coverage, higher radiation interception and extended green crop duration. Similar results have been reported by Pradhan *et al.* (2013).

Water and radiation use efficiency

The water use efficiency (WUE) varied between 6.87 and 9.51 kg/ha/mm (mean 8.25 kg/ha/mm in 2009-10 and between 7.77 and 13.27 kg/ha/mm (mean 11.08 kg/ha/mm) in 2010-11 (data not shown). The WUE decreased by 26% in 2009-10 compared to the year 2010-11 (Table 2). Both PBW 502 (8.50 kg/ha/mm) and DBW 17 (8.00 kg/ha/mm) were statistically at par in 2009-10 for WUE. However, in 2010-11, WUE of cultivar DBW 17 (12.23 kg/ha/mm) was significantly higher than that of the cultivar PBW 502 (9.92 kg/ha/mm). The pooled data showed that wheat cultivars PBW 502 (9.22 kg/ha/mm) and DBW 17 (10.11kg/ha/mm) did not significantly differ in WUE. The WUE for the year 2009-10 was significantly higher in I_4 (9.25 kg/ha/mm) than I_1 (7.27 kg/ha/mm) treatment whereas I_2 (8.22 kg/ha/mm) was at par with I_4 as well as with I_1. In 2010-11, I_2 (12.99kg/ha/mm) registered highest WUE whereas I_4 (10.75 kg/ha/mm) and I_1 (9.50 kg/ha/mm) were statistically at par. Thus I_2 (10.61 kg/ha/mm) showed significantly higher WUE compared to I_1 (8.39 kg/ha/mm) but was at par with I_4 (10.00 kg/ha/mm). The correlation between grain yield and WUE (0.84) was higher than the correlation between ET and WUE (0.49). It indicated that the variation in WUE was mostly resulted from variation of grain yield. Pradhan *et al.* (2014b) also reported that variation of WUE of wheat under various nitrogen treatments were due to variation in grain yield.

The radiation use efficiency (RUE) varied between 1.40 and 2.04 MJ/m^2 (mean 1.74 g/MJ) in 2009-10 and between 1.97 and 2.58 MJ/m^2 (mean 2.27 g/MJ) in 2010-11. The RUE in 2009-10 was 23% lower

Table 1: Wheat grain yield (kg/ha) and aboveground biomass (kg/ha) as influenced by cultivars and irrigations

	Grain yield (kg/ha)			Aboveground biomass (kg/ha)		
	2009-10	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
PBW 502	2430a	3530b	2980b	8500a	11833a	10167a
DBW 17	2300a	4340a	3320a	7500b	12250a	9875a
I_1	1710c	2523b	2116c	5625c	9688b	7656c
I_2	2360b	4300a	3330b	8500b	11813b	10156b
I_4	3025a	4983a	4004a	9875a	14625a	12250a

Table 2: Water use efficiency (kg/ha/mm) and radiation use efficiency (g/MJ) of wheat

	Water use efficiency (kg/ha/mm)			Radiation use efficiency(g/MJ)		
	2009-10	**2010-11**	**Pooled**	**2009-10**	**2010-11**	**Pooled**
PBW 502	8.50a	9.92b	9.22a	1.82a	2.29a	2.06a
DBW 17	8.00a	12.23a	10.11a	1.65b	2.25a	1.95a
I_1	7.27b	9.50b	8.39b	1.53b	2.04b	1.79c
I_2	8.22ab	12.99a	10.61a	1.76a	2.22b	1.99b
I_4	9.25a	10.75ab	10.00a	1.93a	2.54a	2.23a

compared to 2010-11 (Table 2). PBW 502 (1.82 g/MJ) registered significantly higher RUE compared to DBW 17 (1.65 g/MJ) during 2009-10. However, in 2010-11, PBW 502 (2.29 g/MJ) and DBW 17 (2.25 g/MJ) were statistically at par with respect to RUE. The pooled data also showed no significant differences in RUE of cultivars for RUE. The RUE increased with increase in irrigation levels. The RUE in case of I_4 (1.93 g/MJ, 1.76 g/MJ) was highest in both years and significantly higher than treatment I_1 (1.53 g/MJ) in 2009-10, and I_2 (2.22 g/MJ) in 2010-11. Pooled RUE mean in I_4 (2.23 g/MJ) was significantly higher than I_2 (1.99 g/MJ) and I_1 (1.79 g/MJ). Pandey *et al.* (2004) also observed higher RUE of wheat crop under higher moisture regimes compared to moisture stress conditions. This may be attributed to higher biomass production and higher radiation interception at higher irrigation levels. The correlation between aboveground biomass yield and RUE (0.97) was higher than the correlation between TIPAR and RUE (0.82). It indicated that the variation in RUE mostly accrued from variation of aboveground biomass yield. Han *et al.* (2008) and Pradhan *et al.* (2014b) also observed significant positive correlation between RUE and crop yield of wheat.

CONCLUSION

Higher grain yield, aboveground biomass, water and radiation use efficiency of wheat cultivar PBW 502 and DBW 17 can be obtained with four irrigation applied at CRI, tillering, flowering and grain formation stage in the semi-arid subtropical environment of Delhi.

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