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Effect of tillage and irrigation management on radiation use efficiency of wheat (*Triticum aestivum*)

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ABSTRACT

Field experiments were conducted during 2015–16 and 2016–17 on wheat (cv HD2967) in a sandy loam soil at ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of tillage and irrigation management on radiation use efficiency (RUE) of wheat. The treatments comprising of three levels of tillage as main plot factor (Conventional tillage, Deep tillage and No tillage) and three levels of irrigation as subplot factor (I_1: 1 irrigation, I_3: 3 Irrigations and I_5: 5 Irrigations) were evaluated in a split plot design. The results showed that there was no significant difference among tillage treatments with respect to extinction coefficient. However, pooled data of 2 years, extinction coefficient due to I_5 was significantly higher than that of I_3 and I_1 by 8.8 and 23.8%, respectively, and extinction coefficient due to I_3 was significantly higher than I_1 by 13.8%. There was no significant difference among the tillage treatments with respect to radiation use efficiency (RUE) of wheat, but RUE increased significantly with increasing irrigation level. RUE of wheat under I_5 was significantly higher than that of I_1 and I_3 treatments but there was no significance difference between I_1 and I_3 with respect to RUE of wheat in both the years.

Keywords: fIPAR, Radiation use efficiency, Tillage, Wheat

The ground biomass (AGB) production of a crop depends upon the amount of solar radiation intercepted and; the net primary production is linearly related with intercepted photosynthetically active radiation (IPAR) by the crop canopy during its life cycle (Monteith 1977, Pradhan *et al*. 2014). The AGB per unit of total IPAR is called as radiation use efficiency (RUE) (Sinclair and Muchow 1999). The RUE of cereals is constant in non-stressful environments (Sinclair and Muchow 1999). Therefore, AGB produced can be expressed as a product of the cumulative IPAR during the crop growth cycle and RUE (Sandana *et al*. 2012). This approach is commonly employed in radiation use efficiency based crop growth models (Ritchie *et al*. 1985, Brisson *et al*. 2003, Aggarwal *et al*. 2004). The cumulative total IPAR of crops is mostly controlled by fraction of the incoming photosynthetically active radiation by the canopy, which is a function of green leaf area index (LAI) and the efficiency with which the green leaf area intercepts solar radiation, described by the light extinction coefficient (κ) (Plenet *et al*. 2000, Sandana *et al*. 2009). Several studies have shown that total IPAR is negatively related to both water and nitrogen deficiencies in wheat (Salvagiotti and Miralles 2008, Pradhan *et al*. 2014). The κ value for wheat varies between 0.37 and 0.82 (O'Connell *et al*. 2004, Muurinen and Peltonen-Sainio 2006). Though there are studies on the effect of irrigation and nitrogen on total IPAR and light extinction coefficient interactive effect of tillage and irrigation on these parameters is limited.

Besides species and cultivars, RUE is mostly affected by the management factors such as tillage, water and nitrogen application (Muurinen and Peltonen-Sainio 2006, Stöckle and Kemanian 2009). Under non-stressed conditions, the RUE value of wheat varies from 1.46–2.93 (Gregory *et al*. 1992, Yunusa *et al*. 1993). Water stress reduces RUE by reducing the utilization of photosynthates for growth as lower intercepted photosynthetically active radiation occurs from reduced LAI (O'Connell *et al*. 2004). Keeping these in view, the objectives of this study were to study the effect of tillage and irrigation management on radiation interception, extinction coefficient and radiation use efficiency of wheat in a maize-wheat system in a semi-arid location of India.

MATERIALS AND METHODS

Soil and Climate of the experimental site: The soil of the experimental site was sandy loam (Typic Haplustept) of Gangetic alluvial origin, very deep (>2 m), flat and well

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drained. The soil was mildly alkaline, non-saline, low in organic C (Walkley and Black C) and available N, and medium in available P and K content. New Delhi has sub-tropical semi-arid climate with dry hot summer and brief severe winter. The average monthly minimum and maximum temperature in January (the coldest month) ranged between 5.9 and 19.9°C. The corresponding temperature in May (the hottest month) ranged between 24.4 and 38.6°C. The average annual rainfall is 651 mm, out of which 75% is received through south-west monsoon during July to September.

Experiment details: The field experiments were conducted during *rabi* 2015–16 and 2016–17 at ICAR-Indian Agricultural Research Institute, New Delhi (28° 35'N latitude, 77° 12'E longitude and at an altitude of 228.16 m amsl) farm (MB 4C) to study the effects of tillage and irrigation management on radiation interception, extinction coefficient and radiation use efficiency of wheat (*Triticum aestivum* L) in a maize-wheat system. The treatments comprising of three levels of tillage as main plot factor (Conventional tillage (CT), No Tillage with maize residues @5 t/ha (NT), Deep tillage (DT)), and three levels of irrigation (I_1: 1 irrigation (CRI), I_3: 3 Irrigations (CRI, Tillering, Flowering) and I_5: 5 Irrigations (CRI, Tillering, Jointing, Flowering, Milk)) as subplot factors, were evaluated in a split plot design with three replications. The subplot size was 4 m × 11 m.

Wheat (cv. HD 2967) was sown on 28th and 22nd November in 2015 and 2016 respectively, by a tractor drawn no-till seed drill (at a depth of –5 cm) with a row spacing of 22.5 cm at a seed rate of 100 kg/ha and harvested on 5th April 2016 and 7th April 2017, respectively. In CT treatment, the plot was ploughed once with disk plough and once with duck-foot tine cultivator followed by leveling and sowing by seed drill. In NT treatment, the seeds were directly sown using an inverted T type no-till seed drill. Maize residue was applied manually at the rate of 5 t/ha in NT treatment after CRI stage. In DT treatment, the plot was ploughed with a Chisel plough to a depth of 35±5 cm at 50 cm spacing during *kharif* once in two years. Weedicide Glyphosate @10 ml/l was used to control weeds before sowing wheat. Nitrogen was supplied as urea in three splits i.e. 50% at sowing, 25% at CRI stage and rest 25% at flowering stage. All the plots received a uniform dose of 60 kg N/ha as urea, 60 kg P_2O_5/ha as single super phosphate and 60 kg K_2O/ha as muriate of potash applied as basal dose at sowing. Field was kept weed free by employing manual weeding 3–4 times during crop growth stages.

Experiment methods: Leaf area index (LAI) was measured at regular intervals using a Plant canopy analyzer (LAI-2000, LI- COR, Lincoln, NE, USA). Both incoming and outgoing photosynthetically active radiation (PAR) values were measured periodically at the top and bottom of the wheat canopy throughout the season using Line quantum sensor LI-191SA (LICOR Inc., Lincoln, NE, USA). The above measurements were taken at regular intervals on clear days between 11:00 and 12:00 h Indian Standard Time (IST) when disturbances due to leaf shading and leaf curling and solar zenith angle were minimum (Pradhan *et al*. 2014). The fraction intercepted PAR (fIPAR) was calculated as: $fIPAR = (I_o - I)/I_o$ (Monteith 1981), where 'I_o' is incident PAR at the top of canopy and 'I' is the transmitted PAR at the bottom of the canopy.

The canopy fIPAR and LAI were related by the relationship: $fIPAR = 1 - e^{(-\kappa \times LAI)}$ where κ is the canopy radiation extinction coefficient and LAI is the leaf area index. The κ was determined with least-square regression by calculating the slope of the relationship between 1−fIPAR and LAI with intercept set to zero (Robertson *et al*. 2001). Values for fIPAR for each day after sowing were interpolated between actual measurements by linear interpolation throughout the crop season (Pradhan *et al*. 2014). Daily incoming solar radiation was calculated by using bright sunshine hours in the Angstrom equation (Allen *et al*. 1998). The daily incoming solar radiation was multiplied by a factor 0.48 (Monteith 1972) to get incoming incident PAR. Then the daily incident PAR values were multiplied by corresponding daily fIPAR values to compute daily intercepted PAR (IPAR). The daily IPAR was integrated for the whole crop season to get total IPAR (TIPAR). The RUE was calculated by dividing above ground biomass (g/m^2) with the TIPAR (MJ/m^2) for the whole crop duration (Pradhan *et al*. 2014). The net plot was harvested manually by cutting the plants close to ground after leaving the border rows. The plant samples were dried and weighed for above ground biomass yield and expressed in kg/ha. Threshing of wheat was done mechanically and the grain yield was expressed in kg/ha.

Statistical analysis: The data were statistically analyzed using analysis of variance (ANOVA) as applicable to split plot design (Gomez and Gomez 1984). F test was employed to see the significance of the treatment effects. The difference between the means was estimated using least significance difference at 5% probability level. Regression analyses were performed using the data analysis tool pack of MS Excel.

RESULTS AND DISCUSSION

Weather: It was observed that during 2016–17 the crop received the total rainfall 92.7 mm against 2.8 mm rainfall received during 2015–16. January was wettest month during 2016–17. The average bright sunshine hour during 2016–17 (5.4) was higher than 2015–16 (4.8). The mean relative humidity during 2016–17 (66.8%) was lower than 2015–16 (69.4%).

Leaf Area Index (LAI): In both the years 2015–16 and 2016–17, LAI followed polynomial relationship with the days after sowing. In 2016–17 maximum LAI (4.21) was higher than 2015–16 (4.02), which is attributed to higher rainfall received during 2016–17 than 2015–16. Averaged over irrigation levels, the maximum LAI under DT, CT and NT were 3.93, 4.12 and 4.00 for 2015–16 and 4.47, 4.35 and 3.81 for the year 2016–17, respectively. With increasing irrigation level the value of maximum LAI also increased in both the years. Averaged over tillage treatments, maximum LAI due to I_1, I_3 and I_5 were 3.37, 4.15 and 4.53 for 2015–16 and 3.88, 4.26 and 4.29 for the year 2016–17, respectively. Increased water stress due to deficit irrigation levels might have led to increased abscission rate and hence decreased in LAI (Akram 2011, Thomas 2013). During 2015–16, maximum LAI was obtained in CT (4.12) whereas during 2016–17 maximum LAI was recorded under DT (4.47). Higher LAI under DT is in agreement with the finding of Qamar *et al*. (2013). They also reported that LAI under CT was higher than that of NT, which is in agreement with the present study.

Fraction intercepted photosynthetically active radiation (fIPAR): The fraction intercepted photosynthetically active radiation fIPAR followed similar pattern as that of LAI, i.e. this also followed polynomial distribution with days after sowing. The fIPAR increased with increasing irrigation level in both the years. Under DT maximum fIPAR ranged from 0.825–0.907 with mean value 0.868 during 2015–16 and from 0.801–0.960 with mean value 0.8 during 2016–17. Under CT maximum fIPAR ranged from 0.830–0.880 with mean value 0.860 during 2015–16 and from 0.800–0.880 with mean value 0.850 during 2016–17. Under NT maximum fIPAR ranged from 0.695–0.894 with mean value 0.801 during 2015–16 and from 0.690–0.888 with mean value 0.805 during 2016–17. There was no significant difference between tillage with respect to fIPAR of wheat but it increased significantly with increasing irrigation level which can be attributed to higher LAI. Bassu *et al*. (2011) has also observed lower fIPAR in durum wheat due to lower LAI.

Extinction coefficient: During 2015–16, extinction coefficient (k) ranged from 0.35–0.47 with mean value 0.42 whereas during 2016–17, extinction coefficient ranged from 0.35–0.55 with mean value 0.45 (Fig 1). The estimated κ values fall within the range of 0.41 and 0.78 reported for bread wheat (Yunusa *et al*. 1993, O'Connell *et al*. 2004, Muurinen and Peltonen-Sainio 2006). There was no significant difference among tillage treatment with respect to extinction coefficient however with increasing irrigation level extinction coefficient increased significantly. Extinction coefficient due to I_1, I_3 and I_5 were 0.39, 0.42 and 0.45 during 2015–16 and 0.38, 0.46 and 0.51 during 2016–17, respectively. Pooled over years, extinction coefficient due to I_5 was significantly higher than that of I_3 and I_1 by 8.8 and 23.8%, respectively, and extinction coefficient due to I_3 was significantly higher than I_1 by 13.8%. This indicated that at decreased irrigation level, leaves become erect resulting better penetration of PAR into canopy causing lower fIPAR.

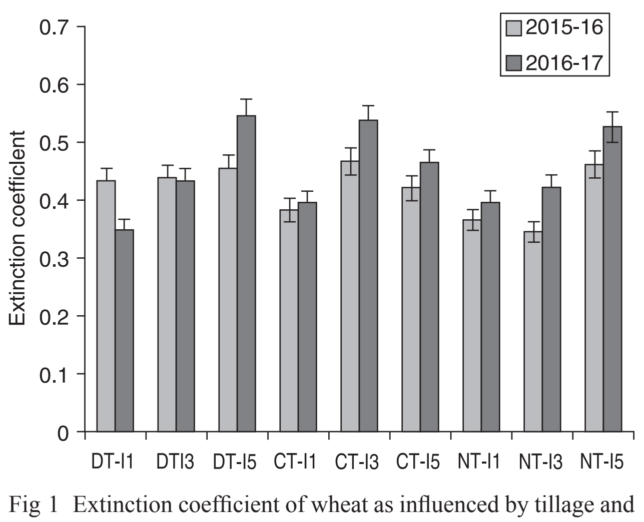

Fig 1 Extinction coefficient of wheat as influenced by tillage and irrigation management in 2015–16 and 2016–17. The error bars indicate standard error.

Grain and Biomass yield: Grain and biomass yield of wheat during 2016–17 was higher than 2015–16 by 39.2 and 24.4%, respectively (Table 1). This was attributed to higher rainfall, lower maximum air temperature and more bright sunshine hours received during 2016–17 than 2015–16. It was observed that there was no significant difference among DT, CT and NT tillage treatments with respect to grain and biomass yield for both the year. Tillage and irrigation interaction was also not significant for both the years. This may be due to the fact that this experiment is only two years old and tillage effect on yield is seen only in long term experiments. Ngwira *et al*. (2014) found that the positive effect of no till system with residue retention in maize-cowpea rotation was seen from fifth year in which

Table 1 Grain and Biomass yield of wheat as influenced by tillage and irrigation management

Treatment	Grain yield (kg/ha)		Biomass yield (kg/ha)	
	2015–16	2016–17	2015–16	2016–17
Effect of tillage				
DT	2503A#	3786A	8694A	10278A
CT	2430A	3271A	7666A	10056A
NT	2267A	2967A	7611A	9500A
Effect of Irrigation				
I_1	1925B	2496B	6472B	7500B
I_3	2632A	3182B	7444B	9333B
I_5	2643A	4346A	10056A	13000A
Effect of Tillage ×Irrigation				
DTI_1	2056a	2989a	7583a	8167a
DTI_3	2683a	3651a	8333a	9500a
DTI_5	2772a	4717a	10167a	13167a
CTI_1	2112a	2276a	6167a	7333a
CTI_3	2618a	3263a	7167a	9667a
CTI_5	2559a	4276a	9667a	13167a
NTI_1	1607a	2222a	5667a	7000a
NTI_3	2596a	2633a	6833a	8833a
NTI_5	2599a	4047a	10333a	12667a
LSD (T)	NS	NS	NS	NS
LSD (I)	287*	698*	1571*	2260*
LSD (T × I)	NS	NS	NS	NS

Values in a column followed by same letters are not significantly different at P<0.05 as per DMRT; * Significant at P<0.05; The uppercase letters and the lower case letters are used for comparing main effects and interaction effects, respectively.

the crop shows higher yield than conventional agriculture and also CA was less susceptible to climate variability than CT. However Ghosh *et al*. (2015) reported that the wheat equivalent yield under CA was significantly higher than conventional agriculture by 47% under maize-wheat rotation in a sandy loam soil. However, with the increasing irrigation level, grain and biomass yield of wheat increased significantly. During 2015–16, there was no significant difference in grain yield of wheat due to I_3 and I_5, treatments, but these treatments were superior to I_1 treatment. However, during 2016–17, grain yield under I_5 was significantly higher than that of I_1 and I_3, treatments but there was no significant difference between I_1 and I_3 treatments. During both the years, the biomass yield of wheat under I_5 was significant higher than I_1 and I_3, but there was no significant difference between I_1 and I_3 treatments with respect to biomass yield. The harvest index of wheat ranged from 0.25–0.39 with mean value 0.31 during 2015–16 and from 0.30–0.38 with mean value 0.34 during 2016–17.

Total intercepted photosynthetic active radiation (TIPAR) and Radiation use efficiency (RUE): Total intercepted photosynthetic active radiation (TIPAR) ranged from 358.4–521.2 MJ/m^2 with a mean value 467.1 MJ/m^2 during 2015–16 whereas it ranged from 456.9–613.3 MJ/m^2 with a mean value of 552.4 MJ/m^2 during 2016–17 (Table 2). During 2016–17 TIPAR was higher than 2015–16 by 18.3%. In both the years, TIPAR under DT was maximum (484.3 MJ/m^2 during 2015–16 and 573 MJ/m^2 during 2016–17) followed by CT and NT. The TIPAR under DT was significantly higher than NT by 10.1 and 8.1% during 2015–16 and 2016–17, respectively. With increasing irrigation level, TIPAR increased significantly in both the years. TIPAR due to I_1, I_3 and I_5 was 417.7, 478.9 and 504.6 MJ/m^2 respectively during 2015–16 and 490.4, 572.6 and 594.3 MJ/m^2 during 2016–17. At I_5 irrigation level, TIPAR increased significantly over I_3 and I_1 by 5.4 and 20.8%, respectively in 2015–16 and by 3.8 and 21.2%, respectively in 2016–17. Similarly at I_3 irrigation level, TIPAR increased significantly over I_1 by 14.6 and 16.8% in 2015–16 and 2016–17, respectively. The higher TIPAR at higher irrigation levels is attributed to higher LAI (Han *et al*. 2008, Li *et al*. 2008, Bassu *et al*. 2011, Pradhan *et al*. 2014). Effect of tillage and irrigation interaction was not significant on TIPAR of wheat in both the years.

During 2015–16, RUE ranged from 1.4–2.0 g/MJ with mean value 1.7 g/MJ whereas during 2016–17, RUE ranged from 1.4–2.3 g/MJ with mean value 1.8 g/MJ (Table 2). The RUE of wheat in the present experiment are within the range of 1.2 to 2.93 g/MJ reported in literature for wheat across the a range of environment (Kiniry *et al*. 1989, Siddique *et al*. 1989, Gregory *et al*. 1992, Gregory and Eastham 1996). There was no significant difference between DT, CT and NT with respect to RUE in both the years. However, RUE increased significantly with increasing irrigation level. RUE under I_5 treatment was significantly higher than that of I_1 and I_3 in both the years but there was no significant difference between I_1 and I_3 treatments with respect to RUE of wheat. Under I_5 irrigation level, RUE was significantly higher than that of I_2 by 28.6 and 43.4% during 2015–16 and 2016–17, respectively. The effect of tillage and irrigation interaction was not significant with respect to TIPAR and RUE of wheat in both the years.

Table 2 Total intercepted photosynthetically active radiations (TIPAR) and Radiation use efficiency (RUE) in wheat as influenced by tillage and irrigation management

Treatment	TIPAR (MJ/m^2)		RUE (g/MJ)	
	2015–16	2016–17	2015–16	2016–17
Effect of tillage				
DT	484.3^A	573.0^A	1.79^A	1.78^A
CT	477.0^B	554.3^B	1.60^{AB}	1.80^A
NT	440.0^C	530.0^C	1.71^A	1.77^A
Effect of Irrigation				
I_1	417.7^C	490.4^C	1.55^B	1.53^B
I_3	478.9^B	572.6^B	1.56^B	1.63^B
I_5	504.6^A	594.3^A	1.99^A	2.19^A
Effect of Tillage × Irrigation				
DTI_1	457.5^a	505.8^a	1.66^a	1.61^a
DTI_3	491.8^a	599.8^a	1.69^a	1.58^a
DTI_5	503.6^a	613.3^a	2.02^a	2.15^a
CTI_1	437.3^a	508.5^a	1.41^a	1.44^a
CTI_3	504.6^a	590.2^a	1.42^a	1.64^a
CTI_5	489.0^a	564.3a	1.98^a	2.33^a
NTI_1	358.4^a	456.9^a	1.58^a	1.53^a
NTI_3	440.3^a	528.0^a	1.55^a	1.67^a
NTI_5	521.2^a	605.3^a	1.98^a	2.09^a
LSD (T)	5.76*	3.41*	NS	NS
LSD (I)	3.85*	5.49*	0.21*	0.30*
LSD (T×I)	NS	NS	NS	NS

Values in a column followed by same letters are not significantly different at $P<0.05$ as per DMRT; The uppercase letters and the lower case letters are used for comparing main effects and interaction effects, respectively.

Thus from this study it may be concluded that there was improvement in leaf area index, fraction intercepted photosynthetic active radiation, total intercepted photosynthetic active radiation, extinction coefficient, radiation use efficiency, grain and biomass yield of wheat with the increase in irrigation levels. However, the effect of tillage treatments was not significant on grain and biomass yield and radiation use efficiency of wheat. So, wheat may be grown under no-tillage with residue retention or deep tillage in alternate years with five irrigations at critical growth stages to have higher yield and radiation use efficiency in the sandy loam soils of Indo-gangetic plain region.

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