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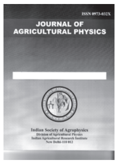

Research Article

Evaluating Radiation Use Efficiency, Growth and Yield Relationships of Wheat Under Different Management Practices

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ABSTRACT

Field experiment was conducted on wheat during the *rabi* 2013-14 and 2014-15 at the Research farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana comprising of three temperature regimes achieved by three dates of sowing(D$_1$- October 30, D$_2$- November 15 and D$_3$- November 30), three nitrogen levels (N$_1$- RDF- Recommended dose of N, N$_2$- 125% RDF (25% more than recommended N), N$_3$- 150% RDF (50% more than recommended N) and four stress management strategies (P$_0$- Control– No Spray, P$_1$-Water sprayed, P$_2$- Foliar spray of $ZnSO_4.7H_2O$ @ 0.5% P$_3$- Foliar spray of Thiourea @ 10 mM) at anthesis and 20 days after anthesis. The late sown (November 30) crop intercepted less photosynthetically active radiation (PAR) as compared toearly sown andtimely sown (October 30 and November 15) crop due to enhanced maturity under late sown conditions. Application of higher nitrogen dose (150% RDF) improved the crop stand and LAI resulting in more PAR interception and radiation use efficiency (RUE). Higher the leaf area of crop, higher the radiation interception resulting in better grain yield. Spray of $ZnSO_4.7H_2O$ (0.5%) (45.80 q/ha) and Thiourea (10 mM) (45.27 q/ha) recorded increase in grain yield as compared to control plots (43.71 q/ha), although differences were non-significant.

Key words: Dry matter accumulation, Leaf area index, PAR interception, Grain yield, Radiation use efficiency, Regression analysis, Wheat

Introduction

Wheat, the major cereal crop fulfilling the calories demands of ever increasing population of the world, is predicted to be adversely affected by climate change. The abiotic stresses such as intense sunlight, high winds, extreme temperatures, drought, floods and salinity and nutrient stress are impacting plant growth and production adversely (Sharma and Sharma, 2017). Wheat demand is likely to increase to 60 per cent by 2050 while at same time, climate-induced temperature rise is projected to reduce wheat yield by 20-30 per cent in developing countries (Rosegrant and Agcaoili, 2010).

Temperature plays a dominant role for wheat production in India. Wheat is prone to heat stress as it is highly thermo-sensitive crop (Wahid *et al.,* 2007).In tropical climates, excess of radiation and high temperatures are often the most limiting factors affecting plant growth and final crop yield (Hatfield and Prueger, 2015). Radiation use efficiency (RUE) plays a critical role in the process of cropproductivity and depends on the ability of the canopy tocapture incoming photosynthetically active radiation (PAR),water and nutrients (Albrizio *et al.,* 2005) which isaffected by the leaf area index (LAI) and

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canopycharacters, and the conversion to the biomass (Gifford *et al.,* 1994). Both the start and end of wheat crop seasons are limited by temperature regimes. Within the growing season itself, warmer temperature shortens the vegetative crop duration (Yadav *et al.,* 2010). The high temperature stress at reproductive phase of crop results in poor yield due to reduced number of grains per spike and shriveled grains with poor quality (Nagarajan *et al.,* 2005). It is predicted that there is 6 per cent reduction in global wheat production with 1 ÚC increase in growing season temperature (Asseng *et al.,* 2015).Along with temperature stress, the continuous availability of nutrients to wheat during various phases of its growth and development is important factor which influence the grain quality and yield of wheat (Kumari *et al.,* 2000).Among the several nutrients, nitrogen is the most important and is responsible, to a great extent, for the higher yields under intensive agriculture.Increased crop growth due to nitrogen fertilization is attributed to increased leaf-area index (LAI) and radiation interception (Caviglia and Sadras, 2001). Lower LAI reduces the maximumphotosynthetic rate per unit ground area due to lower PAR interception (O'Connell *et al.,* 2004). Kumar *et al.* (1998) concluded that the nutrient content in grain and straw increased with delayed sowing but uptake of nutrients decreased with delayed sowing.

Every plant community creates its own microclimate. Microclimate within the field can be modified by altering sowing time, planting methods, irrigation scheduling and nutrient management etc. These govern the crop phenological development, intercepted PAR and the efficientconversion of biomass into economic yield (Kredl *et al.,* 2012).Generally, light interception varies with crop development from emergence to the harvesting (Liu *et al.,* 2012). Investigation of within-canopy microclimatic variations can assist in better understanding of plant microclimate characteristics and its effect on plant processes. Therefore, it becomes imperative to develop suitable production practices for obtaining higher yield under temperature and nutrient stress conditions. Keeping all this in view, the present study was planned to evaluate the radiation use efficiency, growth and yield relationships of wheat under different growing environments.

Materials and Methods

Field experiment

Field experiment was laid out in split-split plot design at the Research Farm of Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana with three temperature regimes achieved by three dates of sowing (D_1=October 30, D_2=November 15 and D_3= November 30) in main plot, three nitrogen levels (N_1=RDF (Recommended dose of N), N_2=125 per cent RDF (25% more than recommended N), N_3=150 per cent RDF (50% more than recommended N) in sub plot and four post- anthesis strategies (P_0=Control, P_1=Water sprayed, P_2=Foliar spray of $ZnSO_4.7H_2O$(0.5%), P_3= Thiourea (10 mM) at anthesis and 20 days after anthesis in sub-sub plot during both years. The nitrogen was applied in two splits *i.e.* half of N was applied at the time of sowing and remaining after first irrigation.

Measurement of crop growth parameters and grain yield

The leaf area index was recorded at 30 days interval with the help of calibrated Plant Canopy Analyzer (LICOR-make). Dry matter accumulation was also recorded at 30 days intervals from one metre row length. Grain yield was recorded during harvesting of crop.

Photosynthetically active radiation (PAR) interception

The PAR interception was calculated by using the following formula:

$$\text{PAR interception (\%)} = \frac{\text{PAR (I)} - [\text{PAR (T)} + \text{PAR (R)}]}{\text{PAR (I)}} \times 100$$

Where

PAR (I) – PAR incoming above the canopy

PAR (T) – PAR transmitted to the ground

PAR (R) – PAR reflected from the canopy

Radiation use efficiency

The radiation use efficiency was calculated using the given below formula

$$\text{Radiation use efficiency (gMJ}^{-1}\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{(AIPAR)}}$$

Whereas,

AIPAR - Accumulated intercepted Photosynthetically active radiation

AIPAR (M J/m^2/day) = 0.0007826 x PAR (M J/m^2/s) × BSS

Where,

BSS- Bright Sunshine Hours of that particular day

Results and Discussion

Leaf area index

The maximum leaf area index (4.9) was recorded at 90 DAS under the October 30 sown crop followed by November 15 (4.6) and for November 30 (4.3) sown crop during pooled analysis (2013-14 and 2014-15) (Table 1). The LAI of October 30 sown crop was statistically at par with November 15 sown crop but LAI of November 15 sown crop was significantly higher than November 30 sown crop. The crop sown on October 30 attains significant higher values of LAI than November 30 sown crop. Sardana *et al.* (2002) and Shivani *et al*. (2003) were also reported that timely sowing of wheat recorded higher leaf area index than delayed sowing.

Among the nitrogen level, maximum leaf area index (5.0) was found in 150% RDF followed by 125% RDF (4.6) and RDF (4.2) during both seasons. The 150% RDF produced significantly higher values of LAI over 125% RDF and RDF treatment. The values of LAI in 125% RDF was also significantly higher than that of RDF treatment. The was significant increase in leaf area index with increase in nitrogen application. The different nitrogen levels had significant effects on LAI. Similar results were also obtained by Hussain *et al.* (2006) and Iqbal *et al.* (2012).

Among the post-anthesis strategies, foliar spray with water and stress alleviating chemicals such as $ZnSO_4$ and Thiourea at anthesis and 20

Table 1. Effect of temperature regimes, nitrogen levels and post-anthesis strategies on growth parameters and yield of wheat (Pooled data analysis of 2013-14 and 2014-15)

Treatments	Leaf area index (LAI)	Dry matter accumulation (g/m^2)	Grain yield (q/ha)
		Temperature regimes	
October 30	4.90	1752.1	48.72
November 15	4.61	1602.6	44.66
November 30	4.36	1448.4	41.00
CD (p=0.05)	0.26	84.1	2.73
		Nitrogen levels	
RDF*	4.22	1479.1	42.51
125% RDF	4.63	1557.9	45.20
150% RDF	5.02	1761.1	46.68
CD (p=0.05)	0.13	85.0	1.85
		Post- Anthesis strategies	
Control	4.60	1599.0	43.26
Water sprayed	4.63	1600.3	43.84
$ZnSO_4.7H_2O$ (0.5%)	4.65	1603.8	46.29
Thiourea (10 mM)	4.61	1601.1	45.77
CD (p=0.05)	NS	NS	NS

*Recommended dose of fertilizers

days interval after anthesis helped the crop to overcome the effect of high temperature during this stage. The foliar spray with $ZnSO_4.7H_2O$ (0.5%) or Thiourea (10 mM) or water over control had higher value of LAI although differences observed were non significant in pooled analysis during 2013-14 and 2014-15.

Dry matter accumulation

The pooled data for *rabi* 2013-14 and 2014-15 related to the effect of sowing time, nitrogen level and post anthesis strategies on maximum dry matter accumulation at harvesting have been given in Table 1. The maximum dry matter accumulation (1752.1 g/m^2) was recorded at harvesting under the October 30 sown crop followed by November 15 (1602.6 g/m^2) and November 30 (1448.4 g/m^2) sown crop. The dry matter accumulation in October 30 sown crop was significantly higher than that of November 15 and November 30 sown crop. The reduction in dry matter production in delayed sowing was due to reduction in vegetative growth phase. Mukherjee, (2012) also reported that the normal sown crop accumulated higher dry matter in different plant parts and yielded higher than late sown crop.

Among the nitrogen levels, it was observed that maximum dry matter accumulation was found at harvesting in 150% RDF (1761.1 g/m^2) followed by 125% RDF (1557.9 g/m^2) and RDF (1479.1 g/m^2). Significantly higher dry matter accumulated in 150% RDF treatment than 125% RDF and RDF treatment. Haile *et al.* (2012) and Iqbal *et al.* (2012) also reported that maximum dry matter accumulation was observed at the nitrogen rate of 200 kg ha^{-1}.

Among the post-anthesis strategies, although no significant difference in dry matter accumulation was recorded in all the treatments but crop sprayed with $ZnSO_4.7H_2O$ (0.5%) had slightly higher value of dry matter accumulation (1603.8 g/m^2) followed by Thiourea (10 mM) (1600.1 g/m^2), water sprayed (1600.3 g/m^2) over Control (1599.0 g/m^2) during pooled analysis of 2013-14 and 2014-15.The foliar spray with $ZnSO_4.7H_2O$ (0.5%) or Thiourea (10 mM) or water over control at anthesis and 20 days interval after anthesis had higher dry matter accumulation but values obtained were statistically at par with one another. Singh *et al.* (2015) also observed similar results.

Photosynthetically active radiation (PAR)

Photosynthetically active radiation within crop canopy was recorded at different phenological stages *i.e.* tillering, jointing, booting, heading, anthesis and dough stage under different temperature regimes and nitrogen levels duringpooled analysis of *rabi* seasons of 2013-14 and 2014-15.

The PAR interception was higher during heading stage under October 30 (84.6%) sown crop followed by November 15 (81.0%) and November 30 (77.7%) as shown in Fig. 1(a) because crop took more number of days to mature and intercept more radiation. The late sown crop intercepted less radiation as compared to timely sown crop as growing period of the crop decreased. Variation in the amount of incident radiation by sowing dates was also reported by Otegui and Bonhomme, (1998). Among nitrogen level, crop having 150% RDF (87.9 %) treatment intercepted more amount of radiation as compared to 125% RDF (82.7%) and RDF (80.2%) treatments as shown in Fig. 1(b) because more nitrogenous fertilizer application improved the crop stand, higher LAI which resulted in more interception percentage.Dreccer *et al.* (2000) observed that nitrogen limitation affected wheat growth by reduction of the intercepted PAR. At 60 days after sowing, nitrogen level of 150 kg/ha had significantly higher PAR interception as compared to other nitrogen levels and was statistically at par with 90 and 120 kg N/ha.

Grain yield

The grain yield as influenced by the different temperature regimes, nitrogen level and post-anthesis strategies have been presented in Table 1. The highest grain yield was recorded in October 30 (48.72 q/ha) sowing which was significantly better than November 15 (44.66 q/ha) and November 30 (41.00 q/ha) sowing. The higher grain yield in early sowing (October 30)

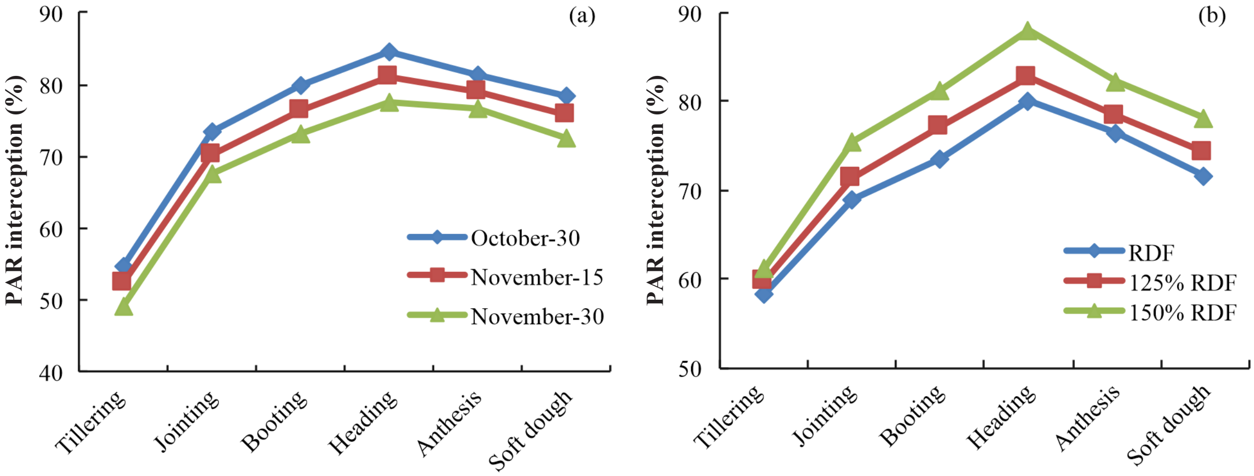

Fig. 1. PAR interception (%) under different temperature regimes and nitrogen levels of wheat (Pooled data analysis of 2013-14 and 2014-15)

was also due to longer duration of different phenophases as compared to November 15 and November 30 sowing dates. The significantly highest grain yield was obtained in 1 November sowing (5.20 t/ha) and was at par with 16 November sowing (5.05 t/ha) (Meena *et al.,* 2015). Roy *et al*. also reported that timely sown (15 November) crop had better growth and yield as compared to late (4th December) very late sown crop (22nd December). Timely sowing of wheat crop generally gives higher yield as compared to late sown crop. Late sown wheat crop faces high temperature stress during ripening phase (Kingra *et al*., 2019).

Among nitrogen levels, based on the pooled statistical analysis of 2013-14 and 2014-15 *rabi* seasons, 150% RDF (46.68 q/ha) recorded highest grain yield followed by 125% RDF (45.20 q/ha) and RDF (42.51 q/ha) treatment. The grain yield recorded in 150% RDF was statistically at par with 125% RDF. Ali *et al*. (2003) indicated that grain yield of wheat increased with the application of 150 kg N ha^{-1}.

Among post anthesis strategies, although differences in grain yield were non-significant however $ZnSO_4.7H_2O$ (0.5%) and Thiourea (10 mM) recorded higher grain yield as compared to that recorded in control plots. The numerically higher grain yield recorded in $ZnSO_4.7H_2O$ (0.5%) (46.29 q/ha) and Thiourea (10 mM) (45.77 q/ha) spray treatments was might be due to higher 1000 grain weight and longer duration of reproductive stage. Das and Sarkar (1981) reported that encouraging results were obtained with post flowering foliar application of various nutrients on yield of wheat. The higher grain yield of wheat was obtained by spraying 0.5 per cent KNO_3 at 50 per cent flowering stage of the crop (Singh *et al*., 2015). Sarkar and Tripathy, (1994) revealed that both K+ and Ca^{2+} gave beneficial effect on grain yield of wheat when applied as foliar spray at 50 per cent flowering stage of the crop.

Radiation use efficiency

The radiation use efficiency decreased with the delay in sowing of the crop during both the years. Highest radiation use efficiency was found in October 30 (3.21 and 3.39 g/MJ) sown crop as compared to the crops sown on November 15 (2.99 and 3.19 g/MJ) and November 30 (2.63 and 3.01 g/MJ) during 2013-14 and 2014-15 respectively (Fig. 2a). Similar results were also obtained by Giunta and Motzo, (2004). RUE is also known to be limited by nutrient availability especially nitrogen status and fertilization (Awal and Ikeda, 2003). During *rabi* seasons of 2013-14 and 2014-15, highest radiation use efficiency was obtained under 150% RDF (3.31 and 3.61 g/MJ) treatment followed by 125 % RDF (3.09 and

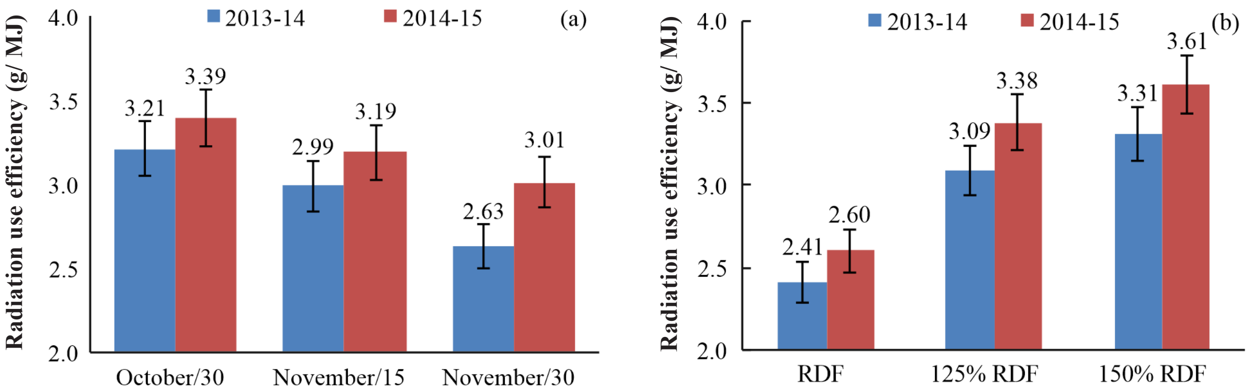

Fig. 2. Radiation use efficiency (g/ MJ) under different temperature regimes and nitrogen levels of wheat

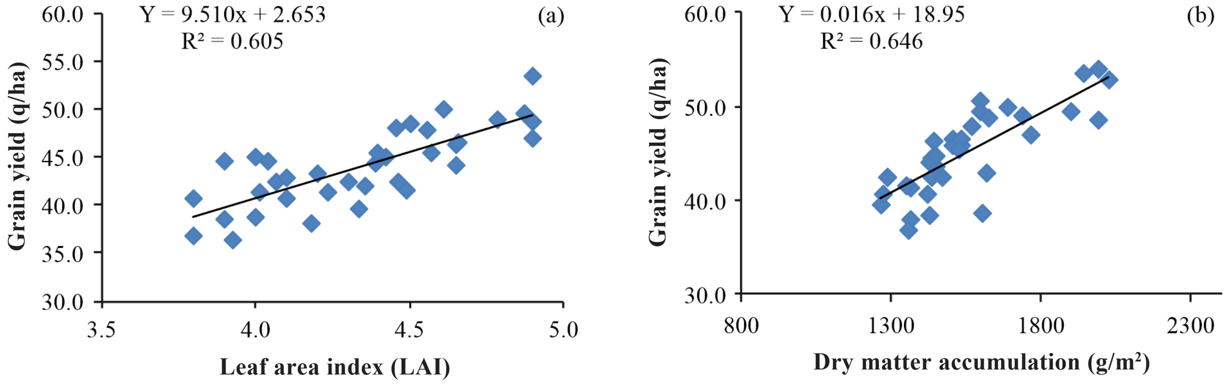

Fig. 3. Relationship of leaf area index and dry matter accumulation with grain yield (Pooled data analysis of 2013-14 and 2014-15)

3.38 g/MJ) and RDF (2.41 and 2.60 g/MJ) treatment. Crop growth depends on the ability of the canopy to capture incoming photosynthetically active radiation (PAR) water and nutrients, which is affected by the leaf area index (LAI). Increasing the dose of nitrogenous fertilizer has a significant effect on the LAI values and it directly increases the radiation interception by crop (Iqbal *et al.,* 2012; Albrizio *et al*., 2005, Pardhan *et al.,*2018).

Regression relationship of biophysical parameters, PAR interception and radiation use efficiency with grain yield

The relationships of grain yield with leaf area index, dry matter accumulation, PAR interception and radiation use efficiency was worked out for pooled data of *rabi* seasons of 2013-14 and 2014-15 showing a positive and linear regression relationship. The coefficient of determination explained about 60.5, 64.6, 72.7 and 77.8% variation in grain yield by the leaf area index (Fig. 3a), dry matter accumulation (Fig. 3b), PAR interception (Fig. 4a) and radiation use efficiency (Fig. 4b) respectively. It showed that the increase in leaf area index and dry matter accumulation contributed higher radiation interception and radiation use efficiency ultimately leading to higher grain yield. Chen *et al.* (2003) and Li *et al.* (2008) also observed positive relationship between crop yield and RUE.

Conclusions

The study concluded that sowing of wheat on October 30 with 150% recommended dose of fertilizer coupled with foliar spray of $ZnSO_4.7H_2O$ (0.5%) during anthesis can be the best adaptive

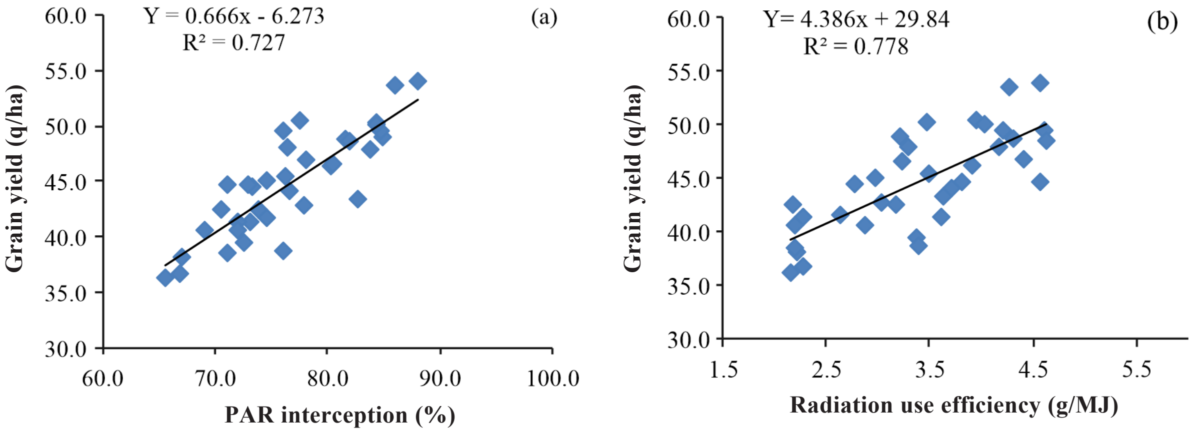

Fig. 4. Relationship of PAR interception and radiation use efficiency with grain yield (Pooled data analysis of 2013-14 and 2014-15)

strategy in this study to avoid temperature stress and improve yield and radiation use efficiency.

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