Indian Journal of Agronomy **65** (1): 53–60 (March 2020)

Research Paper

Effect of sowing time, planting methods and irrigation scheduling on yield response, water and radiation-use efficiencies of wheat (*Triticum aestivum*) in Punjab, India

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Received: July 2019; Revised accepted: June 2020

ABSTRACT

A field experiment was conducted during the winter season (*rabi)* of 2016–17 and 2017–18 at Ludhiana, Punjab, to evaluate the photosynthetically active radiation (PAR) interception, yield response, water and radiation-use efficiencies of wheat (*Triticum aestivum* L.) in response to sowing time, planting methods and irrigation treatments. Wheat variety 'WH 1105' was sown on 2 dates (10 and 30 November) under 2 planting methods (flat planting and bed planting) and 3 irrigation treatments (I_1, 3 post-sowing irrigations at crown-root initiation (CRI), flag-leaf emergence and soft dough stages; I_2, $I_1 + 4^{th}$ irrigation during the last week of March; and I_3, recommended 4 post-sowing irrigations) with 4 replications. Crop sown on 10 November under bed planting with I_2 irrigation treatment had the maximum dry matter accumulation, leaf area index, number of effective tillers, ear length, grains/ear and 1,000-grain weight as compared to the other treatments. The PAR interception was also higher in 10 November sowing under bed planting in I_2 irrigation treatment, which had direct effect on radiation-use efficiency (RUE) of the crop. Water-use efficiency (WUE) was higher (12.5 and 11.4 kg/ha/mm) under I_1 treatment followed by I_3 treatment (12.3 and 10.6 kg/ha/mm) and the lowest in I_2, treatment (10.5 and 9.3 kg/ha/mm). The grain yield, WUE and RUE were higher by 5–10, 10–15 and 1–5%, respectively under bed planting compared to flat planting during both the seasons. Significant and positive correlation (r) of grain yield with yield-attributing characters, viz. no. of effective tillers (0.71), grains/ear (0.76), ear length (0.74), 1,000-grain weight (0.65), water (0.76) and RUE (0.69) were observed with pooled analysis.

Key words : Bed planting, Flat planting, Photosynthetically active radiation, Radiation-use efficiency, Wheat, Water-use efficiency,

Climate variability is one of the most significant factors influencing year-to-year crop production, even in high-yield and high-technology agricultural areas (Bhan and Behera, 2014). The more important componenta of climate variability are the decline in rainfall and rise in temperature. Wheat is the first important winter (*rabi*) cereal crop for food security of India. The vulnerability of wheat yield is expected to increase in future due to expected rise in future temperature. The increase in temperature can adversely affect the actual and potential wheat yields and the decline may amount to the extent of 38 and 50%, respectively, with 5°C rise in temperature (Aggarwal and Rani, 2009). So, adoption of resource-conservation technologies (RCTs) for enhancing crop productivity and resource-use efficiency (RUE) is very important besides achieving sustainability in agriculture. The time of sowing is one of the most important non-monetary inputs for optimizing crop growth according to prevailing agro-climatic conditions (Singh *et al.,* 2011). Early planting of wheat gives the highest yield than delayed one due to long-growing duration and better growth and development owing to rapid seedling and uniform emergence along with higher leaf area and fertile tillers (Tanveer *et al.,* 2003). Along with time of sowing, wheat like other field crops, responds differently to various management practices especially planting methods. Despite its high yield potential, yield/ha is low in India compared to other wheat-producing countries. Better irrigation-and soil-management technologies are needed to improve water-use efficiency (Majeed *et al*., 2015). Different RCTs include mainly bed planting, zero tillage and laser-land leveling of fields.

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Wheat cultivation on raised beds has been investigated for its suitability in rice–wheat and other cropping systems (cotton–wheat) in the Indo-Gangetic Plains (Hobbs and Gupta, 2003). The use of raised beds in wheat facilitates double-cropping and offers significant advantages in controlling soil moisture, both irrigation and drainage, and are amendable to narrow row spacing (Mascagni *et al.,* 2010). The comparison of wheat on flat and bed layouts at farmer's field indicates significant savings in irrigation water applications (RWC-CIMMYT, 2003). It is believed that an increase in agricultural water productivity is the key approach to mitigate water shortage and to reduce environmental problems. Water productivity is a useful indicator for quantifying the impact of irrigation-scheduling decisions with regard to water management. Irrigation interval largely depends on environmental conditions, stage of the crop and rainfall received. In view of the climate changes, there is an urgent need to conserve the natural resource base for agriculture. To respond effectively to these conditions, farmers require technological options that maintain or increase productivity, reduce costs, and maintain production systems in a sustainable manner. Also to meet the increasing food demand, the productivity of the rice–wheat cropping system must be increased and continued. Development or adoption of new crop-establishment methods, changing management practices and inclusion of new crops in the system may be some of the ways to enhance productivity and resource conservation. Keeping all this in view, the present study was planned to investigate photosynthetically active radiation (PAR) interception, yield response, water and radiation-use efficiency of winter wheat in response to sowing dates, planting methods and irrigation treatments under Punjab conditions.

MATERIALS AND METHODS

The experiment was conducted on wheat during the winter seasons (*rabi*) of 2016–17 and 2017–18 at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. Wheat variety 'WH 1105' was sown on 2 dates (10 November and 30 November) under 2 planting methods (flat planting and bed planting) and 3 irrigation levels (I_1, 3 post-sowing irrigations at crown-root initiation (CRI), flag leaf emergence and soft dough stages; I_2, $I_1 + 4^{th}$ irrigation during the last week of March; and I_3, recommended 4 post-sowing irrigations) with 4 replications in a split-split-plot design during both the seasons. The recommended package of practices of the PAU were followed. The periodic dry-mater accumulation was recorded at 15-day intervals. The data on grain yield and yield attributes were recorded at harvesting.

The leaf area was recorded at 30 days interval using Plant Canopy Analyzer (LICOR-make). The leaf-area index was measured by placing the sensor once above the canopy followed by placing it at 4 different points below the crop canopy diagonally across the rows.

Line Quantum Sensor (Model LI-190 SB) was used to measure the amount of incoming, reflected and transmitted PAR in the range of 400–700 nm. Diurnal cycles of photosynthetically active radiation (PAR) were taken at hourly interval at different phenological stages. 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 (RUE) was calculated as:

$$\text{RUE (g/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Accumulated intercepted photosynthetically active radiation (AIPAR)}}$$

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

where BSS, Bright sunshine hours of that particular day.

Water-use efficiency (WUE) was calculated as per Hussain and Al-Jaloud, (1995)

$$\text{WUE (kg/ha/mm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Water use (mm)}}$$

The data were statistically analysed using split-split-plot design. All the comparisons were made at 5% level of significance. Correlation coefficients of grain yield with yield attributes, Water-use efficiency and radiation-use efficiency were worked out using standard methods.

RESULTS AND DISCUSSION

Leaf-area index

The first date of sowing (10 November) had higher leaf-area index than (30 November) sowing during both years at booting stage of wheat (Table 1). Alam (2013) also reported higher LAI at booting stage which then declined up to grain-filling stage. The delay in sowing beyond the normal date resulted in decrease in LAI (Mishra *et al.,* 2003). Dar *et al*. (2019) also revealed that leaf-area index decreased significantly with delay in sowing of crop. Among the planting methods, maximum LAI was observed at booting stage in bed planting as compared to flat planting during both years. However, the effect of different irrigation treatments on LAI at booting stage was found to be non-significant during both the years under study.

Dry matter accumulation

Maximum dry-matter accumulation (DMA) was recorded at harvesting under 10 November-sown crop as compared to 30 November-sown crop during 2016–17 and 2017–18 (Table 1). Crop sown early received higher incident radiation and accumulated more temperature over the duration of its growth influencing leaf appearance, canopy closure and interception of photosynthetic active radiation (Martini *et al.,* 2009). Higher level of intercepted PAR is positively related to above ground biomass accumulation (Prado *et al.,* 2017). Planting methods significantly affected the DMA during both years. Bed planting of wheat recorded higher DMA at harvesting as compared to flat planting during both years. The significantly higher DMA was also obtained by applying 1 extra irrigation under I_2 treatment (CRI + flag-leaf emergence + soft dough + during the last week of March) compared to I_3 treatment and least in I_1 treatment during both the years. Liu and Ouyang (2012) also observed that, supplementary irrigation increased the DMA and improved the contribution of post-anthesis dry matter to grain yield.

Photosynthetically active radiation

The photosynthetically active radiation (PAR) interception was recorded maximum at 90 days after sowing (DAS) and decreased afterwards as crop progressed towards the maturity. The date of sowing affected the PAR interception and it decreased with delay in sowing. The PAR interception was higher under 10 November sowing than 30 November sowing during both years (Fig. 1a, 2a) which might be owing to higher LAI and longer duration of crop under 10 November sowing as compared to 30 November sowing. The PAR interception also differed with the planting methods. The PAR interception recorded at different phenological stages was higher under the bed planting than that under flat planting during both the seasons (Fig 1b, 2b). This might be owing to higher LAI and better plant stand obtained under bed planting, thus, resulting in higher interception. Among the irrigation treatments, PAR interception was higher under I_2 treatment, followed by I_3 and I_1 treatments (Fig. 1c, 2c). These results may be attributed to higher LAI under bed planting and I_2 irrigation treatment.

Yield-attributing characteristics

It was observed that significantly higher number of effective tillers were produced in 10 November sowing as compared to 30 November sowing during both the years (Table 2). Normal sowing prolongs the duration of tillering and produces more number of tillers and effective tillers (Kamrozzaman *et al.,* 2016). The maximum number of effective tillers/m^2 were observed in bed planting as compared to flat planting. The I_2 irrigation treatment resulted in significantly higher number of effective tillers, followed by I_3 irrigation treatment and I_1 irrigation treatment during both the winter seasons.The number of grains/ear were significantly affected by sowing dates, planting methods and irrigation treatments. The grains/ear were found maximum in

Table 1. Maximum leaf-area index and dry-matter accumulation of wheat under different dates of sowing, planting methods and irrigation treatments during winters of 2016–17 and 2017–18

Treatment	Leaf-area index at *booting stage*		Dry-matter accumulation (g/m^2) at *physiological maturity*	
	2016–17	2017–18	2016–17	2017–18
Date of sowing				
10 November	4.01	3.41	1620.70	1512.80
30 November	3.46	2.86	1492.00	1372.50
SEm±	0.13	0.16	34.22	26.32
CD (P=0.05)	0.39	0.51	106.10	81.60
Planting methods				
Flat planting	3.62	2.96	1509.0	1360.60
Bed planting	3.86	3.31	1603.6	1524.80
SEm±	0.06	0.10	20.77	29.97
CD (P=0.05)	0.18	0.31	64.40	92.90
Irrigation treatments				
I_1	3.62	3.06	1496.0	1380.1
I_2	3.82	3.21	1634.8	1525.4
I_3	3.76	3.13	1538.1	1422.6
SEm±	0.02	0.03	27.74	33.42
CD (P=0.05)	NS	NS	86.00	103.6

Note: I_1, 3 post-sowing irrigation at crown root initiation, flag-leaf emergence and soft dough stages; I_2, I_1 + fourth irrigation during the last week of March; I_3, recommended 4 post-sowing irrigations

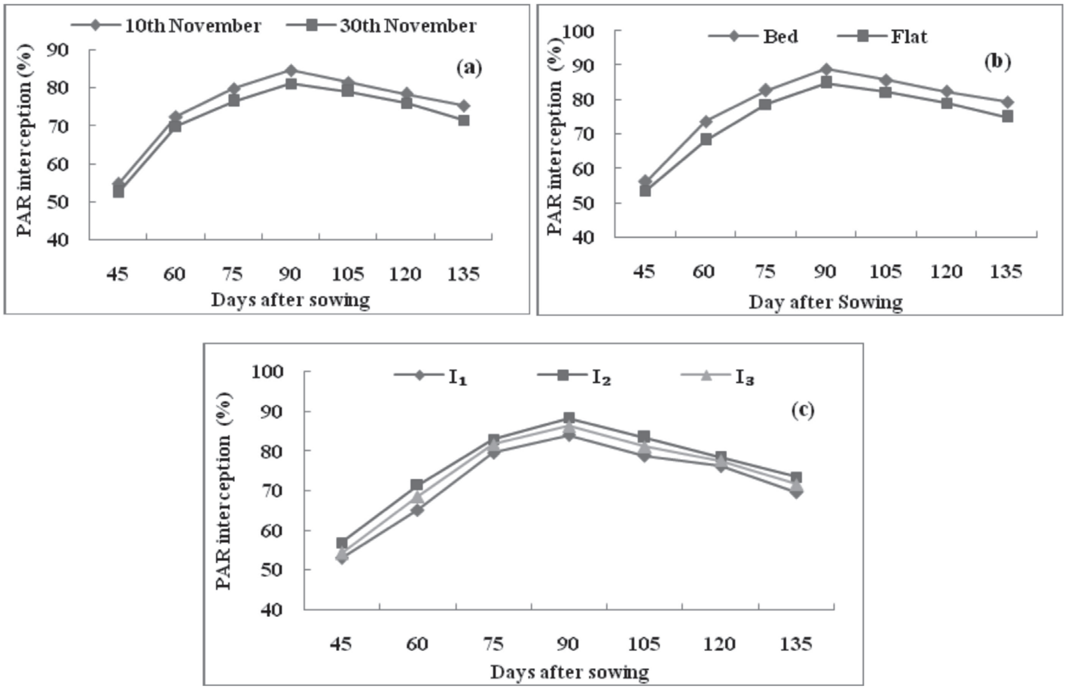

Fig. 1. Photosynthetically active radiation (PAR) interception by wheat under different date of sowing, planting methods and irrigation treatments during 2016–17

Table 2. Grain yield and yield attributes of wheat under different dates of sowing, planting methods and irrigation treatments

Treatments	Yield attributes								Grain yield (t/ha)	
	Number of effective tillers/m^2		Number of grains/ear		Ear length/ear (cm)		1000-grain weight (g)			
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Date of sowing										
10 November	448.8	421.6	53.9	51.0	11.0	10.6	34.3	33.1	4.79	4.54
30 November	390.4	358.4	47.3	42.9	9.6	9.3	30.3	28.4	4.49	4.16
SEm±	5.3	3.9	1.9	1.7	0.1	0.2	1.2	0.4	0.01	0.09
CD (*P*=0.05)	16.5	12.1	5.9	5.3	0.3	0.7	3.7	1.1	0.03	0.27
Planting methods										
Flat planting	409.3	373.9	47.1	43.3	9.9	9.3	30.2	28.6	4.44	4.20
Bed planting	430.1	406.0	54.0	49.7	10.7	10.5	34.4	32.9	4.85	4.51
SEm±	6.3	7.9	2.1	1.6	0.2	0.3	1.0	0.8	0.03	0.1
CD (*P*=0.05)	19.4	24.6	6.40	5.1	0.76	0.9	3.0	2.4	0.08	0.31
Irrigation treatments										
I_1	394.8	359.3	46.4	41.8	9.3	9.1	30.1	28.7	4.53	4.03
I_2	447.8	421.6	54.9	52.5	11.2	10.4	34.4	32.8	4.75	4.62
I_3	416.5	389.1	50.6	46.2	10.5	10.1	32.4	30.8	4.66	4.42
SEm±	6.5	7.1	1.2	1.3	0.3	0.3	0.7	0.6	0.1	0.1
CD (P=0.05)	20.3	21.9	3.8	4.1	0.86	0.7	2.3	1.8	0.17	0.29

I_1, 3 post-sowing irrigation at CRI, flag leaf emergence and soft dough stages; I_2, I_1 + fourth irrigation during last week of March; and I_3, recommended 4 post-sowing irrigation

10th November sowing compared to 30th November sowing during both the years. Higher number of grains/ear were recorded in bed planting than flat planting. Significantly higher number of grains/ear were obtained under I_2 treatment, followed by I_3 and I_1 treatment. The maximum ear length was observed in 10th November sowing compared to 30th November-sown crop. Baloch *et al.* (2010) also reported that, optimum sowing dates resulted in better ear development owing to longer growing period. In planting methods, bed planting favoured higher ear length than flat planting crop. Significantly higher ear length was recorded under I_2 treatment, followed by I_3 treatment and I_1 treatment during both seasons. The 1,000-grain weight was higher in 10th November sowing as compared to 30th November sowing. Kamrozzaman *et al.* (2016) reported that high temperature in delayed sowing shortened the duration of crop and results in shriveled grains which ultimately reduced the grain weight. The higher 1,000-grain weight was recorded in bed planting than flat planting. The significantly higher grain weight was recorded in I_2 than I_3 and I_1 treatments during both the years.

Grain yield

The sowing dates, planting methods and irrigation treatments significantly affected the grain yield of wheat (Table 2). The highest grain yield was recorded in 10 November-sown crop, while the lowest was recorded in 30 November-sown crop during both the years. Kalwar *et al.* (2018) revealed that, normal sowing recorded the maximum grain yield than late sowing. The decrease in grain yield with late sowing might be due to shriveled grains, resulting from lower 1,000-grain weight. Bed planting resulted in higher grain yield than flat planting during both the years.. This might be owing to higher PAR interception and adequate availability of water for higher uptake of nutrients which boosted the growth, leading to development of higher yield attributes through the supply of more photosynthates towards the sink. Similarly, Hossain *et al.* (2004) found that, planting of wheat on beds increased grain yield up to 21% over flat planting. Wang *et al.* (2011) also revealed that, yield difference between 2 planting system varied between 6.6 and 12% in favour of raised bed planting. Similar results were also reported by Sagar and Naresh (2019). The grain yield was also influenced by different irrigation treatments (Table 2). Maximum grain yield was obtained under I_2 as compared to I_3 and I_1 treatments.

Water-use efficiency

It was observed that 10 November-sown crop exhibited more water-use efficiency (WUE) than 30 November-sown crop during both the years (Fig. 3a). Seasonal consumptive water use, its rate and WUE decreased in proportion with delay in sowing time. Timely sown wheat crop utilized water at its maximum rate, while late-sown crop utilized water at its lower rate during crop-growth period. This may be due to the fact that the late-sown crop produces less photosynthates than normal sown crop. The highest WUE was recorded under bed planting as compared to flat planting during both the years (Fig. 3). Higher WUE in bed planting might be owing to increased grain yield as well as

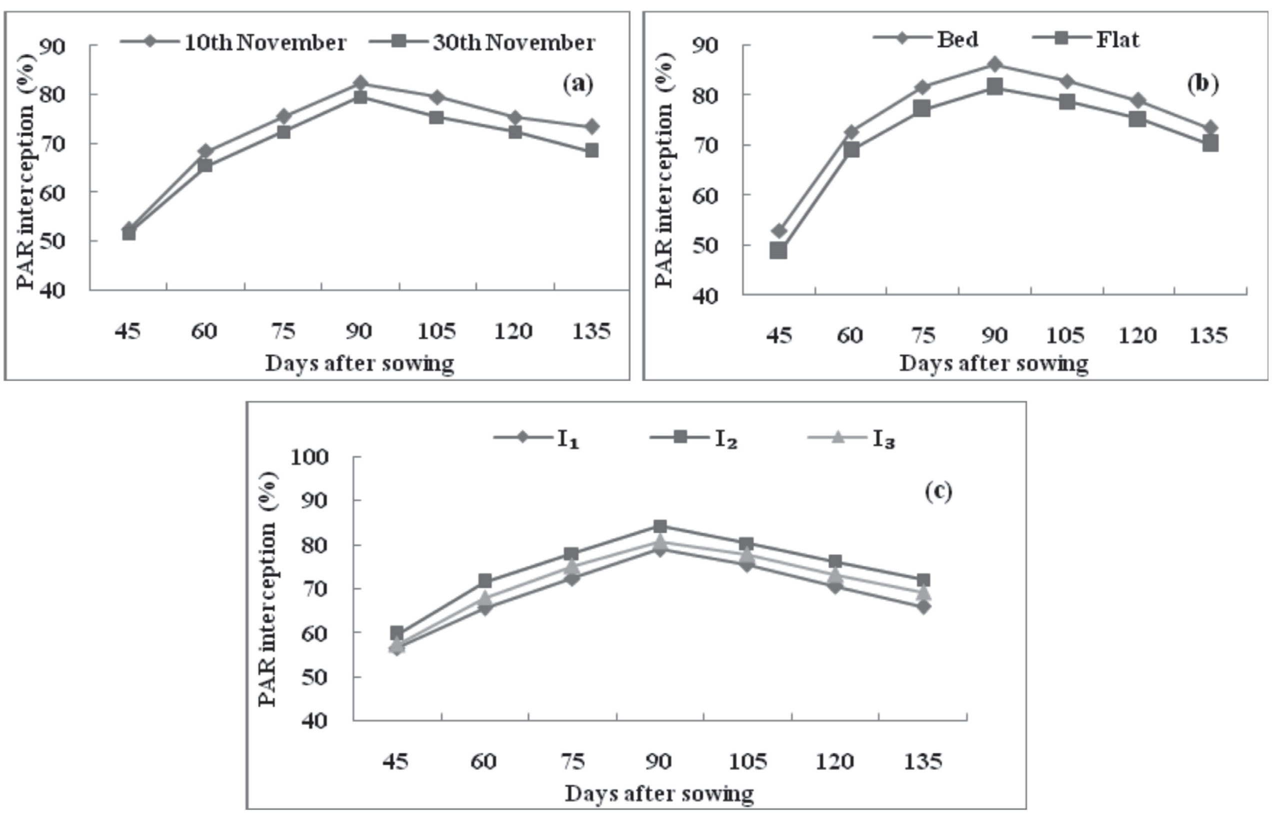

Fig. 2. Photosynthetically active radiation (PAR) interception by wheat under crop sown under different dates of sowing, planting methods and irrigation treatments during 2017–18

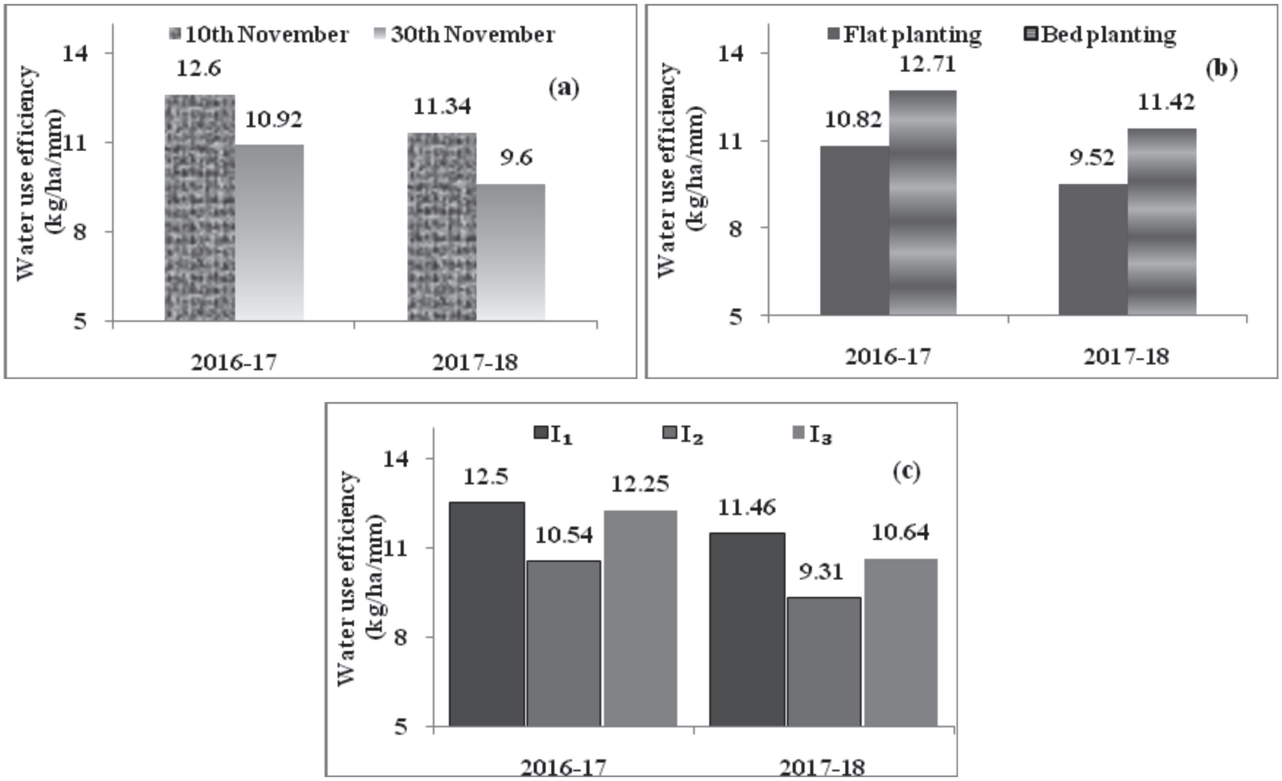

Fig. 3. Water-ruse efficiency (kg/ha/mm) of wheat under different dates of sowing, planting methods and irrigation treatments during winter season 2016–17 and 2017–18

saving in irrigation water. Hossain *et al.* (2004) reported that, all permanent bed tillage systems showed substantial water saving (32%) over conventionally tilled on the flat bed. Mollah *et al.* (2009) also indicated that, bed planting of wheat saved 41 to 48% irrigation water over flat planting. Among the irrigation treatments, WUE was higher under I_1, followed by I_3 and lowest in I_2 treatment (Fig. 3c). This might be due to the fact that under more irrigation, evaporation was at potential rate due to availability of more water than the crop irrigated with less irrigation.

Radiation-use efficiency

The highest radiation-use efficiency (RUE) was observed in 10th November sowing than 30th November sowing during both the years (Fig. 4 a). It decreased with delay in sowing which might be due to higher LAI and more radiation interception by the early-sown crop which decreased with delay in sowing. The highest RUE was recorded under bed planting as compared to flat planting during both the years (Fig. 4 b). This might be due to the reason that the amount of light intercepted by bed planting crop canopy exceeded light interception by the flat planting crop canopy. The substantial decrease in LAI during the whole growing season in flat planting crop might have caused large reduction in the amount of PAR absorbed by the crop, therefore RUE in the flat planting was significantly lower than that of bed planting. Better performance of crop depends on availability of irrigation water, especially at various growth stages. The RUE was higher under I_2 than I_3 and I_1 treatments during the both years (Fig. 4 c). Non-availability of water at early stages of crop growth showed reduction both in the amount of intercepted PAR and RUE and ultimately yield (Chen *et al*., 2003).

Relationships of grain yield with yield attributes and water-use efficiency

The grain yield was significantly and positively correlated with effective tillers, number of grains/ear, ear length, 1,000-grain weight, WUE and RUE during both the years (Table 3). The pooled analysis of 2 years data also showed

Table 3. Correlation of between grain yield of wheat with yield attributes and water-use efficiency

Parameters	Grain yield		
	2016–17	2017–18	Pooled
Number of effective tillers	0.78*	0.61*	0.71*
Number of grains/ear	0.71*	0.69*	0.76*
Ear length	0.65*	0.79*	0.74*
1,000-grain weight	0.50**	0.75*	0.65*
Water-use efficiency	0.58*	0.83*	0.76*
Radiation use efficiency	0.74*	0.70*	0.69*

*P=0.05; **P=0.10

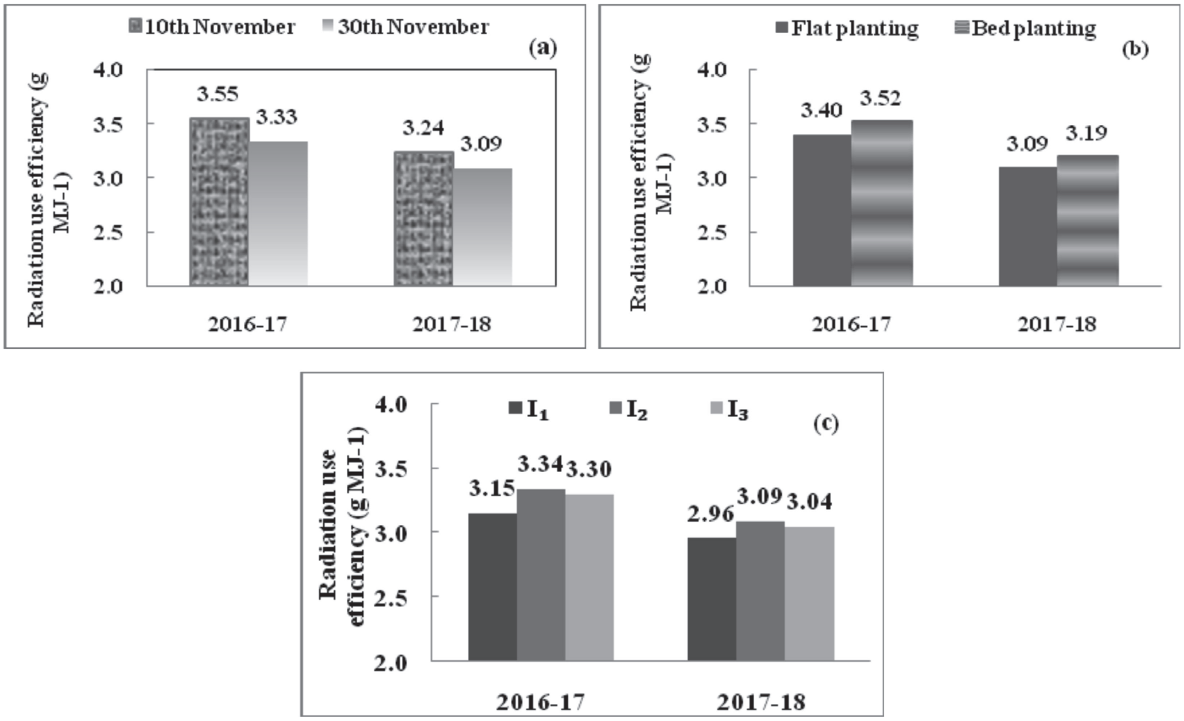

Fig. 4. Radiation-use efficiency (g/MJ) of wheat under different dates of sowing, planting methods and irrigation treatments during winter season of 2016–17 and 2017–18.

the positive and significant relationship of yield attributes, WUE and RUE with grain yield. Kashif and Khaliq (2004) reported that yield components, viz. effective tillers, had significantly contributed towards grain yield. They also noted that grains/ear and 1,000-grain weight were the main contributors to grain yield in wheat. Li *et al.* (2006) showed that RUE appeared to be closely and positively associated with the number of grains and ultimately to grain yield.

It is concluded that wheat grain yield can be increased by bed planting over the flat planting. It also improved the water-use efficiency and radiation-use efficiency. The crop sown on 10 November under bed planting with 4 irrigations at crown-root initiation, flag-leaf emergence, soft dough stage and the last week of march had higher growth and grain yield as compared to the other treatments.

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