

## Enhancing yield and water productivity of wheat (*Triticum aestivum*) through furrow irrigated raised bed system in the Indo-Gangetic Plains of India

ASHOK KUMAR<sup>1</sup>, K D SHARMA<sup>2</sup> and ASHOK YADAV<sup>3</sup>

CCS Haryana Agricultural University, Hisar, Haryana 125 004

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### ABSTRACT

A field experiment was conducted during 2006–08 at Hisar, India to study the effects of planting patterns and cultivars on the water productivity and grain yield of wheat (*Triticum aestivum* L. emend. Fiori & Paol.). In this experiment, 3 wheat cultivars were sown in 6 planting patterns including 5 bed configurations in furrow irrigated bed planting systems and 1 flat planting with row-to-row distance of 22.5 cm. In furrow irrigated bed planting systems, the crop was planted on the top of beds of 75 cm bed, 2 rows (B<sub>75-2</sub>); 75 cm bed, 3 rows (B<sub>75-3</sub>); 90 cm bed, 2 rows (B<sub>90-2</sub>); 90 cm bed, 3 rows (B<sub>90-3</sub>) and 90 cm bed, 4 rows (B<sub>90-4</sub>). The results showed that by following furrow irrigated bed planting systems, on an average 40% water was saved as compared to 1 flat planting with row spacing of 22.5 cm with significant increase in the productivity of water. In furrow irrigated bed planting systems, B<sub>90-3</sub> and 'WH 1022' displayed significantly higher water productivity compared with other treatments (2.25 and 1.75 kg/m<sup>3</sup>). Physiological traits, yield attributes and yields were significantly influenced by planting patterns and wheat cultivars. However planting pattern×cultivar interaction was significant for leaf area index, photosynthetic rate, the number of spikes/m<sup>2</sup> and biological yield. 'WH 1022' showed higher photosynthetic rate than 'PBW 343' and 'WH 711' in furrow irrigated bed planting system except B<sub>90-4</sub> while the latter 2 cultivars showed higher photosynthetic rate in flat planting with row spacing of 22.5 cm. On an average, transpiration rate was higher for 'WH 1022' and 'PBW 343' than the 'WH 711'. In all planting patterns, 'WH 1022' and 'PBW 343' gave significant higher number of spikes/m<sup>2</sup> except in flat planting with row spacing of 22.5 cm and biological yield than 'WH 711'. The grain yield was significantly higher in B<sub>90-3</sub> (6180.39 kg/ha) and cultivar 'WH 1022' (5 219 kg/ha).

**Key words:** Furrow irrigated raised bed system, Planting pattern, Water productivity, Wheat

The Indo-Gangetic Plains occupies large areas of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L. emend. Fiori & Paol.) cropping system in India, Bangladesh, Nepal and Pakistan. Studies in past decade indicate that sustainability of rice–wheat system in the Indo-Gangetic Plains has been at risk mainly due to declining groundwater levels, soil organic matter content and nutrient availability, increased soil salinization, incidence of pests and diseases. However, water availability may become a major limiting factor for sustained productivity of wheat crop grown in the dry winter season and are dependent on supplemental irrigation either by canal or underground water. Therefore, research efforts are urgently needed to develop and promote new technologies to enhance the productivity of water and its judicious use.

To increase the water productivity of wheat, CYMMIT introduced a planting pattern termed as bed planting or furrow

irrigated raised bed planting system in Mexico. The adoption of the system rose from 6% of farmers in 1981 to 75% in 1994 in high-yielding irrigated wheat-growing areas of north-western Mexico (Sayre and Hobbs 2004). In this system, the crop is planted on the top of beds and irrigation water is applied in furrows. The width of the bed and furrows commonly used are 40–45 and 25–30 cm, respectively, and the bed height is 15 cm– 20 cm. Inspired by the success of irrigated maize–wheat on permanent raised beds in Mexico, furrow irrigated raised bed planting system was introduced in Indo-Gangetic Plains in the mid 1990s for wheat (Hobbs 2001, Sayre and Hobbs 2004). Even after 2 decades of its introduction and promotion, a few farmers preferred bed planting over the conventional flat planting system. This was mainly due to lack of yield advantage in furrow irrigated raised bed planting system over flat planting system. Farmers can easily respond to this technology if efforts are diverted to demonstrate yield differences between flat and bed planting systems either by modifying bed configuration or crop rows planted on the top of the bed or selection of suitable cultivars.

<sup>1</sup>Professor of Agronomy(Crop Physiology Laboratory) (Email: dtr10@hau.ernet.in), <sup>2</sup>Plant Physiologist (email: kamald@hau.ernet.in), <sup>3</sup>Professor of Agronomy (email: dtr10@hau.ernet.in), Department of Agronomy.

Keeping in view the above points, a study was conducted to compare furrow irrigated raised bed planting system in different bed size configurations and rows planted on the top of the bed with flat planting by including popular high-yielding wheat cultivars. Different planting patterns were assessed for water saving and wheat productivity.

**MATERIALS AND METHODS**

The field experiment was conducted at CCS Haryana Agricultural University, Hisar, Haryana (20 10' N longitude, 75 45' E latitude) during 2006–08. The plot comprised sandy loam soil with organic carbon 0.26%, available N 132 kg/ha, P 16 kg/ha and K 350 kg/ha. Agriculture in the region is intensified by a double cropping system (2 crops a year) with rice, cotton and pearl millet in the rainy season and wheat, mustard and chickpea in the winter season. The site is characterized by a summer monsoon climate with a mean annual precipitation of 320 mm, 70–80% of which falls in the summer season from July to September with the remainder falling in winter wheat-growing season from October to April. In 2006–08, the precipitation in the wheat season was 138.6 (86.1 mm in February and 44.3 mm in March 2007) and 21.9 mm, respectively. The crop was sown after a pre-sowing irrigation of 7 cm using 100 kg seed/ha in flat planting, B<sub>75-3</sub> and B<sub>90-4</sub>, 90 kg/ha in B<sub>90-3</sub> and B<sub>75-2</sub> and 80 kg/ha in B<sub>90-2</sub>. At the time of sowing, 60 kg nitrogen and 60 kg P<sub>2</sub>O<sub>5</sub>/ha were applied. The remaining nitrogen (60 kg/ha) was applied before first irrigation (crown root initiation stage). Five irrigations were applied to the crop coinciding with crown root initiation, tillering, flag leaf appearance, heading and milk ripening stages. Water was applied from the canal to the plots measured by a partial flume (Table 1).

Six planting patterns including 5 furrow irrigated raised bed planting systems and 1 flat planting were followed (Fig 1). In furrow irrigated raised bed planting system, the crop was planted on the top of beds in bed configurations of 75 cm bed, 2 rows (B<sub>75-2</sub>); 75 cm bed, 3 rows (B<sub>75-3</sub>); 90 cm bed, 2 rows (B<sub>90-2</sub>); 90 cm bed, 3 rows (B<sub>90-3</sub>) and 90 cm bed, 4 rows (B<sub>90-4</sub>). In flat planting, a uniform row-to-row distance of 22.5 cm was maintained. Three wheat cultivars,

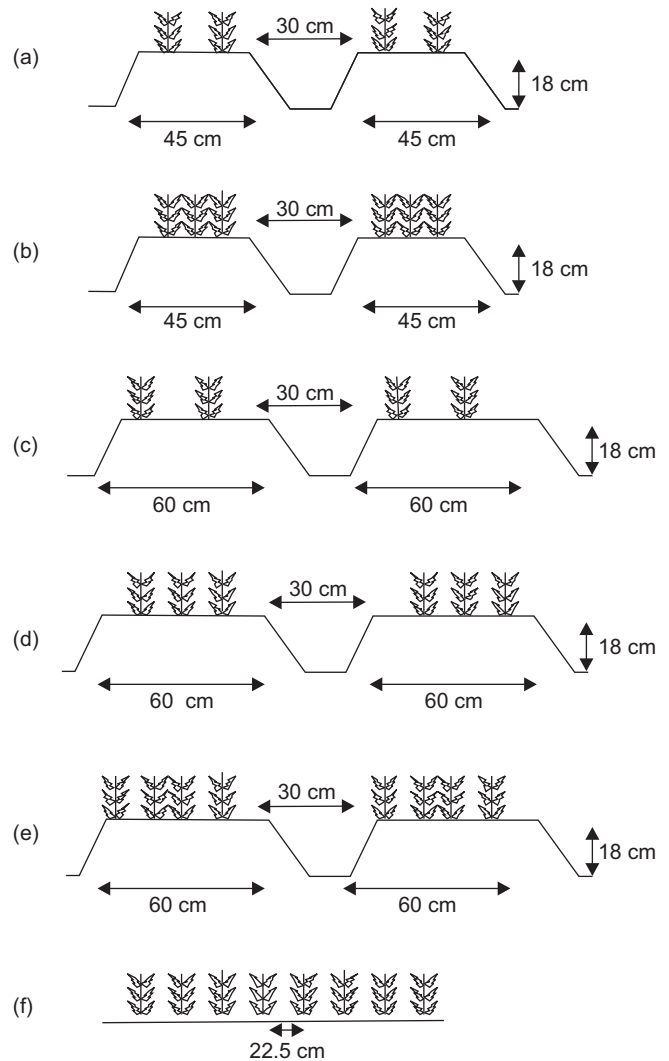


Fig 1 Description of planting patterns (a) 75 cm beds, 2 rows on the top of bed (B<sub>75-2</sub>), (b) 75 cm beds, 3 rows on the top of bed (B<sub>75-3</sub>), (c) 90 cm beds, 2 rows on the top of bed (B<sub>90-2</sub>), (d) 90 cm beds, 3 rows on the top of bed (B<sub>90-3</sub>), (e) 90 cm beds, 4 rows on the top of bed (B<sub>90-4</sub>) and (f) flat planting, rows 22.5 cm apart

Table 1 Quantity of irrigation water applied and water savings in different irrigations in wheat

Planting pattern	Number of irrigation/irrigation water applied (m <sup>3</sup> /ha)					Total
	1st	2nd	3rd	4th	5th	
B <sub>75-2</sub>	630.0 (10.0)	490.3 (29.9)	419.7 (40.0)	384.7 (45.0)	280.0 (60.0)	2 204.7 (37.0)
B <sub>75-3</sub>	629.7 (10.0)	511.0 (27.0)	440.7 (37.0)	406.0 (42.0)	299.7 (57.2)	2 287.0 (34.7)
B <sub>90-2</sub>	583.1 (16.7)	443.1 (36.7)	373.0 (46.7)	337.4 (51.8)	231.4 (66.9)	1 968.1 (43.8)
B <sub>90-3</sub>	583.2 (16.7)	464.7 (33.6)	393.4 (43.8)	357.4 (48.9)	252.4 (63.9)	2 051.3 (41.4)
B <sub>90-4</sub>	583.2 (16.7)	471.1 (32.7)	401.8 (42.6)	373.1 (46.7)	267.1 (61.8)	2 096.3 (40.1)
Flat planting	700.3	699.7	700.0	699.7	700.0	3 499.7
CD (P = 0.05)	5.6	3.0	2.2	2.5	2.2	9.4

A pre-sowing irrigation of 7 cm (700 m<sup>3</sup>/ha) was applied uniformly in the experimental plot  
 Figures in parentheses are per cent water savings over flat planting

'PBW 343', 'WH 711' and 'WH 1022' were used. The experiment was designed as split-plot with planting patterns in the main plots and wheat cultivars in the sub-plots and the treatments were replicated thrice. The area of the sub-plot was 90 m<sup>2</sup> (7.20 m × 12.5 m).

Soil moisture content was measured at seeding, and before and after each irrigation on the top of the ridge and furrow in furrow irrigated raised bed planting system and between the 2 rows in flat planting by using neutron moisture meter. Water saving (WS) was calculated as:

$$WS = (Q_F - Q_B)/Q_F \times 100,$$

where  $Q_F$  and  $Q_B$  are quantity of water applied in flat planting and furrow irrigated raised bed planting system, respectively. Water productivity of each treatment was determined as the ratio of grain yield to irrigation water applied. Measurements of rates of photosynthesis and transpiration were carried out at anthesis on the flag leaf with a portable photosynthesis system (Infrared gas analyzer, CIRAS-1, PP Systems). Average of 4 leaves sampled represent one replication or plot. Leaf area was also recorded at anthesis by an area meter. The number of spikes/m<sup>2</sup>, ear length, spikelets/spike, grains/spike and 1 000-seed weight were recorded after the final harvest at physiological maturity. The plot was harvested to obtain biological and seed yield. Harvest index was calculated as the ratio of grain to total biological yield.

Data were subjected to analysis of variance (ANOVA) using Online Statistical Analysis Package (OPSTAT, Computer Section, CCS Haryana Agricultural University, Hisar) with level of significance at  $P = 0.05$ . The trend of yield attributes and yields was similar during 2006–08, therefore, pooled analysis of data was carried out.

## RESULTS AND DISCUSSION

### Irrigation water saving

Many advantages of growing wheat on furrow irrigated raised bed planting system over the conventional flat planting in the Indo-Gangetic Plains have been reported (Sayre and Hobbs 2004, Ram *et al.* 2005). Among these, water saving is extremely crucial issue in the Indo-Gangetic Plains, which rely on irrigation water for wheat. As the competition for water between urban and rural areas intensifies and the groundwater tables in most areas are declining, it is very important to use the available water judiciously without affecting the crop yields. In this study, in each irrigation and the total water applied in 5 irrigations in flat planting was significantly higher than furrow irrigated raised bed planting system (Table 1). The quantity of irrigation water applied in successive irrigations sharply decreased in furrow irrigated raised bed planting system, whereas it was more or less same in flat planting. In furrow irrigated raised bed planting system, the quantity of water applied was significantly higher in 75 cm than 90 cm beds, higher in  $B_{75-3}$  than  $B_{75-2}$ , followed by  $B_{90-4}$ ,  $B_{90-3}$  and  $B_{90-2}$  in descending order. Water saving in

furrow irrigated raised bed planting system over flat planting increased with successive irrigations, ranged from 10 to 16.7% in the first irrigation and from 37.2 to 66.9% in the fifth irrigation. Total irrigation water, 43.8% in  $B_{90-2}$ , 41.4% in  $B_{90-3}$ , 40.1% in  $B_{90-4}$ , 37% in  $B_{75-2}$  and 34.7% in  $B_{75-3}$  was saved over the flat planting.

### Availability of soil moisture

Water saving is beneficial only if it does not cause soil or plant water deficit, which adversely affects crop performance. Measurement of soil moisture content showed that water recharge after irrigation was similar in flat planting and furrow irrigated raised bed planting system in the furrows (Fig 2). While on the top of 75 cm beds, soil moisture content was lower than flat planting. This might be due to rapid drying of beds in 75 cm beds than the flats due to their greater surface area and the greater concentration of roots in the bed tops, which resulted into plant water deficit and thereby reduced crop yields (Singh *et al.* 2009). This appeared to be the main reason for lack of adoption of furrow irrigated raised bed planting system by the farmers. Most importantly, soil moisture content on the top of 90 cm beds was higher than that of flat planting and 75 cm beds. This implied that the resistance to water transport from soil to plant was lower in

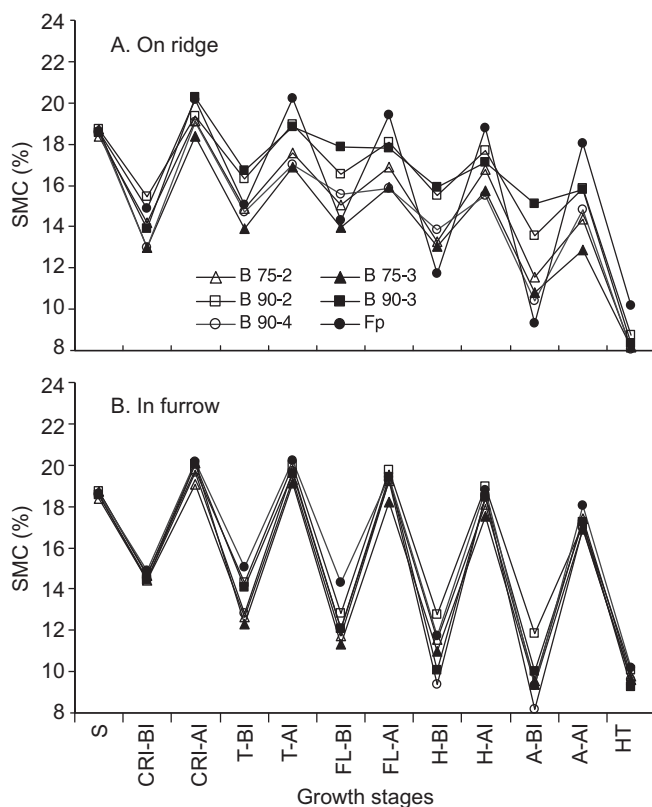


Fig 2 Changes in soil moisture content (SMC) during the growing period in different treatments, A- on ridge and B- in furrow. S, Sowing; CRI, crown root initiation; T, tillering; FL, flag leaf; H, heading; A, anthesis; HT, harvest; BI, before irrigation; AI, 3 days after irrigation.

Table 2 Rates of photosynthesis and transpiration as influenced by planting patterns and wheat cultivars. Measurements were made on the flag leaf at anthesis on a clear day

Planting pattern	Photosynthesis ( $\mu\text{mol}/\text{m}^2/\text{s}$ )				Transpiration ( $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$ )			
	'WH 711'	'WH 1022'	'PBW 343'	Mean	'WH 711'	'WH 1022'	'PBW 343'	Mean
B <sub>75-2</sub>	12.10	13.00	12.33	12.47	7.96	8.96	8.46	8.46
B <sub>75-3</sub>	11.70	12.30	11.83	11.94	7.73	8.10	8.23	8.02
B <sub>90-2</sub>	13.23	14.33	13.40	13.65	7.53	8.53	8.03	8.03
B <sub>90-3</sub>	13.06	14.06	13.36	13.50	7.16	7.80	7.66	7.54
B <sub>90-4</sub>	12.23	12.13	12.30	12.22	7.13	7.03	7.63	7.26
Flat planting	11.96	11.66	12.20	11.94	7.20	7.23	7.70	7.37+
Mean	12.38	12.91	12.57		7.45	7.94	7.95	
CD ( $P = 0.05$ )								
Planting pattern (P)		0.23					0.31	
Cultivar (C)		0.18					0.14	
C at same level of P		0.45					0.36	
P at same level of C		0.43					0.42	

90 cm beds due to greater availability of soil moisture content, which helped the plants to maintain metabolic activities higher than that in flat planting and 75 cm beds. However, it needs to be investigated further.

#### Physiological characters

It is well known that flag leaf is the major contributor to photosynthesis and transpiration after anthesis in wheat (Fang *et al.* 2006). The results of this study revealed that planting patterns B<sub>90-3</sub> and B<sub>90-2</sub> and 'WH 1022' cultivar showed higher rates of photosynthesis than the remaining planting patterns and cultivars (Table 2). The low rates of photosynthesis in 75 cm beds may be due to low soil moisture content and reduced amount of PAR absorbed by the canopy in these treatments, which was itself the consequence of reduced leaf area index (Table 3), (Quanqi *et al.* 2007). Irrespective of bed size transpiration rate was higher in B<sub>75-2</sub> and B<sub>90-2</sub> than B<sub>75-3</sub>, B<sub>90-3</sub>, flat planting and B<sub>90-4</sub>. This indicated that the wider row spacing and fewer leaves (lower leaf area index) resulted into higher evaporation and thus higher transpiration as compared to closer row spacing.

Table 3 Leaf area index as influenced by planting patterns and wheat cultivars during anthesis stage

Planting pattern	Wheat cultivars			Mean
	'PBW 343'	'WH 711'	'WH 1022'	
B <sub>75-2</sub>	4.00	3.97	4.17	4.04
B <sub>75-3</sub>	4.17	4.17	4.37	4.23
B <sub>90-2</sub>	3.77	3.87	3.90	3.84
B <sub>90-3</sub>	5.17	5.07	5.73	5.32
B <sub>90-4</sub>	4.67	4.60	4.70	4.66
Flat planting	4.97	4.97	5.23	5.06
Mean	4.46	4.44	4.68	
CD ( $P = 0.05$ )				
Planting pattern (P)			0.26	
Cultivar (C)			0.10	
C at same level of P			0.24	
P at same level of C			0.32	

Khicher and Ram Niwas (2005) reported that the wider row spacing in bed planting system transmitted more solar radiation to soil surface, which causes higher evaporation from ground, thereby contributing to higher rates of transpiration in widely spaced crop rows. Cultivar 'WH 1022' showed higher transpiration rate than 'WH 711' and 'PBW 343' except at B<sub>90-4</sub> and flat planting, when it was higher in 'PBW 343' than 'WH 1022' and 'WH 711'.

#### Yield attributes and yields

The plants were significantly taller in flat planting and B<sub>90-2</sub> as compared to the remaining planting patterns (Table 4). Ear length was statistically at par in flat planting, B<sub>90-3</sub> and B<sub>75-2</sub> but significantly greater than B<sub>75-3</sub>, B<sub>90-2</sub> and B<sub>90-4</sub>, which showed no differences amongst them. The number of spikelets/spike and the number of grains/spike were significantly higher in B<sub>90-2</sub> than B<sub>90-3</sub>, followed by B<sub>75-2</sub>, flat planting, B<sub>75-3</sub> and B<sub>90-4</sub>. The harvest index was recorded significantly higher in B<sub>90-3</sub> than B<sub>75-3</sub>, B<sub>75-2</sub>, B<sub>90-4</sub>, B<sub>90-2</sub> and flat planting. The latter 4 planting patterns showed similar harvest indices. The grain yield was significantly higher in B<sub>90-3</sub> than flat planting, followed by B<sub>90-4</sub>, B<sub>75-3</sub>, B<sub>75-2</sub> and B<sub>90-2</sub>.

The plants of cultivar 'PBW 343' were taller than the plants of cultivars 'WH 1022' and 'WH 711'. Ear length was also longer in 'PBW 343' than 'WH 1022' and 'WH 711'. No significant difference was found among the cultivars for the number of spikelets/spike and grains/spike and harvest index. Significantly higher grain yield was recorded in 'WH 1022' than 'PBW 343' and 'WH 711'. The latter 2 cultivars showed no differences in grain yield.

The interaction, cultivar $\times$ planting pattern was significant for the number of spikes/m<sup>2</sup> and biological yield. The number of spikes/m<sup>2</sup> was significantly higher in B<sub>90-3</sub> and flat planting as compared to B<sub>90-4</sub>, B<sub>75-3</sub>, B<sub>75-2</sub> and B<sub>90-2</sub>. No significant differences were found for the number of spikes/m<sup>2</sup> between cultivars 'PBW 343' and 'WH 1022' but the 2 cultivars produced higher number of spikes/m<sup>2</sup> than 'WH

Table 4 Yield-attributes, yield and productivity of water as influenced by planting patterns and wheat cultivars

Planting technique/ variety	Plant height (cm)	Ear length (cm)	Number of spikes/ m <sup>2</sup>	Number of spikelets/ spike	Number of grains/ spike	Harvest index (%)	Biological yield (kg/ha)	Grain yield (kg/ha)	Productivity of water (kg/m)
<i>Planting pattern</i>									
B <sub>75-2</sub>	95.63	9.83	344.5	17.11	49.62	37.20	11 925	4 429	1.52
B <sub>75-3</sub>	90.85	8.71	386.3	15.25	39.67	39.29	11 703	4 560	1.53
B <sub>90-2</sub>	97.66	9.04	333.2	19.55	56.71	36.27	12 026	4 357	1.63
B <sub>90-3</sub>	95.44	9.72	445.7	18.66	53.20	42.49	14 575	6 180	2.25
B <sub>90-4</sub>	95.44	8.83	384.7	16.29	39.92	36.67	13 398	4 890	1.75
Flat planting	97.18	10.04	426.1	17.92	48.40	35.11	15 151	5 282	1.26
CD ( <i>P</i> =0.05)	1.21	0.36	19.84	0.59	1.60	2.43	917	343	0.11
<i>'Wheat cultivar'</i>									
'PBW 343'	100.85	9.83	398.4	17.37	47.67	36.55	13 355	4 893	1.64
'WH 711'	88.25	9.03	363.7	17.25	47.36	38.01	12 502	4 736	1.58
'WH 1022'	97.00	9.24	398.2	17.77	48.72	38.92	13 532	5 219	1.75
CD ( <i>P</i> =0.05)	0.84	0.25	10.22	NS	NS	NS	571	206	0.07

711' except in B<sub>75-3</sub> and flat planting. Highest number of spikes/m<sup>2</sup> was produced by the cultivars in B<sub>90-3</sub>. The crop produced significantly higher biological yield in B<sub>90-3</sub> and flat planting as compared to B<sub>90-4</sub>, followed by B<sub>75-2</sub>, B<sub>75-3</sub> and B<sub>90-2</sub>. The biological yield was similar in cultivars 'PBW 343' and 'WH 1022' but significantly higher than 'WH 711'.

In cereals such as wheat grain yield is a function of number of spikes/m<sup>2</sup>, number of grains/spike and seed size, and the latter two traits are decided by the current rates of photosynthesis (depending on leaf area index) and remobilization of stored assimilates, ie, crop biomass. In general, the numbers of spikes/m<sup>2</sup> were statistically similar in B<sub>90-3</sub> and flat planting but higher than the remaining planting pattern under furrow irrigated raised bed planting system. The number of grains/spike was higher in 90 cm than 75 cm beds and flat planting. Three cultivars produced highest leaf area index and maximum number of spikes/m<sup>2</sup> in B<sub>90-3</sub>, which led to higher biological yield in B<sub>90-3</sub>. The improved yield attributes and biological yield resulted into higher grain yield in B<sub>90-3</sub> than flat planting and the remaining planting pattern under furrow irrigated raised bed planting system. Among the cultivars 'PBW 343' and 'WH 1022' produced higher number of spikes and biological yield than 'WH 711' and therefore, higher grain yield. The differences in grain yield among the planting patterns and wheat cultivars may also be related to the differences in leaf area index and the rates of photosynthesis in flag leaf at anthesis (Tables 2, 3). The results have clearly shown that the grain yield of wheat in bed configurations B<sub>75-2</sub>, B<sub>75-3</sub>, B<sub>90-2</sub> and B<sub>90-4</sub> was lower than that in flat planting due to low plant density, but the yield was higher in B<sub>90-3</sub> than flat planting when the former had improved physiological characters and yield-attributes including plant density. Also the yield potential in different planting patterns varied with the tested cultivars of wheat. The cultivars having good tillering and higher rates of photosynthesis, had high biomass production and therefore were more suited for furrow

irrigated raised bed planting system than flat planting. Therefore, there is need to identify cultivars that will grow well on beds to obtain increased water productivity. The crop planted on 90 cm beds with 3 rows on the top of the bed is important in the Indo-Gangetic Plains to achieve sustainable increase in wheat production to meet future demand while conserving natural resources, especially irrigation water for improving livelihood of farmers and reducing the negative effects on the environment.

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