Pak. J. Agri. Sci., Vol. 55(4), 965-972; 2018
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/18.5242
http://www.pakjas.com.pk

IMPROVING CROP WATER PRODUCTIVITY OF MAJOR CROPS BY ADOPTING BED PLANTING IN RECHNA DOAB PAKISTAN

Allah Bakhsh[1,*], Junaid Nawaz Chauhdary[2] and Niaz Ahmad[1]

[1]Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan;
[2]Water Management Research Centre, University of Agriculture, Faisalabad, Pakistan.
[*]Corresponding author's e-mail: bakhsh@uaf.edu.pk

Bed planting, being a proven technology, can increase crop yields and save irrigation water to improve water productivity. The experiments were conducted on three major crops including wheat, cotton and rice in three different cropping zones of Punjab, Pakistan including rice-wheat (Khurrianwala), cotton-wheat (Mungi) and mixed (Killianwala) cropping zone during three cropping seasons of 2008 to 2010. Wheat sown on beds showed significantly better results as compared to that under flat sowing regarding germination rate (117.0/m^2 vs 88.8/m^2), number of tillers (511.1/m^2 vs 421.4/m^2) and dry matter weight (13148 kg/ha vs 11230 kg/ha). Wheat yields under bed planting (4470 kg/ha) was 19.9% more than that under flat sowing (3727 kg/ha). Cotton also showed significantly better performance, when compared with conventional sowing, regarding plant height (125.3 cm vs 110.7 cm) and no of bolls per plant (42.8/plant vs 38.7/plant). Moreover, cotton yield was 12.1% more under bed planting (3779 kg/ha) compared with that under conventional sowing (3371 kg/ha). The results of experiments on rice, revealed that bed planting produced significantly higher number of tillers per square meter (32/m^2) and grain yields (5512 kg/ha) than that under flat sowing (23.9/m^2 and 4242 kg/ha), respectively. Moreover, bed planting produced 29.9% more rice grain yield. The results indicated that wheat, cotton and rice sown under bed planting saved 42.6, 38.7 and 31.5% of irrigation water, respectively. Under bed planting, increase in water productivity was 108, 82 and 90.6% for wheat, cotton and rice, respectively.

Key words: Water resources, irrigation water, bed planting, crop productivity, water productivity, cotton

INTRODUCTION

The food and fiber requirements of Pakistan are increasing because of its population growth rate of 1.85%, which has increased population to 207 million in 2017 and is expected to reach 333 million in 2050 (GOP, 2016-17). To meet demands of the growing population, there is tremendous pressure on land and water resources of the country (Ali *et al*., 2011). The gap between irrigation water demand and supply in Pakistan will reach 6.2 MAF by the year of 2020 (Bhatti *et al*., 2009). Considering higher food demand and irrigation gap, it is need of the time to adopt conservation agriculture instead of conventional agriculture for production of major crops in the country.

Wheat (*Triticum*) is a staple food of Pakistan and constitutes the most important crop that contributed 9.9% to the value added in agriculture and 2% to country's gross domestic product (GDP) with a cultivated area of 9.2 million hectares (GOP, 2016-17). In Pakistan wheat is sown mostly through broadcasting on a large area hence wheat yield in Pakistan is 27% lower as compared with that in many other countries (Arifullah *et al.,* 2009) and even the farmer's yield within the country is 30-35% of the potential yield. Crop and water productivity can be improved by sowing wheat on beds (Chauhdary *et al.,* 2016). Similar to wheat, there is a need to improve yield of other cash crops like cotton which is the most grown crop after wheat in Pakistan.

Cotton (*Gossypium hirsutum* L.) is the Pakistan's leading fiber producing crop and is grown on 2.9 million hectares with an annual production of 10 million bales (GOP, 2016-17). Pakistan stands at fourth position in the world for cotton production (GOP, 2013-14), which can be improved further by increasing the yield. Cotton production is currently at stagnant condition because farmers do not fully follow the improved techniques in an integrated way, which creates a yield gap. In this situation, farmers, researchers, and scientists are looking for new sowing methods or technologies to get higher cotton yield. There is also need to improve water productivity of cotton as currently it is only 0.69 kg/m^3 (Ahmad *et al.,* 2011). Soomro *et al.* (2000) reported that maximum yield and water productivity can be obtained when cotton is sown under bed planting method and plant spacing that is necessary for optimum growth and better aeration. Water productivity is also more important in high delta crops like rice.

Rice (*Oryza sativa*) is the 2nd most important food crop in Pakistan, not only for local consumption but also in view of large exports. In Pakistan, the average production of rice is 2479 kg/ha, which is only 60% of its potential yield (GOP, 2016-17). Due to shortage of irrigation water and low crop

productivity, the production area of rice is restricted to 2.89 million hectare as most of the rice grown under conventional method of flat sowing with heavy flood irrigation that ultimately decreases its water productivity. To increase its productivity, there is a need to adopt improved methods of sowing such as bed planting (Beecher *et al.,* 2006; Bhuyan, *et al*., 2012; Choudhury *et al*., 2007).

Worldwide, bed planting technology is suitable for water saving along with other advantages like better crop stand, easy drainage of excess water after raining, easy weed control and increase in yield. Bed planting has shown a considerable saving of water as compared to conventional sowing method and has eliminated the formation of crust on the soil surface (Ahmad *et al*., 2009; Ashraf, 2014; Fahong *et al*., 2003). Bed planting has several advantages like better fertilizer use efficiency, water distribution efficiency and lesser lodging in comparison to flat sowing (Hobbs and Gupta, 2003; Sayre, 2000; Peries *et al*., 2001). Ahmad and Mahmood (2005) reported better crop stand and yield due to improvement in root proliferation under bed planting. Fahong *et al.* (2003) reported that raised bed technology saves more than 30% of irrigation water and needs lesser seed rate without compromising crop yield as compared with those under flat sowing. Bakhsh *et al*. (2016) also reported better crop and water productivity of major crops under bed planting.

Keeping in view the above discussion, a comparison was made between conventional sowing methods and bed planting to asses potential of bed planting and investigate its effect on yield and water productivity of major crops i.e. wheat, cotton and rice, at farmer fields in different cropping zones of Rechna Doab, Punjab, Pakistan.

MATERIALS AND METHODS

The study was conducted at farmer's fields in Faisalabad, Sheikhupura and Toba Tek Singh districts under the project "On-Farm Research and Development Component of Rehabilitating Lower Chenab Canal System (Part-B)" (Fig. 1), in collaboration with PIDA (Punjab Irrigation & Drainage Authority), funded by JICA (Japan International Co-operation Agency) during three cropping seasons of 2008 to 2010. The project was executed on command area of three distributaries located in three cropping zones of Rechna Doab, including Rice-Wheat zone (commanded by Khurrianwala distributary) distributary), Cotton-Wheat zone (commanded by Mungi distributary) and Mixed cropping zone (commanded by Killianwala distributary).

These sites were facing severe shortage of irrigation water supplies with hot and dry climate. The insufficient and unpredicted rainfall occurs in the area and farmers cannot rely on it for production of their crops. Therefore, farmers use marginal to low quality groundwater (Shakoor *et al.*, 2015) as an alternate of canal water. The soil of the study area was analyzed as sandy loam. The detail of the sites is shown in Figure 1 and Table 1.

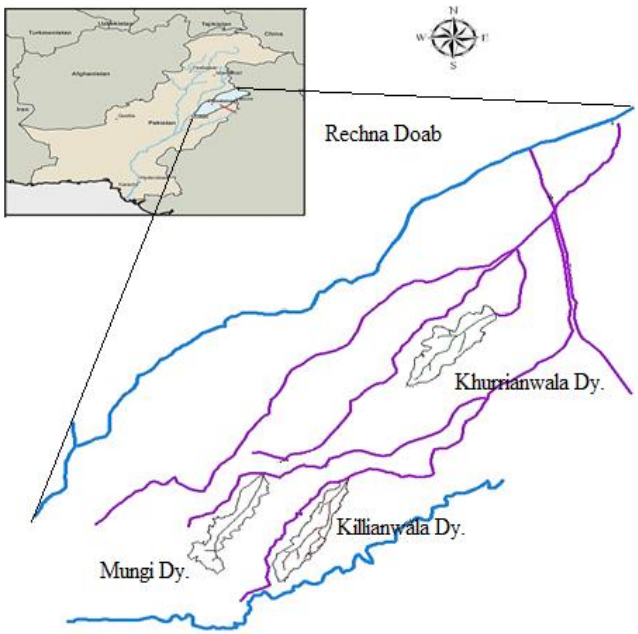

Figure 1. Location of the study sites

To compare the conventional methods of sowing under bed planting, these crops (wheat, cotton and rice) were sown on beds and under conventional methods of sowing. Depending on the crop and crop geometry, the UAF bed planting machine has the provision to make beds from 30 cm to 150 cm and furrows from 20 cm to 30 cm. The management practices were kept constant for crops under bed planting and conventional sowing. The detail of wheat, cotton and

Table 1. Description of study sites.

Cropping zones	Distributary name	District	Major Crops	Length of distributary (km)	Command Area (000 ha)
Rice -Wheat	Khurrianwala Distributary	Sheikhupura	Wheat, rice and sugarcane	37.74	18.88
Mixed crop	Killianwala Distributary	Faisalabad	Wheat, maize, cotton, sugarcane and vegetables	46.06	19.91
Cotton Wheat	Mungi Distributary	Toba Tek Singh	Wheat, cotton and vegetables	36.89	16.85

Table 2. Detail of bed planting.

Crop	Year	Site	No. of farmers	Cumulative Area (ha)	
				Bed planting	Conventional
Wheat	2008	Khurrianwala	12	4.86	4.86
		Mungi	19	7.69	7.69
		Killianwala	7	2.83	2.83
	2009	Khurrianwala	20	8.10	8.10
		Mungi	26	10.53	10.53
		Killianwala	16	6.48	6.48
	2010	Khurrianwala	11	4.45	4.45
		Mungi	21	8.50	8.50
		Killianwala	17	6.88	6.88
	Sub total		149	60.32	60.32
Rice	2008	Khurrianwala	12	4.86	4.86
	2009	Khurrianwala	17	6.88	6.88
	2010	Khurrianwala	31	12.55	12.55
	Sub total		60	24.29	24.29
Cotton	2008	Mungi	19	7.69	7.69
	2008	Killianwala	19	7.69	7.69
	2009	Mungi	21	8.50	8.50
	2009	Killianwala	31	12.55	12.55
	2010	Mungi	21	8.50	8.50
	2010	Killianwala	19	7.69	7.69
	Sub total		130	52.63	52.63
Grand total			339	137.25	137.25

rice sowing are given below (Table 1):

***Wheat sowing*:** Beds and furrows were made by using UAF bed planter following the conventional land preparation. Bed planter was used for direct sowing of wheat along with bed formation in such a way that four rows of wheat were sown on each bed with the following geometry (Fig. 2). The wheat was sown at all the project sites (Khurrianwala, Killianwala and Mungi). The wheat varieties including Sehar, Shafaq, Inqalab, Watan and Bhakkar were sown at all the sites. The trials on wheat were conducted at farmers' fields in such a way that bed planting and flat sowing fields were adjacent to each other to compare both sowing methods. The year wise detail of farmers and cultivated area is given in Table 2.

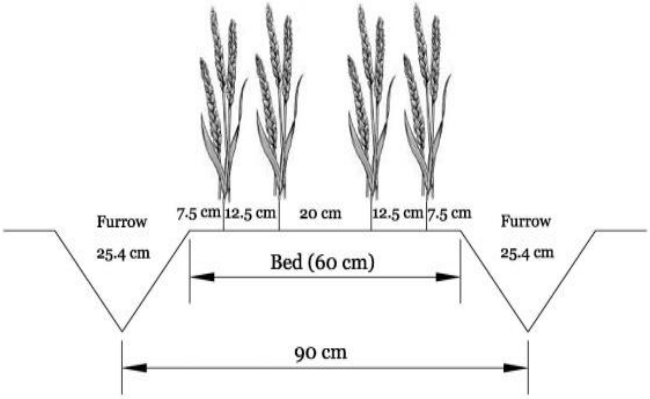

Figure 2. Geometry of wheat lines on bed.

***Rice sowing*:** Similar to cotton, bed planter was used as bed shaper to form beds with geometry of 60 cm bed and 30 cm furrow. After that the 25-30 days mature seedling of rice were transplanted manually on beds in such a way that four lines of rice were placed on bed at a spacing shown in (Fig. 3), like wheat. The plant to plant spacing for rice was 15 cm. The recommended rice verities including Basmati-385, Basmati-2000 and K-S-285 were sown at Khurrianwala site. The detail of farmer fields and cultivated area is given in Table 2. In field, under conventional sowing, the transplanting of rice seedling was done randomly in standing water. On average, the plant population of rice under bed planting was 28/m^2 and under flat sowing; it was 18-20/m^2.

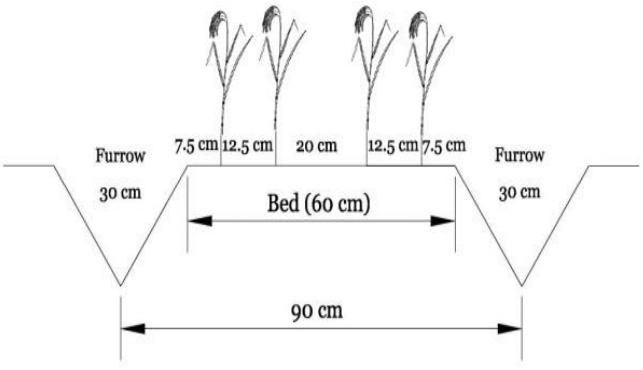

Figure 3. Geometry of rice lines on bed.

***Cotton sowing*:** For cotton sowing, bed planter was used only as bed shaper to form bed of 60 cm with 30 cm furrow. After formation of the beds, the seeds of cotton were sown manually (Choca method) on both edges of bed in zigzag pattern at 30 cm plant to plant spacing. The spacing between lines on bed was 55 cm as shown in figure 4. Whereas under conventional sowing, cotton was sown on beds (75 cm bed with 45 cm furrow) at 70 cm row to row space and 30 cm plant to plant spacing. The plant population of cotton under bed planting and conventional sowing was 7.14/m^2 and 5.38/m^2, respectively. The varieties for cotton including BT-802, BT-701, BT-703, BT-121 and hybrid were sown on both sites (Killianwala and Mungi) during study period of 2008 to 2010.

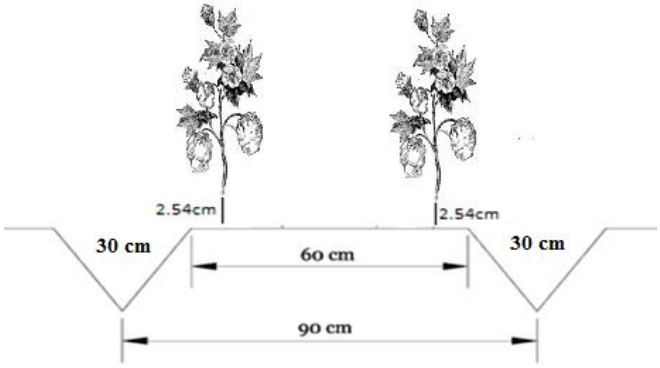

Figure 4. Geometry of cotton lines on bed.

***Data collection*:** The crop data were collected for germination rate, number of tillers/m^2, plant height (cm), dry matter weight (kg/ha) and grain yield (kg/ha) for wheat. The plant height (cm), number of bolls per plant and cotton yield were measured as plant growth parameters for cotton. For rice, number of tillers/m^2 and grain yield (kg/ha) were measured. The detail of these parameters is as under:

***Germination rate*:** Germination rate for wheat was observed by counting germinated seeds per square meter area using one square meter iron frame on beds at three points, randomly selected in the experimental fields. Similarly, control plots were also observed for germination rate for comparison purpose.

***Numbers of tillers*:** Number of tillers is an important growth parameter of wheat and rice. The same procedure was adopted for counting number of tillers as for germination rate. Number of tillers per square meter on bed furrow system was counted at five different locations on randomly selected points at all experimental fields. The same was also done for adjacent control plots for comparison purpose.

***Plant height*:** In cotton, plant height is a good indicator of plant growth because cotton plants mostly grow in vertical direction. Although, it is difficult to measure exact height of cotton plant, however, height of plant was measured from ground surface to the highest plant shoot with metallic measuring tape at crop maturity. These measurements were made for both bed planting and conventional sowing methods.

***Dry matter weight*:** The biomass except kernels after drying is called dry matter weight. For calculation of dry matter weight, wheat samples from 1 m^2 area, were collected and threshed manually with care. After threshing all kernels, the dry matter was dried in oven for 24 hours at 70^0C. After 24 hours, the dry matter was weighed for dry matter analysis.

***Number of bolls per plant*:** Thirty plants were selected randomly in each field under bed planting and conventional sowing. The data regarding number of bolls was counted, stating from first picking till end of the season. The cumulated number of bolls were calculated for each plant.

***Grain/cotton yield*:** Grain yield of wheat and rice were measured by collecting data on per square meter area on beds including all 4-rows randomly at 3 locations in the same field. Adjacent control plots were also selected for comparison purposes. The samples were harvested/threshed/shelled and weighed for grain yield analysis of wheat and rice. For cotton, the number of bolls for each plant were weighed after each picking. At end of the season, weight of all pickings was added to calculate total yield.

***Irrigation application*:** Total water depth of each irrigation for every crop (wheat, rice and cotton) at each site (Khurrianwala, Killianwala and Mungi) was measured. At first, discharge was measured using cut throat flume of 20.32 cm x 7.62 cm size and at second, time of irrigation was recorded with stopwatch for each sowing method. Then volume of irrigation water was calculated from discharge and irrigation time. The depth of water was calculated from volume of irrigation and area under irrigation. Water productivity for each crop was calculated by dividing grain/cotton yield (kg/ha) with total volume of water applied per hectare under that crop regarding bed planting and flat sowing.

$$\text{Water Productivity (WP)} = \frac{\text{Grain yield (kg/ha)}}{\text{Volume of applied water (m}^3\text{/ha)}} \quad (1)$$

The data were analyzed using analysis of variance technique, as used and recommended by many researchers ~~like~~ (Chauhdary *et al*., 2015; Arsalan *et al*., 2016; Chauhdary *et al*., 2017) through SAS 9.1 software to determine significance level of treatment effects on yield, biomass, irrigation depth, and comparison of treatment means was made using least significance difference test at 5% probability level ($LSD_{0.05}$).

RESULTS & DISCUSSION

***Wheat crop*:** It was observed that on the average, germination of wheat per square meter area was 117

plants/m^2 on beds as compared to 88.8 plants/m^2 under flat sowing. Similarly, the number of tillers per square meter under bed planting were significantly more (511.1 tillers/m^2) than that under conventional sowing (421.4 tillers/m^2). Iqbal *et al*. (2010) also reported better germination and number of tillers per square meter on beds. It was noted that bed planting produced 21.2% more tillers than that under conventional sowing. The results for dry matter weight revealed that bed planted fields produced significantly higher dry matter (13148 kg/ha) in comparison with that under conventional sowing (11230 kg/ha). The average percent increase in dry matter weight was found to be 17.1%. Overall, bed planting showed better results for wheat production and crop growth parameters. Results are shown in Table 3.

Average observed yield for wheat under bed planting was 4470 kg/ha and under conventional sowing, it was 3727 kg/ha. The yield increase under bed planting was 19.9% more than that under conventional sowing. The results indicated that major crop like wheat can be successfully grown on bed furrow system. These findings for yield increase under bed planting are in close agreement with the works of Chauhdary *et al*. (2016), who reported 13% more yield under bed planting in comparison to that under conventional flat sowing.

As the application area for irrigation is less under bed planting than that under conventional flat sowing, the water saving under bed planting was 42.6% compared with that under flat sowing. The average total depth of irrigation was 260 mm under bed planting and 453 mm under conventional sowing for wheat. The water saving under bed planting is similar as reported by Fahong *et al.* (2003). The water productivity of wheat under bed planting (1.743 kg/m^3) was significantly better than that under flat sowing (0.838 kg/m^3). Chauhdary *et al*. (2016) conducted experiments on wheat and reported that water productivity under bed planting was higher (2.303 kg/m^3) as compared to that under flat sowing (1.318 kg/m^3).

***Rice crop*:** As the number of plants per square meter under bed planting was more than that under flat sowing, so rice under bed planting has more number of tillers per square meter (32/m^2) than that under flat sowing (23.9/m^2). Similar finding regarding number of tillers/m^2 of rice sown on beds was reported by Bhuyan *et al*. (2012). Borrell *et al.* (1998) reported that under bed planting, there were more number of tillers due to better utilization of nutrients and water.

The yield increase under bed planting over conventional method was 29.9 % as rice yield under bed planting and conventional method was 5512 kg/ha and 4242 kg/ha, respectively. Increase in yield, could be due to production of heavier grains under planting as reported by Zhongming and Fahong (2005) and Meisner *et al.* (2005). Likewise, Choudhury *et al*. (2007) found that rice yield was more due to heavier grain weight. The higher yield for planting rice on beds compared to flat sowing was also reported by Balasubramanian *et al*. (2003), Jat and Sharma (2005) and Tang *et al*. (2005).

It can be seen from Table 4 that average irrigation depth under rice on bed planting to fulfill its crop water requirement (CWR) was 756 mm whereas the same for rice under flat sowing was 1103 mm. The rice under bed planting saved 31.5% irrigation water in comparison to that under flat sowing. The water productivity was 0.732 kg/m^3 under bed planting which is significantly better than that (0.384 kg/m^3) under flat sowing. Similarly, Thompson *et al.* (2003) compared bed planting and flat sowing and found that 14% irrigation water was saved under bed planting. The research work of Bhuyan *et al.* (2012) has shown that bed planting has better water productivity than flat sowing. Likewise, Beecher *et al.* (2006) and Boulala *et al.* (2012) compared

Table 3. Results of wheat yield, yield components and water saving.

Treatments	Plant parameters					
	Germination/ m^2	No. of tillers/ m^2	Dry matter (kg/ha)	Grain Yield (kg/ha)	Irrigation depth (mm)	Water productivity (kg/m^3)
Flat sowing	88.8 b	421.4 b	11230 b	3727 b	453 a	0.838 b
Bed planting	117.0 a	511.1 a	13148 a	4470 a	260 b	1.743 a
LSD	7.87	69.75	1142.8	472.9	44.6	0.266

Treatment mean with different letters are significantly different (p=0.05).

Table 4. Results regarding rice.

Treatment	Plant parameters			
	No. of tillers/ plant	Yield (kg/ha)	Irrigation depth (mm)	Water productivity (kg/m^3)
Flat sowing	23.9 b	4242 b	1103 a	0.384 a
Bed planting	32.0 a	5512 a	756 b	0.732 b
LSD	1.71	745	42.9	0.103

Treatment mean with different letters are significantly different (p=0.05).

Table 5. Results regarding cotton.

Treatment	Plant parameters				
	Plant height (cm)	No. of bolls/ Plant	Yield (kg/ha)	Irrigation depth (mm)	Water productivity (kg/m^3)
Flat sowing	110.7 b	38.7 b	3371 b	532 a	0.637
Bed planting	125.3 a	42.8 a	3779 a	326 b	1.165
LSD	8.40	3.79	299.1	31.6	0.123

Treatment mean with different letters are significantly different (p=0.05).

water productivity under flat and raised bed methods and found that there is a good scope for improving water productivity through rice planting on beds.

***Cotton crop*:** It can be seen from Table 5 that plant height was significantly higher for bed planted fields (125.3 cm) as compared with that under conventional sowing (110.7 cm). The average increase in plant height was 13.2% more than that under bed planting which showed better vegetative growth of cotton. Research work by Anwar *et al.* (2003) also showed similar response of plant height for cotton.

It is clear from data (Table 5) that number of bolls per plant were significantly higher under bed planting. The cotton under bed planting produced 10.6% more number of bolls per plant as compared to conventional sowing. The average number of boll at Mungi and killianwala for three years (2008-2010) were 42.8/plant under bed planting and 38.7/plant under conventional sowing. Findings of Ahmad *et al.* (2011) and Dutt *et al*. (2004) are also in accordance with the experiment results regarding number of boll per plant.

The cotton yield under bed planting was significantly higher (3779 kg/ha) and produced 12.1 % more yield than that under conventional method of ridge sowing (3371 kg/ha). The increase in cotton yield could be due to higher no of bolls per plant, which showed its better reproductive growth under bed planting. The results are in line as reported by Ahmad (2004), Ali *et al*. (2010), Chauhan (2007), Dong *et al*. (2008) and Gill (1999) regarding better crop yield.

Like water saving for wheat under bed planting, in cotton crop 38.7 % irrigation water was saved. The 326 mm depth of irrigation was applied under bed planting throughout the season as compared to 532 mm under conventional sowing method. As the crop yields increased and irrigation water was saved under bed planting, so water productivity was also improved to 1.165 kg/m^3, compared with 0.637 kg/m^3 under conventional ridge sowing. Makhdum *et al.* (2004) conducted experiments on cotton sown on raised beds and concluded that 32 % irrigation can be saved. Ahmad *et al.* (2011) reported 33.8% water saving in cotton sown on beds during two year study.

***Conclusions*:** Based on data collected from field experiments conducted in Rechna Doab, the following conclusions were drawn:

- Wheat, cotton and rice yields on beds were 19.9, 12.1 and 29.9% higher, respectively, than those under conventional flat sowing.
- Bed planting saved 42.6, 38.7 and 31.5% irrigation water under wheat, cotton and rice, respectively, in comparison to those under flat sowing.
- The water productivity under bed planting for wheat, cotton and rice was 1.743, 1.165 and 0.732 kg/m^3, respectively, compared with 0.838, 0.637 and 0.384 kg/m^3, respectively under conventional sowing. Under bed planting, increase in water productivity was 108, 82 and 90.6% for wheat, cotton and rice, respectively.

***Acknowledgement*:** The authors express their sincere appreciations to the UAF administration and all farmers, for their cooperation during execution of the project and particularly to the funding agency "JICA (Japan International Co-operation Agency)" for their financial support and making field visits by JICA officials during project duration.

REFERENCES

Ahmad, N. 2004. Water and disasters: Innovative water saving techniques for sustainable agriculture. Proceedings of one day Seminar on World water day, 8 Apr. 2004, University of Agriculture, Faisalabad, Pakistan; pp 56-64.

Ahmad, N. and N. Mahmood. 2005. Impact of raised bed technology on water productivity and lodging of wheat. Pak. J. Water Res. 9:1-9.

Ahmad, N., M. Arshad and M.A. Shahid. 2009. Bed-furrow system to replace conventional flood irrigation in Pakistan. Proceedings of 20th ICID Conference, 6-11 Dec. 2011. 59th IEC Meeting, New Dehli, India.

Ahamd, N., M. Arshad and M.A. Shahid. 2011. Raised bed technology for crop water productivity of maize and cotton. ICID 21st International Congress on Irrigation and Drainage, 15-23 Oct. 2011, Tehran, Iran.

Ali, M., L. Ali, M. Sattar and M.A. Ali. 2010. Response of seed cotton yield to various plant populations and planting methods. J. Agric. Res. 48:163-169.

Ali, A., F. Rehman, M. Nasir and M.Z. Ranjha. 2011. Agricultural policy and wheat production: a case study of Pakistan. Sarh. J. Agric. 27:201-211.

Anwar, M.M., M.I. Gill and M.S. Zaki. 2003. Effect of bed-furrow planting on cotton crop. The Pak. Cotton Grower 47:41-46.

Arifullah, S.A., A.F. Chishti, M. Zulfiqar, G. Yaseen, N. Farid and I. Ahmad. 2009. Estimating yield potential of major crops and its implication for Pakistan's crops sector. Sarhad J. Agric. 25:611-615.

Arsalan, M., S. Ahmed, J.N. Chauhdary and M. Sarwar. 2016. Effect of vermicompost and phosphorus on crop growth and nutrient uptake in mung bean. J. Appl. Agric. Biotechnol. 1:38-46.

Ashraf, M. 2014. Promising land and water management practices: A manual. International Center for Agricultural Research in Dry Areas (ICARDA); Country Office, Pakistan.

Bakhsh, A., M. Rizwan, N. Ahmad and J.N. Chauhdary. 2016. Improved on-farm water management practices for major crops in pakistan. Proceedings of 2nd World Irrigation Forum (WIF2), W.1.4.07, November 6-8, 2016, Chiang Mai, Thailand.

Balasubramanian, V., J.K. Ladha, R.K. Gupta, R.K. Naresh, R.S. Mehla and Y.B. Singh. 2003. Technology option for rice in the rice-wheat systems in Asia. In: Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact. Am. Soc. Agron. Special Publ. 65:115-148.

Beecher, H.G., B.W. Dunn, J.A. Thompson, E. Humphreys, S.K. Mathews and J. Timsina. 2006. Effect of raised beds, irrigation and nitrogen management on growth, water use and yield of rice in south-eastern Australia. Aust. J. Exp. Agric. 46:1363-1372.

Bhatti, A.M., P. Suttinon and S. Nasu. 2009. Agriculture water demand management in Pakistan: a review and perspective. J. Soc. Social Manage. Syst. 172:1-7.

Bhuyan, M.H.M., M.R. Ferdousi and M.T. Iqbal. 2012. Yield and growth response to transplanted Aman rice under raised bed over conventional cultivation method. ISRN Agron. DOI: 10.5402/2012/646859.

Borrell, A.K., R.M. Kelly and D.E. Van Cooten. 1998. Improving management of rice in semi-arid eastern Indonesia: Responses to irrigation, plant type and nitrogen. AusT. J. Exp. Agric. 38:261-271.

Boulala, H., H. Gómez-Macphersona and F.J. Villalobosa. 2012. Permanent bed planting in irrigated Mediterranean conditions: short-term effects on soil quality, crop yield and water use efficiency. Field Crops Res. 130:120-127.

Chauhdary, J.N., A. Bakhsh, N. Ahmad and K. Mehmood. 2015. Optimizing chlorine use for improving performance of drip irrigation system under biologically contaminated water source. Pak. J. Agri. Sci. 52:829-835.

Chauhdary, J.N., U.D. Khan, S.H.H. Shah, M.A. Shahid and M. Arsalan. 2016. Effect of sowing methods and seed rates on wheat yield and water productivity. Qual. Assu. Saf. Crop. Food 8:267-272.

Chauhdary, J.N., A. Bakhsh, M. Arshad and M. Maqsood. 2017. Effect of different irrigation and fertigation strategies on corn production under drip irrigation. Pak. J. Agri. Sci. 54:855-863.

Chauhan, S.K. 2007. Seeding technique under saline water irrigation for cotton- wheat rotation. Bhar. Kris. Anu. Pat. 22:273-276.

Choudhury, B.U., B.A.M. Bouman and A.K. Singh. 2007. Yield and water productivity of rice-wheat on raised beds at New Delhi, India. Field Crops Res. 100:229-239.

Dong, H., W. Li, W. Tang and D. Zhang. 2008. Furrow seeding with plastic mulching increases stand establishment and lint yield of cotton in saline field. Agron. J. 100:1640-1646.

Dutt, Y., X.D. Wang, Y.G. ZHU and Y.Y. LI. 2004. Breeding for high yield and fibre quality in colored cotton. Plant Breed. 123:145-151.

Fahong, W., W. Xuquing and K.D. Sayre. 2003. Comparison study on two different planting methods for winter wheat in China. Bed Planting Course, CIMMYT, Mexico.

Hobbs, P.R. and R.K. Gupta. 2003. Rice-wheat cropping systems in the Indo-Gangetic Plains: Issue of water productivity in relation to new resource-conserving technologies. In: J.W. Kijne, R. Barker and D. Molden (eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI, Wallingford, UK; pp.239-253.

Gill, M.I. 1999. Bed and furrow planting method ensures profitable seed cotton yield. Pak. Cotton Grower 3:10-11.

GOP. 2013-14. Pakistan Economy Survey. Govt. of Pakistan, Finance Division, Economic Advisor's Wing, Islamabad, Pakistan.

GOP. 2016-17. Pakistan Economy Survey. Govt. of Pakistan, Finance Division, Economic Advisor's Wing, Islamabad, Pakistan.

Iqbal, N., N. Akbar, M. Ali, M. Sattar and L. Ali. 2010. Effect of seed rate and row spacing on yield and yield components of Wheat (*Triticum aestivum* L.). J. Agric. Res. 48:151-156.

Jat, M.L. and S.K. Sharma. 2005. On-farm studies on FIRB system for improving crop and water productivity and profitability in rice-wheat cropping system. 3rd Regional Technical Coordination Committee Meeting of RWC for the IGP, Technical Coordination Committee, Dhaka, Bangladesh.

Makhdum, M.I. 2004. Response of some cultivars to sulphate of potash and murate of potash. Ph.D. Diss., Dept. Agron., Bahauddin Zakariya University, Multan, Pakistan.

Meisner, C.A., H.M. Talukdar and I. Hossain. 2005. Introduction and implementing a permanent bed system in the rice-wheat cropping pattern in Bangladesh and Pakistan. ACIAR Workshop on Permanent Bed Planting Systems, Griffith, NSW, Australia.

Peries, R., B. Chris and W. Bruce. 2001. Raised bed cropping leading to improved root proliferation in heavy duplex soils prone to water logging. 6th Symposium of the International Society of Root Research Nagouya, Nov. 2001, Japan.

Sayre, K.D. 2000. Effects of tillage, crop residue retention and nitrogen management on the performance of bed-planted, furrow irrigated spring wheat in northwest Maxico. 15th Conference of the International Soil Tillage Research Organization, 2-7 JulY, 2000. Fort Worth, Texas, USA.

Shakoor, A., M. Arshad, A. Bakhsh and R. Ahmed. 2015. GIS based assessment and delineation of groundwater quality zones and its impact on agricultural productivity. Pak. J. Agri. Sci., 52:1-7.

Soomro, A.R., A.W. Soomro, A.M. Memon, M.H. Arain and A.A. Memon. 2000. Yield response of four cotton cultivars under varying plant spacing at CCRI, Sakrand Sindh. Pak. J. BioL. Sci. 3: 1807-1808.

Tang, Y.L., J.G. Zheng and G. Huang. 2005. Studies on permanent-bed-planting with double zero tillage for rice and wheat in Sichuan basin. Southwest China J. Agric. Sci. 18:25-28.

Thompson, J., D. Griffin and S. North. 2003. Improving the water use efficiency of rice. Technol. Rep. 1204, Cooperative Research Centre for Sustainable Rice Production, Yanco, NSW, Australia.

Zhongming, M. and W. Fahong. 2005. Raised bed- planting system for irrigated spring wheat in Hexi Corridor. ACIAR Workshop on Permanent Bed Planting Systems, Griffith, NSW, Australia.