# Water Conservation Through Bed Plantation in Rice-Wheat Croppping System of the Upper Indus Basin


Zamir Ahmed Somroo
Muhammad Ashraf
Zia ul Haq
Khuram Ejaz



Pakistan Council of Research in Water Resources
2019

Citation:

Soomro, Z. A., M. Ashraf, Zia ul Haq, K. Ejaz (2019). Water Conservation through Bed Plantation in Rice-Wheat Cropping System of the upper Indus Basin. Pakistan Council of Research in Water Resources (PCRWR), Islamabad, pp.44.



ISBN: 978-969-8469-71-9

# Water Conservation Through Bed Plantation in Rice-Wheat Cropping System of the Upper Indus Basin


**Zamir Ahmed Soomro**
**Dr. Muhammad Ashraf**
**Zia ul Haq**
**Khuram Ejaz**



**Pakistan Council of Research in Water Resources, Islamabad**

**2019**

# Table of Contents

# List of Tables

# List of Figures

# FOREWORD

Rice and wheat are the most important crops in Pakistan and are directly related to the food security of the country. Rice cultivated area has increased from 1.5 million hectares (Mha) in 1970 to 2.9 Mha in 2017. Similarly, its production has increased from 2.2 million tons (MT) in 1970 to 7.5 (MT) in 2017. During 1970, the wheat cultivated area and production was 5.9 Mha and 6.5 MT, respectively which have increased to 8.8 Mha and 25 MT, respectively during 2017. The average yield of rice increased from 1466 kg/ha in 1970 to 2568 kg/ha in 2017 whereas wheat yield has increased from 1079 kg/ha in 1970 to 2795 kg/ha in 2017.

The horizontal and vertical expansion of rice and wheat has tremendous pressure on the existing surface and groundwater resources. As no new reservoir has been built after 70s, there were no additional surface water supplies to meet the growing water demand of these two crops. Therefore, the pressure was shifted to the groundwater to supplement canal water supplies. As a result, groundwater started depleting in many canal commands.

The rice is considered to be a high-water requiring crop. With this mindset, farmers keep on water standing in rice fields resulting into huge seepage and evaporative losses. Infact, rice water requirement in central Punjab is only 480 mm whereas in the Lower Indus Basin, it is 1200-1400 mm. Similarly, wheat water requirements in the central Punjab is 421 mm whereas it is 388 mm in the Lower Indus Basin.

The farmers normally apply 2-3 times more water to wheat crop and 6-10 time more water to rice crop than their actual requirements. This is mainly due to the flat sowing/ conventional methods of irrigation and lack of knowledge about irrigation scheduling. At the verge of growing water scarcity and competing demands between the various sectors, the existing irrigation practices are no longer a viable option.

Pakistan Council of Research in Water Resources (PCRWR) through a series of experiments proved that the existing water use of these crops could be reduced by more than 50% simply shifting to bed plantation. The report provides an insight into technical and economic benefits that can be derived by adopting bed plantation technique.

Dr. Muhammad Ashraf
Chairman, PCRWR

# ACKNOWLEDGMENTS

The authors would like to acknowledge Pakistan Council of Research in Water Resources and Ministry of science and Technology, Government of Pakistan for providing infrastructure and support for the study. The services of Mr. Fazal Hussain, Field Assistant and his fellow workers in data collection are highly acknowledged. The authors are also thankful to Mr. Tariq Mahmood, APS, Mr. Zeeshan Munawar and Mr. Hamid, DEO, PCRWR for formatting the report.

# CHAPTER - 1

## 1 INTRODUCTION

Wheat followed by rice occupies the area over 26 million hectares (Mha) in South and East Asia to meet their food demand (Timsina and Connor, 2001). About 240 million people in South Asia consume rice and/or wheat produced in rice-wheat system (Benites, 2001). In Pakistan, about 2.90 Mha area is under rice-wheat cropping system. Pakistan has agrarian rural based economy wherein; agriculture sector contributes about 20% to the GDP and absorbs 44% of the labour force whereas; about 60% of the rural population derived their livelihood from agriculture (GoP, 2012).

To meet the growing wheat demand, global production needs annual growth rate of 1.6% to 2.6% which can be mainly achieved through improvement in water productivity. Agriculture sector in Pakistan is continuously under stress due to the low yield of crops as compared to other developed countries (Ather *et al.,* 2006). Increasing population has increased the water demand for industrial and domestic users. In this scenario, low water productivity in agriculture is a great concern.

The shortage of canal water in many areas forced the farmers to rely on groundwater (Taj *et al.,* 2005; Ashraf, 2016). As no new water storage has been built over the last forty years, the increasing requirement of food can only be met by increasing in crop production per unit of water applied. This can be achieved through adoption of innovative irrigation technologies (Farooq *et al.,* 2006; Ashraf, 2016). On average, the world's rice fields use around 1.4 $m^3$ of water for producing 1 kg of rice with water use efficiency (WUE) of 0.71 kg/$m^3$ whereas the WUE of rice in Pakistan is less than 0.45 kg/$m^3$. In case of Basmati rice, the WUE is even as low as 0.08 kg/$m^3$ found in the Lower Bari Doab Canal (LBDC) command (Ashraf *et al*., 2010).

The planting of crops on raised beds is one of the improved irrigation techniques. It is being practiced for all crops, all over the world and is an effective and improved irrigation method with several advantages. Bed plantation is an efficient irrigation method which increases the yield and reduces the crops lodging risk (Hobbs and Gupta, 2003a; Naresh *et al.,* 2017). Studies in the USA have shown considerable water saving with irrigated rice on raised beds over conventional flooding (Vories *et al.,* 2002). Recent research activities in India and Pakistan showed many advantages of bed planting in rice-wheat systems. It improves water distribution and water use efficiency, fertilizer use efficiency, reduced weed infestation and lodging (Gupta *et al*., 2000; Hobbs and Gupta, 2003b).

Pakistan Council of Research in Water Resources (PCRWR) conducted series of experiments for planting of rice and wheat on the beds during 2010-17 at its Research and Demonstration (R&D) Centre Sialmore, Sargodha (Punjab) with the objectives to identify the potential of raised beds in terms of yield and WUE in rice-wheat cropping system in the Indus Basin.

# CHAPTER - 2

## 2 MATERIALS AND METHODS

### 2.1 Study Site

The Research and Demonstration Centre of PCRWR is located in village Hayatpur near Sialmore, district Sargodha, Pakistan at latitude 31.95° E, longitude 73.11° N and altitude of 189 m above mean sea level (Figure1). Major Crops of the district are; wheat, rice and sugarcane but farmers also produce some other crops and vegetables. The Centre falls in Chaj Doab (the area between Chenab and Jhelum rivers). The soil of the Centre is non-saline, sandy loam, having average pH value of 7.9 and Electrical Conductivity (EC) of about 2.0 $dSm^{-1}$. Groundwater is the only source of irrigation. Being adjacent to River Chenab, the groundwater is of good quality; EC of groundwater is 0.85 $dSm^{-1}$, pH 7.5, sodium absorption ratio (SAR) 3.20, and residual sodium carbonate (RSC) of 3.0 meq/l.

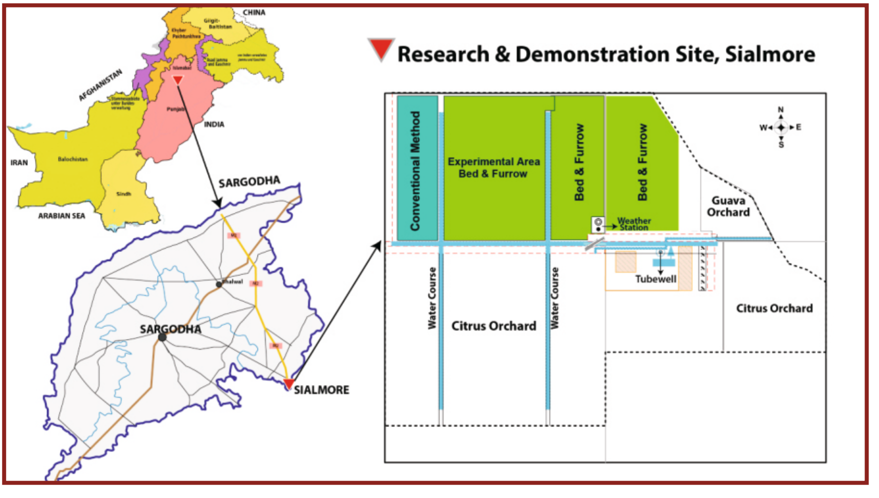



*Figure 1: Location map of the experimental site*

## 2.2 Climate Parameters

The study area is characterized by semi-arid climate; where more than 80% of the rainfall occurs during the monsoon season (June to September). Temperature rises up to 50 °C (122 °F) in the summer whereas in winter the minimum temperature recorded is as low as freezing point. PCRWR has established a hydro-meteorological station at the farm that provides data on temperature (min & max), relative humidity, rainfall, pan evaporation and water-table depth.

During the study period (2010-17) climatic data collected from PCRWR weather station was used in the report. However, for estimating of $ET_0$ by Cropwat model, additional parameters like wind speed and sunshine hours were obtained from the website https://www.worldweatheronline.com/. Average monthly temperature (min & max) and relative humidity of eight years of the study period are presented in Figure 2. Similarly, the monthly average rainfall and $ET_0$ estimated by pan evaporation and Cropwat model are presented in Figure 3. A class pan evaporation was stationed at the farm and reference evapotranspiration ($ET_0$) was computed by multiplying the pan coefficient ($K_p$ = 0.85) with pan evaporation. The pan coefficient value was taken from Food and Agriculture Organization http://www.fao.org/docrep/ X0490E/x0490e08 htm# TopOfPage.

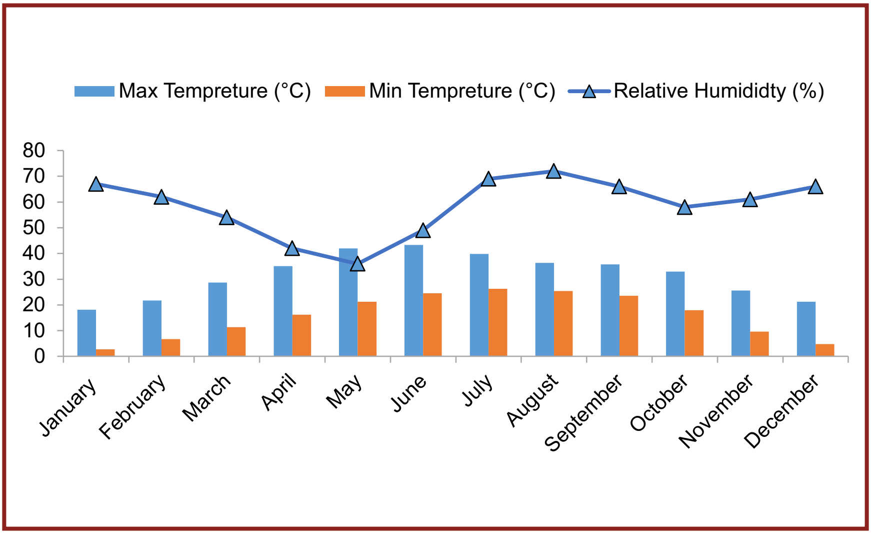



*Figure 2: Monthly average temperature and relative humidity (2010-17)*

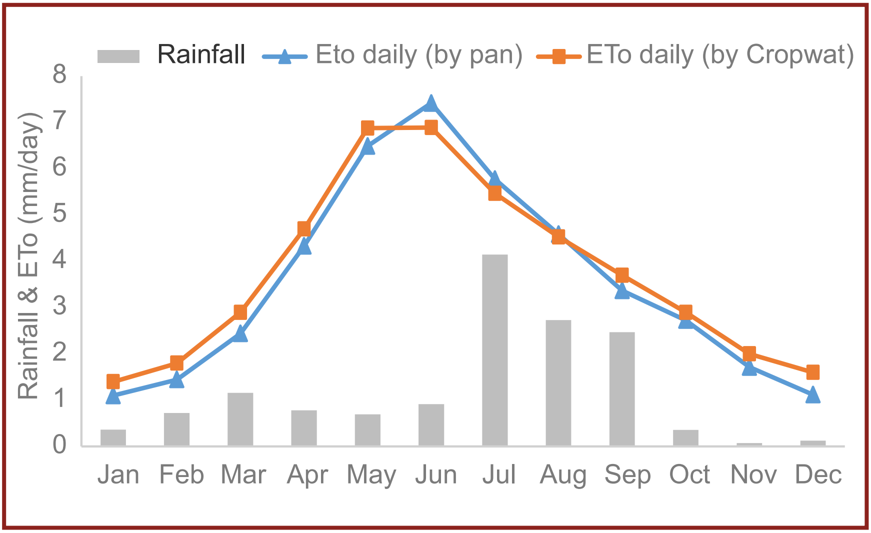



*Figure 3: Monthly average rainfall and $ET_0$ during study period (2010-17)*

A piezometer was installed at the Centre in the year 2007 to record the water-table depth. Figure 4a shows year wise fluctuation of water-table depth. The water-table depth was 6.4 m in the year 2007 which declined at average rate of 0.13 m per year up to 2010. Then a heavy flood occurred and consequently water-table rose to 6.1 m in the year 2011. Similarly, another flood occurred in the year 2014 and again water-table raised up to 5.8 m. After the flood 2014, declining trend can be seen in Figure 4a. Overall declining trend of water-table is observed except flooding years. Similarly, Figure 4b shows that overall the water-table level has been raised after each monsoon season except 2017 where comparatively less monsoon rainfalls were received.

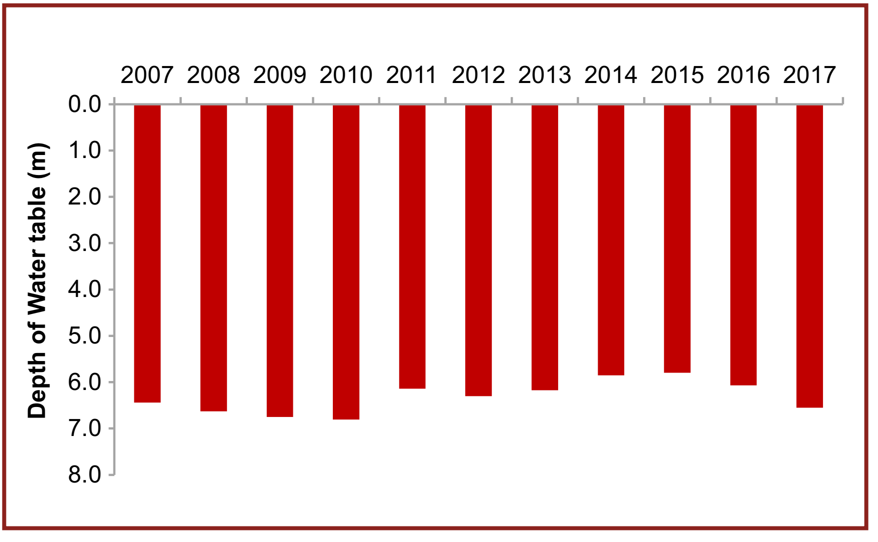



*Figure 4a: Average annual water-table depth (2007-17)*

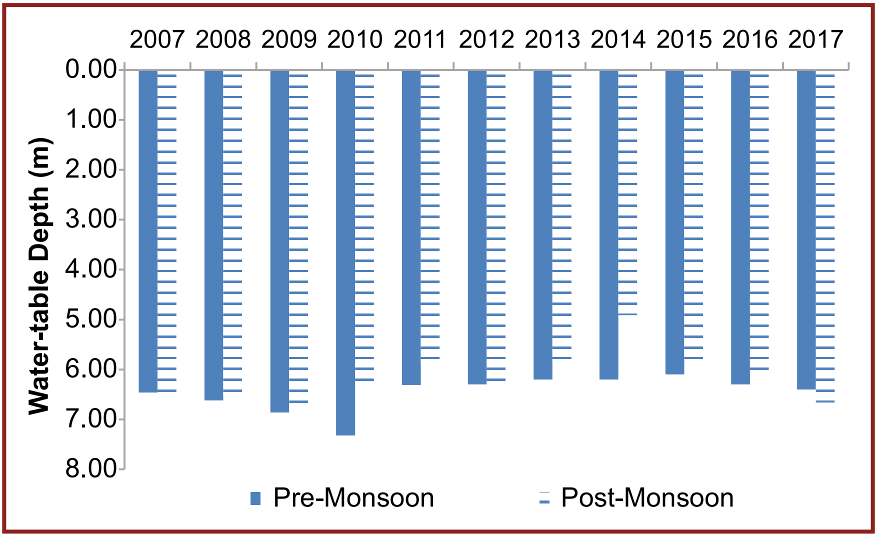



*Figure 4b: Pre-monsoon and post-monsoon water-table depth (2007-17)*

## 2.3 Agronomic Parameters and Practices

**2.3.1. Experimental Layout and Treatments:** Wheat followed by rice crops were grown during the study period (2010-17) under two treatments of irrigation methods viz. (i) bed planting and (ii) conventional. In case of rice crop, the crop was grown by flood irrigation in the conventional treatment whereas for wheat crop, zero tillage method was adopted using flood irrigation. The plots for each treatment were earmarked 0.5 ha in both the crops. In addition to above two treatments, the information on prescribed template (Annex-1 and 2) was collected from farmers during the year 2016-17 regarding water application, yield of crop and inputs etc. to compare it with the experiments. Ten farmers were selected in the vicinity of PCRWR Centre whose interviews were conducted on seasonal basis.

**2.3.2. Land Preparation:** The experimental plots were precisely leveled by LASER Land Leveler once a year (after harvesting of wheat crop). The crop stubbles were not removed from the field. However, the harvested residue (wheat or rice straw) was removed from field before land preparation. The crop wise land preparation practices are described as follows;

a) **Wheat:** Immediately after harvesting of rice crop and removing its straw from field; four ploughings were made with tractor mounted tine harrow followed by planking. Calibrated bed planting drill was used to drill the seed and fertilizer simultaneously (Figure. 5a&b). Wheat under zero tillage method was sown by zero tillage seed drill without any cultivation. However, farmers used traditional broadcast method to sow the wheat crop under the conventional/flood irrigation. At Research Farm, the wheat crop was sown on residual moisture of rice crop available in the soil. No soaking (pre-planting) irrigation was applied in both the treatments before sowing. Seed at the rate of 125 kg/ha. was used equally in all treatments.

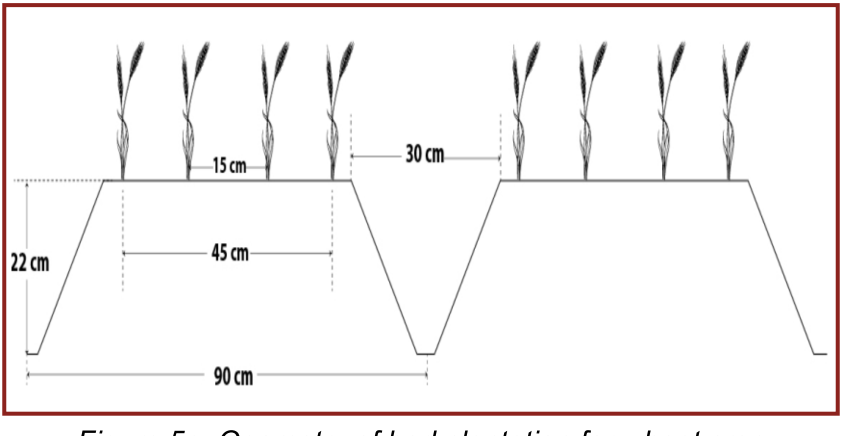



*Figure 5a: Geometry of bed plantation for wheat crop*

*Figure 5b: Bed plantation of wheat crop*

b) **Rice:** There is a gap of about three months between wheat harvest and rice transplantation. After harvesting of wheat crop, the land was ploughed twice with the help of tractor mounted tine harrow and left fallow. About one week earlier to transplantation of rice seedlings, the land was leveled by LASER land leveler and ploughed thrice followed by a planking. The prepared land was further processed for conventional and bed plantation of rice as follows;

i. ***Conventional:*** Soaking irrigation was applied on prepared land to maintain standing water in the field. On the next day of soaking irrigation, the land was ploughed twice to puddle the soil. Irrigation supplement was continued as needed to maintain the standing water in the field. The developed nursery of 30 days was transplanted manually by maintaining plant to plant and row to row distance of approximately 23 cm. The farmers followed their traditional way of sowing without maintaining proper spacing.

ii. ***Bed plantation:*** In conventionally prepared land (dry) as above, the beds and furrows were prepared using the bed shaper. The top width of beds and furrows were adjusted at 30 cm with a height of 22 cm at the time of preparation (Figure 6a&b). The beds were prepared a day before the transplantation of the rice nursery. Irrigation water was applied in the furrows up to 2/3$^{rd}$ height of beds a day before transplantation as well to attaining optimum moisture level. About thirty days old rice nursery was carefully transplanted. Four rows were developed on each bed with a row-to-row distance of 12 cm and plant-to-plant distance of 22 cm (Figure 6a).

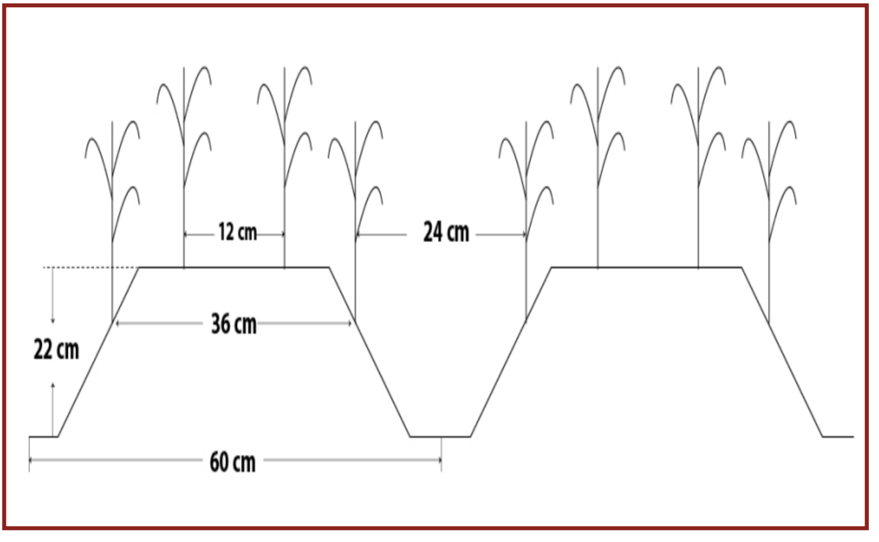



*Figure 6a: Geometry of bed plantation for rice crop*

Figure 6b: Bed plantation of rice crop

## 2.4 Irrigation

Irrigation scheduling was based on soil moisture deficit (SMD), monitored through tensiometers and the evapotranspiration estimated from the pan evaporation. In wheat crop irrigation was applied at 50% SMD, whereas for rice, the irrigation was applied daily in furrows till the establishment of crop (about two weeks). Then irrigation interval gradually increased and scheduling was set at 50% SMD. In conventional plots, standing water was maintained during crop period in accordance with the conventional practices while farmers applied flood irrigation by traditional method.

The tubewell discharge was measured by volumetric method. The amount of water applied in each irrigation was determined. Irrigation in all plots was discontinued at ripen stage of the crop.

## 2.5 Water Use Efficiency and Economic Analysis

The crop yield was determined on whole plot basis and the average yield of each treatment was calculated. Water use efficiency was estimated on the basis of yield obtained against the water used for the crop. Similarly, cost of production and income was compared for the economic benefit. The cost of production included the cost of water and non-water inputs from planting to harvesting of the crop. Similarly, the income includes income from the grain and the biomass.

## 2.6 Agronomic Parameters

Information on agronomic parameters such as date of sowing and harvesting and plant growth parameters for wheat and rice crops were recorded in each cropping season for all the experiments (Table 1).

## 2.7 Soil Analysis

The soil samples were collected by using manual auger from each experimental plot at the depth of 0-15 cm and 16-30 cm pre-sowing and post harvesting of each crop. The samples were analyzed in District Soil Laboratory Sargodha of Agriculture Department, Government of Punjab. The soil samples were analyzed for Electrical Conductivity ($EC_e$), pH, Organic Matter (OM), Phosphorus (P) and Potassium (K).

## 2.8 Data from Farmers Field

A part from the conventional plots (control) at the R&D Farm, five farmers were selected from the surrounding areas and their irrigation practices were recommended for comparing with crops grown at R&D Farm.

Table 1. Agronomic parameters recorded in each season for rice and wheat crops

| Rice crop | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | | 2017 | | |
| Sowing Method | BP | Conv. | BP | Conv. | BP | Conv. | BP | Conv. | BP | Conv. | BP | Conv. | BP | Conv. | Farmer | BP | Conv. | Farmer |
| Variety | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Basmati Pak | Kainaat 1121 | Kainaat 1121 | Kainaat 1121 | Kainaat 1121 | Kainaat 1121 | Kainaat 1121 | Kainaat 1121 | Kainaat 1121 |
| Date of sowing of nursery | 20-Jun | 20-Jun | 08-Jun | 06-Jun | 11-Jun | 11-Jun | 09-Jun | 09-Jun | 05-Jun | 05-Jun | 22-May | 22-May | 25-May | 25-May | 19-May | 02-Jun | 02-Jun | 04-Jun |
| Date of transplantation | 28-Jul | 26-Jul | 25-Jul | 27-Jul | 01-Aug | 02-Aug | 21-Jul | 22-Jul | 20-Jul | 21-Jul | 05-Jul | 03-Jul | 01-Jul | 02-Jul | 28-Jun | 14-Jul | 19-Jul | 13-Jul |
| Date of harvesting | 05-Nov | 05-Nov | 09-Nov | 09-Nov | 12-Nov | 12-Nov | 18-Nov | 18-Nov | 09-Nov | 09-Nov | 19-Oct | 19-Oct | 25-Oct | 25-Oct | 19-Oct | 30-Oct | 30-Oct | 27-Oct |
| Plant population (plants/ha) | * | * | * | * | 230,000 | 150,000 | 200,000 | 130,000 | 220,000 | 170,000 | 210,000 | 170,000 | 220,000 | 160,000 | * | | 210,000 | * |
| Average tillers per plant | * | * | * | * | 15 | 17 | 14 | 16 | 16 | 17 | 12 | 15 | 16 | 18 | * | | 20 | * |

| Wheat crop | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2009-10 | | 2010-11 | | 2011-12 | | 2012-13 | | 2013-14 | | 2014-15 | | 2015-16 | | | 2016-17 | | |
| Sowing Method | BP | ZT | BP | ZT | BP | ZT | BP | ZT | BP | ZT | BP | ZT | BP | ZT | Farmer | BP | ZT | Farmer |
| Seed rate (kg/ha) | 100 | 100 | 100 | 100 | 100 | 100 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 | 125 |
| Variety | Seher 2006 | Seher 2006 | Seher 2006 | Seher 2006 | Seher 2006 | Seher 2006 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 | FSD-2008 |
| Date of sowing | 22-Nov | 11-Nov | 9-Nov | 14-Nov | 30-Nov | 23-Nov | 06-Nov | 24-Nov | 30-Nov | 26-Nov | 27-Nov | 27-Nov | 5-Nov | 5-Nov | 11-Nov | 18-Nov | 18-Nov | 11-Nov |
| Date of harvesting | 2-May | 2-May | 28-Apr | 28-Apr | 1-May | 1-May | 24-Apr | 24-Apr | 16-May | 19-May | 28-Apr | 28-Apr | 25-Apr | 26-Apr | 30-Apr | 29-Apr | 30-Apr | 22-Apr |
| Plant population (plants/ha) | * | * | * | * | 950,000 | 760,000 | 1,050,000 | 800,000 | 800,000 | 580,000 | 1,040,000 | 720,000 | 1,150,000 | 850,000 | * | 1,200,000 | 880,000 | * |
| Average tillers per plant | * | * | * | * | 6 | 6 | 5 | 6 | 6 | 7 | 5 | 5 | 4 | 4 | * | 5 | 4 | * |

*Data not recorded; BP = Bed Plantation; ZT = Zero Tillage; Conv. = Conventional Sowing at R&D Centre; Farmer = Conventional Sowing at Farmer's Field; FSD = Faisalabad wheat on beds and 315 to 318 mm of water to conventional plots.

Soil moisture depletion and irrigation applied for both the treatments in wheat is presented in Figure 7. The straight horizontal line indicates the maximum allowable deficit which was set at 50% SMD. Whereas, actual soil moisture depletion before irrigation for different treatments have been shown in bar chart. The soil moisture depletion and depth of water applied have been calculated on monthly basis by taking the average of irrigation applied during the month.

*Figure 7: Moisture deficit and irrigation depth applied to wheat crop*

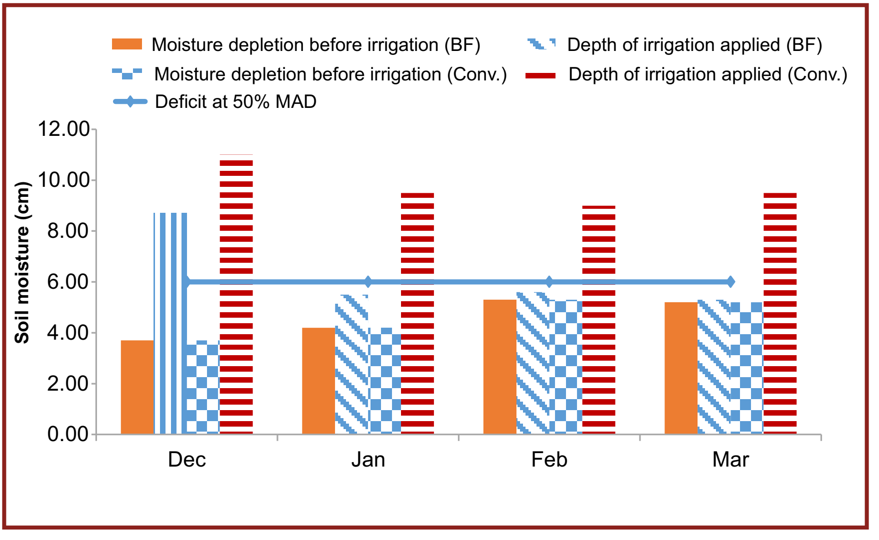
Statistical analysis (t test) was carried out at 95% confidence interval. On average, the difference in amount of water applied is significant between conventional and bed plantation. Depth of water applied is significantly higher in conventional sowing in comparison to bed plantation (Table 2).

### 3.1.2 Rice

On average 1190 mm and 1700 mm water was applied under bed plantation and conventional methods respectively whereas farmers applied 2370 mm water at their fields under conventional sowing (Table 3). The results indicate 30% and 50% water saving in bed plantation of rice crop with respect to conventional treatment at center and farmer practice, respectively. Ultimately, 11,800 $m^3$ water was saved per hectare. In Pakistan rice is grown on about 2.89 Mha. If, 50% of the rice area is brought under bed plantation, on average 7 BCM water can be saved in a year. Figure 8 shows the soil moisture depletion and irrigation applied for both methods. In addition to irrigation applied, average rainfall of 329 mm was received during the crop season.

*Figure 8: Moisture deficit and irrigation depth applied to rice crop*

The crop water requirement of rice in Pakistan is 500 mm to 1500 mm depending on the agro-climatic conditions (Soomro *et al.,* 2018). However, in Pakistan farmers are applying 2-3 times or even more water to rice crop than its actual requirements in a growing season (Ashraf *et al*., 2010; 2014).




There is myth that rice needs standing water to grow. With this mindset, the farmers keep water standing in the fields, resulting into loss of huge amount of precious water, either as deep percolation or evaporation. This is not only the wastage of water but also the wastage of precious nutrients present in the soil (Ashraf and Saeed, 2006).

Bed planting [illegible] on of irrigation water in the field. So[illegible] years (2011-13) experim[illegible] that rice crop consumed [illegible] nder bed and conventiona[illegible] (2009) reported tha[illegible] conventional methods we[illegible] (2012), conducted [illegible] district of Bangladesh[illegible] planting rice and reporte[illegible] 430 mm water was applied [illegible] mm, thereby showing wa[illegible] (2017) also found throu[illegible] pending up on soil type wate[illegible] 0 to 40%.

Statistical a[illegible] reveals that on average, the[illegible] is significant between co[illegible] of water applied is [illegible] sowing in comparison [illegible] significant difference b[illegible] arch farm and farmer pract[illegible]

Table 2: Water applied, yield and water use efficiency (WUE) in bed plantation (BP), zero tillage (ZT) and conventional (Farmer) sowing for wheat crop

| Year | Total water applied (cm) | | | Yield (kg/ha) | | | WUE (kg/m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | BP | ZT | Farmer | BP | ZT | Farmer | BP | ZT | Farmer |
| **2009-10** | 25$^a$ | 38 | - | 4150$^a$ | 3952$^a$ | - | 1.66$^a$ | 1.04$^b$ | - |
| **2009-11** | 24$^a$ | 40$^b$ | - | 4084$^a$ | 3689$^b$ | - | 1.73$^a$ | 0.92$^b$ | - |
| **2011-12** | 26$^a$ | 38$^b$ | - | 3754$^a$ | 3689$^a$ | - | 1.42$^a$ | 0.97$^b$ | - |
| **2012-13** | 25$^a$ | 39$^b$ | - | 3912$^a$ | 4110$^a$ | - | 1.55$^a$ | 1.05$^b$ | - |
| **2013-14** | 22$^a$ | 37$^b$ | - | 3760$^a$ | 3325$^b$ | - | 1.71$^a$ | 0.89$^b$ | - |
| **2014-15** | 24$^a$ | 41$^b$ | - | 3644$^a$ | 3149$^b$ | - | 1.52$^a$ | 0.77$^b$ | - |
| **2015-16** | 27$^a$ | 39$^b$ | 46$^c$ | 3924$^a$ | 3688$^{ab}$ | 3683$^b$ | 1.45$^a$ | 0.95$^b$ | 0.80$^c$ |
| **2016-17** | 25$^a$ | 40$^b$ | 44$^c$ | 3886$^a$ | 3794$^a$ | 3616$^b$ | 1.55$^a$ | 0.95$^b$ | 0.82$^c$ |
| ***Average*** | ***25$^a$*** | ***39$^b$*** | ***45$^c$*** | ***3889$^a$*** | ***3675$^{ab}$*** | ***3651$^b$*** | ***1.57$^a$*** | ***0.94$^b$*** | ***0.81$^c$*** |

*Means with the same letters are not significantly different at P ≤ 0.05*

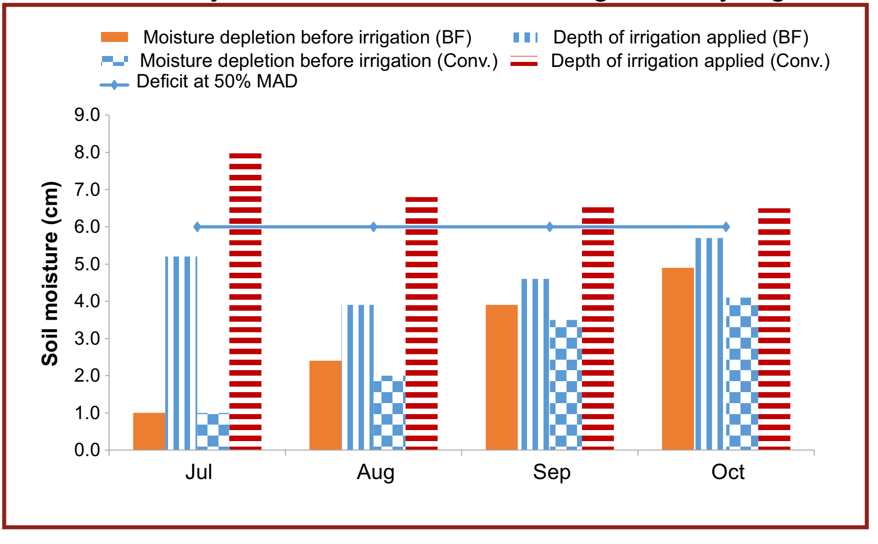
## 3.2 Water [illegible]

Water Use [illegible] that tells how precisely th[illegible] for crop production. [illegible] hed from a unit volume [illegible] that 40%

and 48% higher WUE was obtained in bed plantation of wheat as compared to zero tillage and conventional methods, respectively (Table 2). Naresh *et al.,* (2017) reported WUE of wheat crop in India as 2.20 kg/m$^3$ and 1.29 kg/m$^3$ for bed plantation and conventional sowing, respectively.

On average WUE of rice crop grown on beds was 0.33 kg/m$^3$ whereas conventional practice at research farm produced 0.23 kg/m$^3$ and WUE at farmer's fields was 0.17 kg/m$^3$. It is evident that WUE under bed plantation was 30% and 47% higher as compared to conventional treatment at research farm and farmer's fields, respectively (Table 3). Naresh *et al.,* (2017) reported WUE of rice crop in India as 0.67 kg/m$^3$ and 0.57 kg/m$^3$ for bed plantation and conventional sowing, respectively.

Statistical analysis reveals that WUE is significantly higher in




bed plantation as compared to conventional sowing and farmer's field for both rice and wheat crops (Tables 2 & 3).

The WUE can be improved either by increasing crop yield or by reducing the amount of water applied without affecting the crop yield (Molden *et al*., 2010). Researchers found that better timing of irrigation and controlling amount of water applied can improve irrigation efficiency and water productivity with little additional cost (Jensen, 2007; Vazifedoust *et al*., 2008; Rockstrom *et al*., 2007). Suweis *et al*., (2013) reported that increase in water productivity through agricultural practices improved the sustainability of trade of the water rich countries. Qureshi (2011) affirms that the only way to achieve food security is to increase land and water productivity by introducing water conservation technologies such as precision land leveling, zero tillage and bed planting.

## 3.3 Economic Analysis

The economic analysis has been carried out for individual treatments/methods of irrigation. Total cost of production (water and non-water), gross income (grain and straw) and net return are considered for economic analysis. It was found that bed plantation of rice increased net income by 12% and 68% as compared to conventional methods at research farm and farmer's field, respectively (Table 5). Naresh *et al.,* (2017) also reported that net profit for rice crop in India was IRs 37200 and 60% higher for bed plantation as compared to conventional method. Mollah *et al.,* (2009) reported highest benefit-cost ratio in bed planting for 70 cm wide beds (1.97) and the lowest in conventional method (1.61) for rice.

For wheat, there was 5% and 20% increase in net income in beds plantation as compared to zero tillage and farmer's field, respectively (Table 4). Similarly, Majeed *et al.,* (2015) reported that economic return of wheat crop was 29% higher in bed planting as compared to flat planting. While many researchers also reported lower costs of production for wheat crop in bed planting w[illegible] ran[illegible] fr[illegible] 2[illegible] to [illegible]0% compared to convention[illegible] tho[illegible] Ree[illegible] *et* [illegible], 20[illegible]; Sayre, 2003 and Connor *et* [illegible] 03) [illegible] ore[illegible] r, M[illegible] ah [illegible] *l.,* (2009) reported highest be[illegible] ost [illegible] o[illegible] ed p[illegible] ting [illegible] 70 cm wide beds (2.67) and [illegible] ves [illegible] con[illegible] ntio[illegible] me[illegible] d (1.90) for wheat. Recently, M[illegible] *et* [illegible] (20[illegible]) als[illegible] epo[illegible] d that net profit per acre for wh[illegible] op i[illegible] ndia [illegible] s 2[illegible] hig[illegible] r for bed plantation in comparis[illegible] con[illegible] tion[illegible] sow[illegible]

The statis[illegible] naly[illegible] re[illegible] als [illegible] t fo[illegible] ice there was no significant [illegible] nce [illegible] gro[illegible] nco[illegible] for [illegible] (three) methods of sowing. Ho[illegible] r, si[illegible] fica[illegible] diffe[illegible] nce [illegible] s found in cost of water for a[illegible] ment[illegible] The[illegible] was [illegible] so a [illegible] gnificant difference in cost of p[illegible] tion [illegible] d n[illegible] nco[illegible] be[illegible] en bed plantation and farmer[illegible] tice [illegible] able [illegible]

Similarly fo[illegible] at, s[illegible] istic[illegible] ana[illegible] is r[illegible] als non-significant difference [illegible] oss [illegible] eco[illegible] for [illegible] ll t[illegible] tments. However, significant [illegible] enc[illegible] was [illegible] ound [illegible] n c[illegible] of water for all treatments [illegible] ove [illegible] igni[illegible] nt c[illegible] eren[illegible] was also observed in cost of p[illegible] tion [illegible] d n[illegible] nco[illegible] e be[illegible] een bed plantation and farmer[illegible]

When cost[illegible] ction cost, then there is significant difference in net income of bed plantation as

Table 3: Water applied, yield and water use efficiency (WUE) in bed plantation (BP), conventional (Conv.) at R&D Centre and farmer's conventional (Farmer) sowing for rice crop

| Year | Total water applied (cm) | | | Yield (kg/ha) | | | WUE (kg/m³) | | |
|---|---|---|---|---|---|---|---|---|---|
| | BP | Conv. | Farmer | BP | Conv. | Farmer | BP | Conv. | Farmer |
| 2010 | 121[a] | 172[b] | - | 3480[a] | 3320[a] | - | 0.29[a] | 0.19[b] | - |
| 2011 | 108[a] | 141[b] | - | 3580[a] | 3340[a] | - | 0.33[a] | 0.24[b] | - |
| 2012 | 124[a] | 157[b] | - | 4972[a] | 4784[a] | - | 0.40[a] | 0.30[b] | - |
| 2013 | 103[a] | 135[b] | - | 3917[a] | 3640[a] | - | 0.38[a] | 0.27[b] | - |
| 2014 | 118[a] | 169[b] | - | 2986[a] | 3160[a] | - | 0.25[a] | 0.19[b] | - |
| 2015 | 132[a] | 179[b] | - | 3952[a] | 4290[a] | - | 0.30[a] | 0.24[b] | - |
| 2016 | 129[a] | 199[b] | 240[c] | 4624[a] | 4578[a] | 3903[a] | 0.36[a] | 0.23[b] | 0.16[c] |
| 2017 | 118[a] | 205[b] | 234[b] | 3864[a] | 3804[a] | 4372[a] | 0.33[a] | 0.19[b] | 0.19[b] |
| ***Average*** | ***119[a]*** | ***170[b]*** | ***237[c]*** | ***3921[a]*** | ***3865[a]*** | ***4137[a]*** | ***0.33[a]*** | ***0.23[b]*** | ***0.17[c]*** |

Means with the same letters are not significantly different at P= 0.05

compared to farmer's practice. The net income of bed plantation increased Rs. 64,571 and Rs. 15,900 per hectare in case of rice and wheat crops, respectively.

### 3.4 Soil Analysis

The soil samples were collected from the plots under trial before sowing and after the harvesting of each crop. The ECe increased from 1.3 to 1.7 dS/m and 1.5 to 1.8 dS/m for bed plantation and conventional fields, respectively (Figure 9). Statistical analysis reveals that there was no significant variation in ECe for both the treatments. Similarly, the variation in pH was observed in both treatments but statistically there was no significant difference in pH during the study period. Soil fertility (i.e. organic matter, phosphorus and potassium) fluctuated slightly in both the treatments but there was no significant change over the study period (Figure 10).

*Figure 9: Electrical conductivity (ECe) and pH of the soil*

*Figure 10: Organic matter, phosphorus and potassium of soil*

(Devkota *et al.,* 2015) conducted a study in cotton-wheat-maize rotation system (2007-09) with two tillage methods; permanent raised beds (PB) and conventional tillage (CT) combined with two residue levels (residue harvested and residue retained). In the absence of crop residues, soil salinity under PB increased as compared to CT whereas by retaining crop residues under PB, the soil salinity reduced by 22% as compared to CT without crop residue retention. They concluded that PB with residues retention is a promising option to slow down soil salinization in the irrigated arid lands.

### 3.5 General Discussion

Wheat and rice are the major staple crops in Pakistan. The rice-wheat cropping system is a major water user in the country. However, the low crops yield associated with low water use efficiency have been the major challenges. Flood irrigation system, keeping water standing in rice fields, improper farm layout and lack of knowledge about irrigation scheduling are the major causes of low yield and water use efficiency.

Bed plantation of the crops is one of the improved surface irrigation techniques having several advantages, being practiced for almost all crops over the world. In the current study, on average 250 mm water was applied to wheat crop under bed plantation, 390 mm in zero tillage whereas 450 mm in farmers field under conventional practices. Besides, on average 118 mm rainfall was received during the season. As such, 140 mm (36%) and 200 mm (45%) less water was applied in bed plantation as compared to zero tillage and conventional methods of irrigation, respectively. Therefore, the wheat crop on bed plantation saved about 200 mm (2000 $m^3$/ha) of water as compared to conventional irrigation method. The wheat crop is sown on an area of about 9.2 Mha in Pakistan. If 50% (4.6 Mha) of the wheat crop area is converted to bed plantation, on average 9.2 billion cubic meters (BCM) water can be saved during the wheat cropping season.

There is myth that rice needs standing water to grow. With this mind set, the farmers keep water standing in the fields, resulting into loss of huge amount of precious water, either as deep percolation or evaporation. The farmers are applying 2-3 times or even more water to rice crop than its actual requirements in a growing season (Ashraf *et. al*., 2010; 2014). This is not only the wastage of water but also the wastage of precious nutrients present in the soil (Ashraf and Saeed, 2006).

In the current study, on an average 1190 mm water was applied to rice crop grown on raised beds, whereas 1700 mm water was applied in conventional method at PCRWR R&D Centre (control) and 2370 mm at farmer's field. In addition, there was average rainfall of 329 mm which was assumed uniform over all the fields. Therefore, 510 mm (30%) and 1180 mm (50%) less water was applied in bed plantation as compared to control and the farmer's field, respectively. This is the scenario where only groundwater is available and the farmers have to pay huge energy cost for the operation of tube wells. However, in canal command area, water application to rice is much more (Ashraf *et al*., 2010).

In Pakistan rice is grown on about 2.89 Mha. Bed plantation saved 1180 mm (11,800 $m^3$/ha) of water. If 50% of the total rice area is converted to bed plantation, on average 17 BCM water can be saved from rice cropping season.

In groundwater command area, cost of water plays vital role towards net income of the farmers. In Pakistan, groundwater is free and [illegible] st is [illegible] ly f[illegible] pum[illegible] g of [illegible] groundwater (energy, repair a[illegible] nte[illegible] ce [illegible] the [illegible] e w[illegible]. By adding water pumpin[illegible] sar[illegible] out [illegible] t (ab[illegible] t Rs [illegible] m), the net income of bed p[illegible] on w[illegible] Rs. [illegible] ,57[illegible] nd [illegible] 15,900 per hectare more f[illegible] ar[illegible] whe[illegible] re[illegible] ctiv[illegible] as compared to conven[illegible] ract[illegible] s by [illegible] rme[illegible] Ag[illegible] If we consider to bring 50[illegible] a of [illegible] e ar[illegible] whe[illegible] crop[illegible] 1.45 and 4.6 Mha, respect[illegible] nde[illegible] ed p[illegible] tatic[illegible] the [illegible] income of Rs 167 billion p[illegible] can [illegible] ncr[illegible] ed.

There [illegible] ap[illegible] hen[illegible] the [illegible] mers and some profess[illegible] hat [illegible] oppir[illegible] n b[illegible] ma[illegible] ead to salinity build up over[illegible] owe[illegible], ou[illegible] ight[illegible] ars [illegible] dy shows that there is no ch[illegible] suc[illegible] salin[illegible] buil[illegible] p in [illegible] ice-wheat cropping system.

The be[illegible] nolo[illegible] is [illegible] nev[illegible] n P[illegible] stan. A number of internat[illegible] atio[illegible] and [illegible] ovin[illegible] org[illegible] zations has proved its effe[illegible] ss. [illegible] wev[illegible] the [illegible] ues[illegible] remains how to upscale [illegible] ricu[illegible] e E[illegible] nsic[illegible] Dep[illegible] ments have been establis[illegible] all p[illegible] ince[illegible] up t[illegible] e g[illegible] sroots level. Infact; agricult[illegible] tens[illegible] se[illegible] ces [illegible] e [illegible] igned to increase farmers [illegible] edg[illegible] and [illegible] lls [illegible] ncr[illegible] e farm production through [illegible] ed [illegible] icul[illegible] l pr[illegible] ices[illegible] owever, their main focus ha[illegible] on [illegible] n-wa[illegible] inp[illegible] and [illegible] e efficient irrigation has nev[illegible] on [illegible] rag[illegible] da.

Moreov[illegible] t 90[illegible] farm[illegible] in [illegible] ista[illegible] w[illegible] less than 5 ha of land. Th[illegible] planters. These

Table 4: Economic analysis for wheat crop

| Year | Non water cost (PKR/ha) | | | Water cost (PKR/ha) | | | Total production cost (PKR/ha) | | | Gross income (PKR/ha) | | | Net Income (PKR/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BP | ZT | Farmer | BP | ZT | Farmer | BP | ZT | Farmer | BP | ZT | Farmer | BP | ZT | Farmer |
| 2009-10 | 45100$^a$ | 41600$^a$ | - | 4375$^a$ | 6650$^b$ | - | 49475$^a$ | 48250$^a$ | - | 114125$^a$ | 108680$^a$ | - | 64650$^a$ | 60430$^a$ | - |
| 2009-11 | 45160$^a$ | 41660$^a$ | - | 4139$^a$ | 7000$^b$ | - | 49299$^a$ | 48660$^a$ | - | 117415$^a$ | 106059$^a$ | - | 68116$^a$ | 57399$^b$ | - |
| 2011-12 | 45800$^a$ | 41990$^a$ | - | 4626$^a$ | 6650$^b$ | - | 50426$^a$ | 48640$^a$ | - | 122395$^a$ | 110449$^a$ | - | 61969$^a$ | 61809$^a$ | - |
| 2012-13 | 54900$^a$ | 50340$^a$ | - | 5059$^a$ | 7800$^b$ | - | 59959$^a$ | 58140$^a$ | - | 134964$^a$ | 141795$^a$ | - | 75005$^a$ | 83655$^a$ | - |
| 2013-14 | 58010$^a$ | 52770$^b$ | - | 4400$^a$ | 7400$^b$ | - | 62410$^a$ | 60170$^a$ | - | 138180$^a$ | 122194$^b$ | - | 75770$^a$ | 62024$^b$ | - |
| 2014-15 | 56570$^a$ | 51510$^b$ | - | 5400$^a$ | 9225$^b$ | - | 61970$^a$ | 60735$^a$ | - | 128451$^a$ | 111002$^b$ | - | 66481$^a$ | 50267$^b$ | - |
| 2015-16 | 51750$^a$ | 46620$^b$ | 54340$^a$ | 6750$^a$ | 9750$^b$ | 11500$^b$ | 58500$^a$ | 56370$^a$ | 65840$^b$ | 137340$^a$ | 129080$^a$ | 128983$^a$ | 78840$^a$ | 72710$^a$ | 63143$^b$ |
| 2016-17 | 54541$^a$ | 49291$^b$ | 56193$^a$ | 6250$^a$ | 10000$^b$ | 11000$^b$ | 60791$^a$ | 59291$^a$ | 67193$^b$ | 139663$^a$ | 136356$^{ab}$ | 129962$^b$ | 78872$^a$ | 77065$^a$ | 62769$^b$ |
| ***Average*** | ***51479$^a$*** | ***46973$^a$*** | ***55266$^b$*** | ***5125$^a$*** | ***8059$^b$*** | ***11250$^c$*** | ***56604$^a$*** | ***55032$^a$*** | ***66516$^b$*** | ***127817$^a$*** | ***132718$^a$*** | ***129473$^a$*** | ***78856$^a$*** | ***74888$^a$*** | ***62956$^b$*** |

Means with the same letters are not significantly different at P = 0.05

Table 5: Economic analysis for rice crop

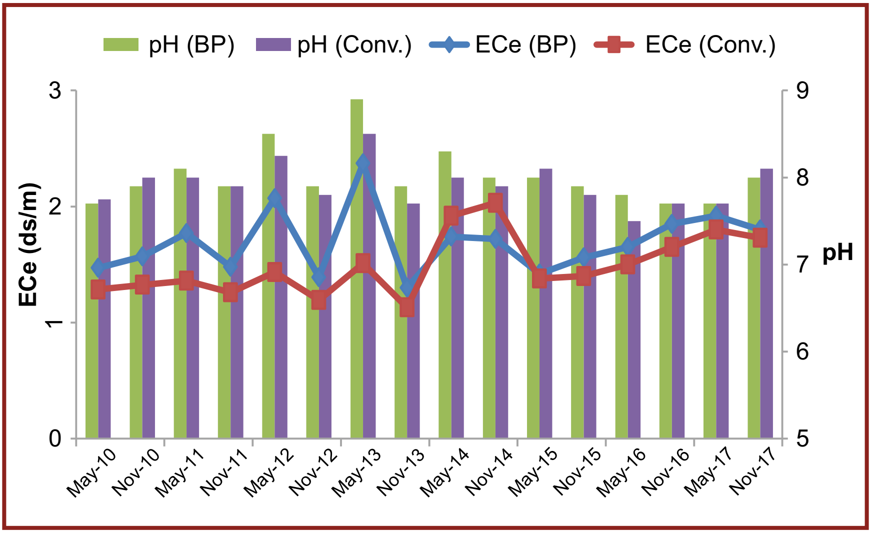
| Year | Non water cost (PKR/ha) | | | Water cost (PKR/ha) | | | Total production cost (PKR/ha) | | | Gross income (PKR/ha) | | | Net Income (PKR/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **BP** | **Conv.** | **Farmer** | **BP** | **Conv.** | **Farmer** | **BP** | **Conv.** | **Farmer** | **BP** | **Conv.** | **Farmer** | **BP** | **Conv.** | **Farmer** |
| **2010** | 51930$^{a}$ | 49290$^{a}$ | - | 21175$^{a}$ | 30100$^{b}$ | - | 73105$^{a}$ | 79390$^{a}$ | - | 146160$^{a}$ | 139440$^{a}$ | - | 73055$^{a}$ | 60050$^{a}$ | - |
| **2011** | 53501$^{a}$ | 49734$^{a}$ | - | 18900$^{a}$ | 24675$^{a}$ | - | 72401$^{a}$ | 74409$^{a}$ | - | 143200$^{a}$ | 133600$^{a}$ | - | 70799$^{a}$ | 59191$^{a}$ | - |
| **2012** | 54676$^{a}$ | 51090$^{a}$ | - | 21700$^{a}$ | 27475$^{a}$ | - | 76376$^{a}$ | 78565$^{a}$ | - | 228727$^{a}$ | 220064$^{a}$ | - | 152351$^{a}$ | 141499$^{a}$ | - |
| **2013** | 59379$^{a}$ | 55412$^{a}$ | - | 20600$^{a}$ | 27000$^{a}$ | - | 79979$^{a}$ | 82412$^{a}$ | - | 244813$^{a}$ | 227500$^{a}$ | - | 164834$^{a}$ | 145089$^{a}$ | - |
| **2014** | 62880$^{a}$ | 62055$^{a}$ | - | 23640$^{a}$ | 33880$^{b}$ | - | 86520$^{a}$ | 95935$^{a}$ | - | 179100$^{a}$ | 187200$^{a}$ | - | 92580$^{a}$ | 91265$^{a}$ | - |
| **2015** | 69022$^{a}$ | 68045$^{a}$ | - | 29790$^{a}$ | 40208$^{b}$ | - | 98812$^{a}$ | 108253$^{a}$ | - | 162032$^{a}$ | 175890$^{a}$ | - | 63220$^{a}$ | 67638$^{a}$ | - |
| **2016** | 69314$^{a}$ | 70058$^{a}$ | 73483$^{a}$ | 32300$^{a}$ | 49670$^{b}$ | 59978$^{b}$ | 101614$^{a}$ | 119728$^{b}$ | 133460$^{b}$ | 194208$^{a}$ | 192276$^{a}$ | 163909$^{a}$ | 92594$^{a}$ | 72548$^{a}$ | 30449$^{b}$ |
| **2017** | 75498$^{a}$ | 76255$^{a}$ | 76817$^{a}$ | 29500$^{a}$ | 46250$^{b}$ | 58500$^{b}$ | 104998$^{a}$ | 122505$^{b}$ | 135317$^{b}$ | 157191$^{a}$ | 152661$^{a}$ | 166132$^{a}$ | 52193$^{a}$ | 30156$^{a}$ | 30815$^{a}$ |
| ***Average*** | ***62025$^{a}$*** | ***60242$^{a}$*** | ***75150$^{b}$*** | ***24701$^{a}$*** | ***34907$^{b}$*** | ***59239$^{c}$*** | ***86726$^{a}$*** | ***95150$^{a}$*** | ***134389$^{b}$*** | ***181929$^{a}$*** | ***178579$^{a}$*** | ***165021$^{a}$*** | ***95203$^{a}$*** | ***83429$^{a}$*** | ***30632$^{b}$*** |

Means with the same letters are not significantly different at P = 0.0

small farmers look towards the Agriculture Service Providers (ASPs) who provide services on rental basis. However, these ASPs neither own such machinery nor they have proper skill to operate these machinery (e.g. calibration of the bed planter before use in the field). Therefore, proper training of the ASPs in the use of such machinery and some kind of subsidy on the machinery will be helpful for its wide scale adoption.

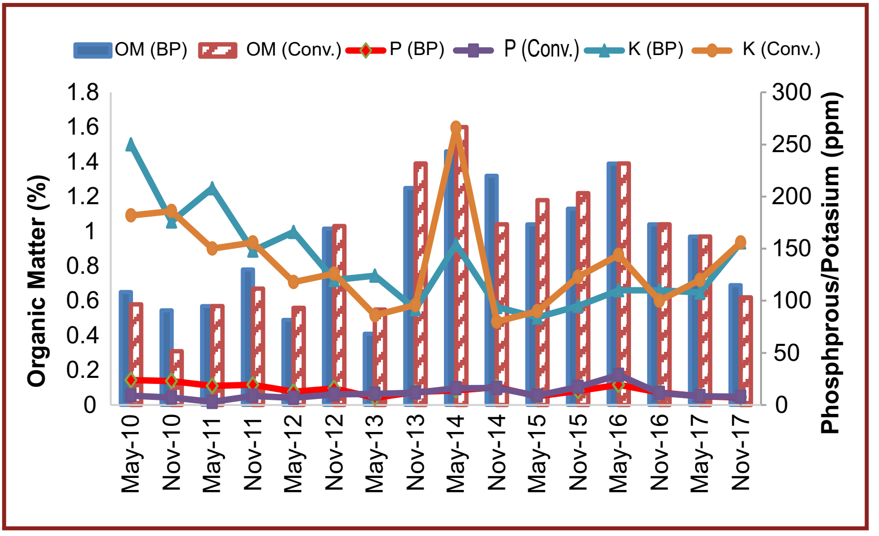
# CHAPTER-IV

## 4 CONCLUSIONS




I) Rice and wheat crops can be successfully grown on beds without compromising the yield.

ii) Bed plantation in rice-wheat cropping system has




vast potential to save the water.

iii) Bed plantation has no effect on soil salinity as compared to conventional sowing method.

iv) It is recommended that Agriculture Extension Departments of Provincial Governments may include the bed plantation technology in their production plans.

## REFERENCES

Ashraf, M. (2016). Managing Water Scarcity in Pakistan: Moving Beyond Rehtoric. proceedings of AASSA-PAS Regional Workshop on Challenges in Water Security to Meet the Growing Food Requirement. Pakistan Academy of Sciences, Islamabad. pp. 3-14.

Ashraf M., A. Nasir, M.M. Saeed (2010). Evaluation of the existing water productivity in the Lower Bari Doab Canal (LBDC) Command – A Case study. Pakistan Journal of Agricultural Sciences, 47(4): 389-396.

Ashraf M., M.K. Marri, I. Rao, A. Salam, M.A. Khan (2014). Pancho-irrigation system – a wasteful practice of irrigation rice fields in the Lower Indus Basin of Pakistan. Pakistan Journal of Agricultural Sciences, 51 (4): 867-873.

Ashraf, M., M.M. Saeed, (2006). Effect of improved cultural practices on crop yield and soil salinity under relatively saline groundwater applications. Irrig. Drain. Syst., 20: 111-124.

Ather M., A. Hussain, A. D. Sheikh. (2006). Recommended Technologies and Production Practices at Farm Level: Wheat Scenario. Socio-economic Research Studies, TTI, Faisalabad. p. 32-43.

Benites, J. R. (2001). Socio-economic perspectives, policy implications and food security for conservation agriculture in Asia. Presented in Intl. Workshop on Conservation Agriculture for Food Security and Environment Protection in Rice-Wheat Cropping Systems. 6-9 Feb. 2001. Lahore, Pakistan.

Bhuyan M.H.M., Ferdousi M.R., Iqbal M.T. (2012). Yield and growth response to transplanted Aman rice under raised bed over conventional cultivation method. Journal of ISRN Agronomy, Article ID 646859.

Connor, D. J., Gupta, R. K., Hobbs, P. R., Sayre, K. D. (2003). Bed planting in rice-wheat systems. In: Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia: A Resource Book. Rice-Wheat Consortium for the Indo-Gangetic Plains. Intl. Maize and Wheat Impr. Cent., New Delhi, India. pp. 103-108.

Devkota M., C. Martius, R.K. Gupta, K.P. Devkota, A.J. McDonald, J.P.A. Lamers (2015). Managing soil salinity with permanent bed planting in irrigated production systems in Central Asia. Agriculture, Ecosystems and Environment 202 (2015) 90–97.

Farooq, U., M. Sharif, O. Erenstein. (2006). Adoption and impacts of zero tillage in the ricewheat zone of irrigated Punjab, Pakistan. Rice-Wheat Consortium for the Indo-Gangetic Plains. CG Block, NASC Complex, DPS Marg, Pusa Campus, New Delhi-110012, India. p.69.

GoP, 2012. Pakistan Economic Survey (2011-12). Government of Pakistan, Finance Division, Economic Adviser's Wing, Islamabad.

Gupta, R. K., Hobbs, P. R., Salim, M., Malik, R. K., Varma, M. R., Pokharel, T. P., Thakur, T. C., Tripathri, J. (2000). Research and extension issues for farm-level impact on the productivity on rice-wheat systems in the Indo-Gangetic Plains of India and Pakistan. Rice-Wheat Consortium Sem. Rep. Ser. 1. Rice-Wheat Consortium for the Indo-Gangetic Plains. New Delhi, India. 26 p.

Hobbs, P. R., Gupta, R. K. (2003a). Resource-conserving technologies for wheat in the rice-wheat system. *In:* Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact. American Soc. Agron. Spec. Publ. **65**, 149-171.

Hobbs, P. R., Gupta, R. K. (2003b). Rice-wheat cropping systems in Indo-Gangetic Plains: Issues of Water Productivity in Relation to New Resource-Conserving Technologies. In: Kijne et al. (ed.) Water Productivity in Agriculture: Limits and Opportunities for Improvement. pp. 239-253.

Jensen, M.E., (2007). Beyond irrigation efficiency. Irrig. Sci., 25: 233-245.

Majeed A., A. Muhmood, A. Niaz, S. Javid, Z.A. Ahmed, S.S.H. Shah, A.H. Shah (2015). Bed planting of wheat (Triticum aestivum L.) improves nitrogen use efficiency and grain yield compared to flat planting. The Crop Journal, Volume 3, Issue 2, Pages: 118-124

Molden D., Oweis T., Steduto P., Bindraban P., Hanjra M.A., Kijni J., (2010). Improving agricultural water productivity: between optimism and caution. Agricultural Water Management 97: 528-535.

Mollah, M. I. U., M. S. U. Bhuiya, M. H. Kabir (2009). Bed Planting – A New Crop Establishment Method for Wheat in RiceWheat Cropping System. J. Agriculture Rural Development 7(1&2): 23-31.

Naresh, R.K., Rathore, R.S., Dwivedi, A., Kumar, V., Kumar, A., Kumar, V., Kumar, M., Kumar, A., Tyagi, S., Kumar, V., Singh, O., Gupta, R.K. (2017). Bed Planting System Promotes Crop Diversification for Improving Livelihoods in Western Uttar Pradesh, India. Int.J.Curr. Microbiol. App.Sci., 6(2): 1580-1590.

Ouda, S., El-Latif, K.A., Khalil, F. (2016). Water Requirements for Major Crops. Springer Briefs in Water Science and Technology, DOI 10.1007/978-3-319-21771-0_2.

Qureshi, A.S., (2011). Water management in the Indus Basin in Pakistan: challenges and opportunities. Mt. Res. Dev., 31(3): 252-260.

Reeves, T. G., Ransom, J. K., Sayre, K. D., Hobbs, P. R., K. Cassaday (2000). From Scarcity to Security: A Global Perspective on Weed Science and the Future Food Situation. Presented in 3rd Weed Sci. Cong. on Global Weed Problems: Local and Global Solutions for the Beginning of the Century. 6-11 Jun. (2000), Foz de Iguacu, Brazil.

Rockstrom, J., M. Lannerstad, M. Falkenmark, (2007). Assessing the water challenge of a new green revolution in developing countries. Proc. Nat. Acad. Sci., USA, 104(15): 6253-6260.

Sayre, K. D. (2003). Raised bed system of cultivation. In: Bed

Planting Training Course. 19 May -21 Jun (2003). Intl. Maize and Wheat Impr. Cent. Mexico. Soomro Z.A., M.D. Arshad, K. Ejaz, A.Z. Bhatti, M. Ashraf (2015). Rice Cultivation on Beds - An Efficient and Viable Irrigation Practice. Pakistan Council of Research in Water Resources (PCRWR), Islamabad. pp. 24.

Soomro Z.A., M.D. Arshad, K. Ejaz, A.Z. Bhatti, M. Ashraf (2015). Rice Cultivation on Beds - An Efficient and Viable Irrigation Practice. Pakistan Council of Research in Water Resources (PCRWR), Islamabad. pp. 24.

Soomro, Z.A., M. Ashraf. K. Ejaz, A.Z. Bhatti, (2018). Water Requirements of Major Crops in the Central Punjab. Pakistan Council of Research in Water Resources (PCRWR), pp. 44.

Suweis, S., A. Rinaldo, A. Maritan, and P.D'Odorico, (2013), Water-controlled wealth of nations, Natil. Acad. Sci. U.S.A, 110(11), 4230-4233.

Taj, S., U. Farooq, N. Akmal, A. Majid. (2005). Economic and gender based employed impacts of introducing dugwells in the rainfed farming system of Punjab, Pakistan. J. Sustainable Develop. Nigeria. 2 (2): 40-52.

Timsina, J. and Connor, D. J. (2001). Productivity and management of rice-wheat cropping systems: issues and challenges. Field Crop Res. 69, 93-132.

Vazifedoust, M., J.C. van Dam, R.A. Feddes, M. Feizi, (2008). Increasing water productivity of irrigated crops under limited water supply at field scale. Agric. Water Manage., 95: 89-102.

Vories E., Counce P., Keisling T.C. (2002). Comparison of flooded and furrow-irrigated rice on clay. Irrigation Science, 21 (3): 139–144.

# ANNEXURES

Annexure-I

## Survey Questionnaire (Rice Crop)

1. Date of survey________________________________

2. Name of the farmer____________________________ Contact #____________________

3. Secondary occupation if any______________________________________________

4. Village____________________ Tehsil________________ District_________________

5. Education of respondent (i) Primary________ (ii) Middle________ (iii) Matric________

(iv) Intermediate______ (v) Graduate_____ (vi) Post Graduate_____ (vii) Illiterate______

6. Land tenancy (i) Self________ (ii) Share crops_________ (iii) On lease__________

7. Total farm size _________ acres Area under cultivation __________acres

8. Sources of irrigation (i) canal ________ (ii) Tubewell ________ (iii) Both _________

9. Distance of farm from the canal outlet _______________________ ft

10. Discharge in cusecs; (i) Canal______________ (ii) Tubewell ___________________

11. Quality of tubewell (if known): EC (dS/m)________ pH___________

12. Area under Rice crop ____________________ acres

13. Variety of rice ___________________

14. Date of Nursery Sowing ____________Date of Transplantation_________________

15. Area under different irrigation method (acres): (i) Border ________ (ii) Other__________

16. Irrigation frequency (days): (i) During crop establishment period _____(ii) After_______

17. Number of irrigation: (i) During crop establishment period ______ (ii) After_______

18. Irrigation time (minutes/irrigation/acre): (i) Establishment period _____ (ii) After _____

19. Share of irrigation water (%); (i) Canal __________ (ii) Tubewell __________

20. Total cost of inputs for rice crop (PKR/acre) ________________________

21. Total crop period ________________ days

22. Yield __________________ mound/acre

## Annexure-II

# Survey Questionnaire (Wheat Crop)

1. Date of survey ______________________________

2. Name of the farmer____________________________ Contact # ____________________

3. Secondary occupation if any______________________________________________

4. Village___________________ Tehsil________________ District__________________

5. Education of respondent (i) Primary________ (ii) Middle________ (iii) Matric________

   (iv) Intermediate______ (v) Graduate_____ (vi) Post Graduate_____ (vii) Illiterate______

6. Land tenancy (I) Self ___________ (ii) Share crops_________ (iii) On lease__________

7. Total farm size _________ acres Area under cultivation __________acres

8. Sources of irrigation (i) canal ________ (ii) Tubewell ________ (iii) Both _________

9. Distance of farm from the canal outlet _______________________ ft

10. Discharge in cusecs; (i) Canal ________________ (ii) Tubewell ___________________

11. Quality of tubewell (if known): EC (dS/m)________ pH___________

12. Area under wheat crop _________________ acres

13. Date of sowing ______________________ Variety of wheat __________________

14. Sowing Method (i) Broad cast _________ (ii) Other _______________

15. Irrigation method (i) Border _________ (ii) Other ___________

16. Area under different irrigation method (acres): (I) Border ______ (ii) Other_________

17. Irrigation frequency: ___________________ days

18. Irrigation time (minutes/irrigation/acres):__________________________

19. Share of irrigation water (%); (i) Canal ____________ (ii) Tubewell _________________

20. Total cost of inputs for wheat crop (PKR/acre) ________________________

21. Total crop period ________________ days: Yield __________________ mound/acre

## Annexure-III

| Monthly Rainfall at PCRWR R&D Center Sialmore, Sargodha | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Years | Months | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| **2010** | 0 | 23 | 15 | 0 | 0 | 18 | 217 | 177 | 119 | 0 | 0 | 0 |
| **2011** | 0 | 28 | 11 | 8 | 21 | 22 | 216 | 88 | 45 | 0 | 0 | 0 |
| **2012** | 14 | 8 | 0 | 34 | 8 | 0 | 118 | 25 | 114 | 14 | 0 | 29 |
| **2013** | 8 | 44 | 0 | 18 | 18 | 46 | 190 | 80 | 17 | 4 | 8 | 0 |
| **2014** | 0 | 18 | 68 | 65 | 40 | 0 | 8 | 73 | 164 | 53 | 3 | 0 |
| **2015** | 22 | 33 | 77 | 11 | 0 | 48 | 36 | 83 | 86 | 15 | 0 | 0 |
| **2016** | 23 | 14 | 77 | 19 | 33 | 54 | 170 | 50 | 6 | 0 | 1 | 0 |
| **2017** | 21 | 6 | 29 | 32 | 46 | 31 | 38 | 79 | 43 | 0 | 6 | 2 |

## Annexure-IV

| Water Table Depth at PCRWR R&D Center Sialmore, Sargodha | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Years | Months | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| **2010** | 6.86 | 6.80 | 7.07 | 7.13 | 7.32 | 7.41 | 7.07 | 6.55 | 6.46 | 6.40 | 6.31 | 6.31 |
| **2011** | 6.28 | 6.25 | 6.16 | 6.25 | 6.31 | 6.22 | 6.10 | 6.10 | 6.19 | 5.98 | 5.91 | 5.91 |
| **2012** | 6.13 | 5.98 | 6.10 | 6.10 | 6.30 | 6.30 | 6.50 | 6.80 | 6.50 | 6.30 | 6.30 | 6.30 |
| **2013** | 6.30 | 6.00 | 6.10 | 6.10 | 6.20 | 6.34 | 6.76 | 6.51 | 6.09 | 5.90 | 5.86 | 5.91 |
| **2014** | 5.96 | 6.04 | 5.89 | 6.15 | 6.20 | 6.34 | 6.37 | 6.61 | 568 | 4.96 | 4.91 | 5.14 |
| **2015** | 5.22 | 5.30 | 5.81 | 6.00 | 6.10 | 6.20 | 5.90 | 5.70 | 5.90 | 5.70 | 5.80 | 5.90 |
| **2016** | 5.80 | 5.90 | 5.80 | 5.90 | 6.10 | 5.80 | 6.40 | 6.20 | 6.20 | 6.20 | 6.30 | 6.20 |
| **2017** | 6.20 | 6.20 | 6.20 | 6.20 | 6.40 | 6.69 | 6.74 | 7.06 | 6.85 | 6.76 | 6.66 | 6.68 |

## Annexure-V

| Details of Economic Analysis for Wheat Crop at PCRWR R&D Center Sialmore, Sargodha | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2009-10** | | **2010-11** | | **2011-12** | | **2012-13** | | **2013-14** | | **2014-15** | | **2015-16** | | **2016-17** | |
| **Sowing Method** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** |
| Yield (kg/ha) | 4150 | 3952 | 4084 | 3689 | 3754 | 3689 | 3912 | 4110 | 3760 | 3325 | 3644 | 3149 | 3924 | 3688 | 3886 | 3794 |
| Selling rate of grain (PKR/kg) | 23 | 23 | 24 | 24 | 25 | 25 | 30 | 30 | 32 | 32 | 30 | 30 | 30 | 30 | 31 | 31 |
| Income from grain (PKR/ha) | 93375 | 88920 | 96995 | 87614 | 93625 | 92004 | 115404 | 121245 | 119380 | 105569 | 110231 | 95257 | 117720 | 110640 | 120233 | 117386 |
| Selling rate of straw (PKR/kg) | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Income from straw (PKR/ha) | 20750 | 19760 | 20420 | 18445 | 18770 | 18445 | 19560 | 20550 | 18800 | 16625 | 18220 | 15745 | 19620 | 18440 | 19430 | 18970 |
| **Gross income (PKR/ha)** | **114125** | **108680** | **117415** | **106059** | **112395** | **110449** | **134964** | **141795** | **138180** | **122194** | **128451** | **111002** | **137340** | **129080** | **139663** | **136356** |
| Total water applied (cm) | 25 | 38 | 24 | 40 | 26 | 38 | 25 | 39 | 22 | 37 | 24 | 41 | 27 | 39 | 25 | 40 |
| Water price (PKR/cm/ha) | 175 | 175 | 175 | 175 | 175 | 175 | 200 | 200 | 200 | 200 | 225 | 225 | 250 | 250 | 250 | 250 |
| Water inputs(PKR/ha) | 4375 | 6650 | 4139 | 7000 | 4626 | 6650 | 5059 | 7800 | 4400 | 7400 | 5400 | 9225 | 6750 | 9750 | 6250 | 10000 |
| WUE (kg/m3) | 1.66 | 1.04 | 1.73 | 0.92 | 1.42 | 0.97 | 1.55 | 1.05 | 1.71 | 0.90 | 1.52 | 0.77 | 1.45 | 0.95 | 1.55 | 0.95 |
| Expenditures: | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Seed (PKR/ha) | 4000 | 4000 | 4000 | 4000 | 4250 | 4250 | 5000 | 5500 | 5500 | 5500 | 5750 | 5750 | 6000 | 6000 | 6341 | 6341 |
| Ploughing (PKR/ha) | 10000 | 6500 | 10000 | 6500 | 10300 | 6490 | 10300 | 5240 | 11200 | 5960 | 10300 | 5240 | 10650 | 5520 | 11250 | 6000 |
| Fertilizer (PKR/ha) | 14300 | 14300 | 14230 | 14230 | 14375 | 14375 | 22750 | 22750 | 24390 | 24390 | 22750 | 22750 | 16750 | 16750 | 17250 | 17250 |
| Weedicide (PKR/ha) | 1650 | 1650 | 1720 | 1720 | 1575 | 1575 | 1490 | 1490 | 1560 | 1560 | 1750 | 1750 | 2270 | 2270 | 2850 | 2850 |
| Harvesting (PKR/ha) | 14250 | 14250 | 14250 | 14250 | 14250 | 14250 | 14250 | 14250 | 14250 | 14250 | 14850 | 14850 | 14850 | 14850 | 15500 | 15500 |
| Labour (PKR/ha) | 900 | 900 | 960 | 960 | 1050 | 1050 | 1110 | 1110 | 1110 | 1110 | 1170 | 1170 | 1230 | 1230 | 1350 | 1350 |
| Non-Water inputs (PKR/ha) | 45100 | 41600 | 45160 | 41660 | 45800 | 41990 | 54900 | 50340 | 58010 | 52770 | 56570 | 51510 | 51750 | 46620 | 54541 | 49291 |
| **Total expenditures (PKR/ha)** | **49475** | **48250** | **49299** | **48660** | **50426** | **48640** | **59959** | **58140** | **62410** | **60170** | **61970** | **60735** | **58500** | **56370** | **60791** | **59291** |
| **Net Income (PKR/ha)** | **64650** | **60430** | **68116** | **57399** | **61969** | **61809** | **75005** | **83655** | **75770** | **62024** | **66481** | **50267** | **78840** | **72710** | **78872** | **77065** |

## Annexure-VI

### Details of Economic Analysis for Rice Crop at PCRWR R&D Center Sialmore, Sargodha

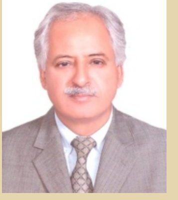
| Year | 2010 | | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sowing Method** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** | **BP** | **Conv.** |
| Yield (kg/ha) | 3480 | 3320 | 3580 | 3340 | 4972 | 4784 | 3917 | 3640 | 3980 | 4160 | 3952 | 4290 | 4624 | 4578 | 4164 | 4044 |
| Selling rate (PKR/kg) | 42 | 42 | 40 | 40 | 46 | 46 | 63 | 63 | 45 | 45 | 41 | 41 | 42 | 42 | 38 | 38 |
| **Gross income (PKR/ha)** | **146160** | **139440** | **143200** | **133600** | **228727** | **220064** | **244813** | **227500** | **179100** | **187200** | **162032** | **175890** | **194208** | **192276** | **157191** | **152661** |
| Total water applied (cm) | 121 | 172 | 108 | 141 | 124 | 157 | 103 | 135 | 118 | 169 | 132 | 179 | 129 | 199 | 118 | 185 |
| Water price (PKR/cm/ha) | 175 | 175 | 175 | 175 | 175 | 175 | 200 | 200 | 200 | 200 | 225 | 225 | 250 | 250 | 250 | 250 |
| Water inputs (PKR/ha) | 21175 | 30100 | 18900 | 24675 | 21700 | 27475 | 20600 | 27000 | 23640 | 33880 | 29790 | 40208 | 32300 | 49670 | 29500 | 46250 |
| WUE (kg/m3) | 0.29 | 0.19 | 0.33 | 0.24 | 0.40 | 0.30 | 0.38 | 0.27 | 0.34 | 0.25 | 0.30 | 0.24 | 0.36 | 0.23 | 0.35 | 0.22 |
| Expenditures: | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Ploughing (PKR/ha) | 8000 | 8500 | 8000 | 8500 | 8000 | 8500 | 8000 | 8500 | 9000 | 10000 | 9000 | 10000 | 12000 | 13000 | 14000 | 15000 |
| Nursery & transplatation (PKR/ha) | 10750 | 7610 | 11611 | 7344 | 11306 | 7220 | 11199 | 6732 | 11200 | 9375 | 11547 | 9570 | 12764 | 12508 | 15673 | 15430 |
| Fertilizer (PKR/ha) | 12680 | 12680 | 13390 | 13390 | 14870 | 14870 | 19680 | 19680 | 20680 | 20680 | 24625 | 24625 | 22250 | 22250 | 22875 | 22875 |
| Pesticide & weedicide (PKR/ha) | 10500 | 10500 | 10500 | 10500 | 10500 | 10500 | 10500 | 10500 | 11500 | 11500 | 12600 | 12600 | 11800 | 11800 | 11200 | 11200 |
| Harvesting (PKR/ha) | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8750 | 8750 | 7500 | 7500 | 8750 | 8750 |
| Labour (PKR/ha) | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 | 2500 | 2500 | 2500 | 2500 | 3000 | 3000 | 3000 | 3000 |
| Non- Water inputs (PKR/ha) | 51930 | 49290 | 53501 | 49734 | 54676 | 51090 | 59379 | 55412 | 62880 | 62055 | 69022 | 68045 | 69314 | 70058 | 75498 | 76255 |
| **Total expenditures (PKR/ha)** | **73105** | **79390** | **72401** | **74409** | **76376** | **78565** | **79979** | **82412** | **86520** | **95935** | **98812** | **108253** | **101614** | **119728** | **104998** | **122505** |
| **Net Income (PKR/ha)** | **73055** | **60050** | **70799** | **59191** | **152351** | **141499** | **164834** | **145088** | **92580** | **91265** | **63220** | **67638** | **92594** | **72548** | **52193** | **30156** |

## About PCRWR

PCRWR is an apex body of the Ministry of Science and Technology and is mandated to conduct, organize, coordinate and promote research on all aspects of water resources including irrigation (surface and groundwater), drainage, soil reclamation, drinking water and wastewater. It has five regional offices located at different agro-ecological zones and conducts research on water-related issues of the respective zones. These Regional Offices are located at Lahore, Bahawalpur, Tandojam, Quetta and Peshawar. Besides these five Regional Offices, PCRWR has a setup of 18 water testing laboratories in major cities of the country. It has all types of infrastructure such as soil and water testing laboratories, groundwater assessment equipment, research farms to conduct and disseminate the research. It is the only organization in Pakistan that owns drainage type lysimeters in Lahore, Tandojam, Quetta and Peshawar. PCRWR has done considerable work on crop water requirements, tile drainage, soil reclamation, on-farm water management technologies, rainwater harvesting, artificial recharge, groundwater assessment and management, skimming wells, drinking water, and indigenous development of salinity and moisture sensors.

## About the Authors

**Engr. Zamir Ahmed Soomro** is an Agriculture Engineer, graduated from Sindh Agriculture University Tando Jam and has a Master of Engineering in Hydraulics and Irrigation from Mehran University of Engineering and Technology, Jamshoro. He has been working for the Pakistan Council of Research in Water Resources for the last 33 years on various water issues including: waterlogging and salinity, desertification control, rainwater harvesting, water conservation in agriculture, irrigation scheduling, water quality monitoring and management, groundwater management, artificial groundwater recharge and published more than 20 national/international articles.



**Dr. Muhammad Ashraf** is basically an Agricultural Engineer and holds a PhD from the University of Newcastle, UK. He has more than 25 years research and development experience in water resources development and management in arid and semi-arid areas and has over 80 national and international research publications to his credit. He has been working for provincial and national organizations such as On Farm Water Management Punjab (OFWM) and Pakistan Council of research in Water Resources (PCRWR). He also has the opportunity to work for international organizations such as International Water Management Institute (IWMI), International Centre for Agriculture Research in the Dry Areas (ICARDA). Currently, he is working as Chairman, PCRWR.

**Engr. Zia-ul-Haq** has been working for PCRWR as Assistant Director since 2017. He has graduated as Agriculture Engineer in 2009 from University of Agriculture Faisalabad, followed by M.Sc. in water resources management from University of Engineering and Technology Lahore. He brings over nine years of experience in multiple facets of high efficiency irrigation system, automatic data acquisition system (Telemetry) of water distribution channels, agricultural water management and hydrological systems. He also contributed in different projects on irrigation system and groundwater investigations. Before joining PCRWR he has more than six years of working experience in different international/national organizations. He has three International/national publications to his credit.

**Engr. Khuram Ejaz** is basically an Agricultural Engineer, graduated from University of Agriculture, Faisalabad. He received M.Sc. (Hons) in Agricultural Engineering from University of Agriculture, Faisalabad. He is currently working as Assistant Director (Water Management) PCRWR. He has about 17 years experience related to water resource management. He has actively participated in various projects and studies conducted by PCRWR in collaboration with national and international organizations like ACIAR, ICARDA, UNICEF, UNDP etc. He has three peer reviewed publications to his credit.


PCRWR

**Pakistan Council of Research in Water Resources**
Ministry of Science and Technology, Government of Pakistan
Khyaban-e-Johar, H-8/1, Islamabad
E-mail: info@pcrwr.gov.pk website: www.pcrwr.gov.pk