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Water Productivity and Economic Feasibility of Growing Rice and Wheat on Beds in Central Punjab of Pakistan

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2023

Citation:

Ejaz, K. and M. Ashraf (2023). Water Productivity and Economic Feasibility of Growing Rice and Wheat on Beds in Central Punjab, Pakistan. Pakistan Council of Research in Water Resources (PCRWR), Islamabad, pp 53.

ISBN: 978-969-8469-96-2

Acknowledgements:
The authors extend their sincere appreciation to Mr. Faizan-ul-Hassan, Mr. Faakhar Raza, Mr. Zia-ul-Haq, Mr. Muhammad Kashif Manzoor and Mr. Salah ud Din for their time to review the report and to Mr. Zeeshan Munawar for formatting it. The authors also extend their deepest gratitude to the dedicated field staff of the Sialmore R&D farm for data collection from sowing to harvesting.

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List of Abbreviations

BP	Bed Planting
B&F	Bed & Furrow
DAP	Di Ammonium Phosphate
EC	Electrical Conductivity
ET_O	Reference Evapotranspiration
GoP	Government of Pakistan
GDP	Gross Domestic Product
LPS	Litter Per Second
MAD	Manageable Allowable Deficit
MAF	Million Acre Foot
OFWM	On Farm Water Management
OM	Organic Matter
PCRWR	Pakistan Council of Research in Water Resources
pH	Power of Hydrogen
PSDP	Public Sector Development Program
R&D	Research & Demonstration Centre
RB	Raised Bed
RCT	Resource Conservation Technologies
SAR	Sodium Adsorption Ratio
SMD	Soil Moisture Deficit
TPR	Transplanted Puddled Rice
WP	Water Productivity
WUE	Water Use Efficiency

Executive Summery

The conventional rice-wheat production methods commonly used in Pakistan have led to soil degradation and decreased farm profitability due to the extensive water use and non-water inputs. Conventional rice transplanting in standing water and excessive flood irrigation has several disadvantages, including low irrigation water use efficiency, inefficient utilization of fertilizer, soil crusting, and higher crop lodging. To address these issues, resource-conservation technologies (RCT), such as precision land leveling (PLL), zero-tillage (ZT), bed planting (BP) and irrigation scheduling (IS) are considered to be potential alternatives. Present study was undertaken during 2017–2020 to establish an understanding of how these technologies performed in the rice-wheat cropping system of Punjab to improve water productivity, profitability and soil physical conditions. It was found that bed planting of wheat and rice can result in significant water savings of 56% and 47%, respectively, compared to traditional transplantation methods. Transplanted puddle rice (TPR) required 88% more water than the BP technique. In wheat, the farmer's practice consumed 79% and 54% more water than the BP and ZT techniques, respectively, while achieving almost equal crop productivity and demonstrating higher water productivity, i.e., 2.19 kg/m^3 and 1.53 kg/m^3, respectively. The BP for rice-wheat cultivation not only conserves water but also reduces the cost of rice production by 34%. Moreover, adopting rice-wheat BP leads to a 20% increase in net income compared to conventional methods. However, the long-term implications of these alternative technologies necessitate exploration across different agro-ecologies. Overall, the study highlights the promising prospects of BP in addressing water scarcity and environmental pollution challenges as it allows for intermittent irrigation, diversification of crops, reduces groundwater pollution and methane emissions. However, changing the mindset of the farmers who are habitual of flood irrigation is a big challenge.

1 Introduction

Wheat is one of the world's most significant cereal crops, along with rice, with an average output of 3.26 t/ha (Cao et al., 2022). It covers around 218.5 million hectares (Mha), or roughly 4% of the entire area set aside for agricultural use (FAO, 2017). According to Snapp et al., (2017), the crop is primarily produced for its grain, which is used as human food, and hay, which is used as animal fodder**.** In South Asia, Bangladesh, India, Nepal, and Pakistan, have devoted nearly half of their total land area of 401.72 Mha to feed and provide livelihoods for 1.8 billion people (Ladha et al., 2016). Over about 13.5 Mha of the Indo-Gangetic plains (IGP), spread over the four countries, these rice and wheat rotation is dominant, covering around 80 % of the area (Gupta et al., 2003; Timsina and Connor, 2001; Huke et al., 1993). The rice–wheat production system is fundamental to employment, income, and livelihoods for hundreds of millions of rural and urban poor of South Asia (Sidhu et al., 2003). Despite priority given to rice and wheat research by the national institutions during the 1940s, 1950s and early 1960s, only limited advances were made in productivity. This, combined with unpredictable climatic conditions, meant that South Asia increasingly relied on imported food grains to feed its growing population. With the explosive growth of population and limited arable land, meeting the increasing demand for food is a serious concern. Climate and management practices show profound effects on rice and winter wheat cultivation (Feng et al., 2017). From 1980 to 2008, climate change has decreased wheat yield by 5.5% globally (Lobell et al., 2011). Due to shortages, ineffective irrigation systems, poor maintenance, and low agricultural water production, water availability per unit of irrigated land is declining in the Indus Basin regions (Siyal et al., 2021). With regard to the ever-increasing population and the impact of climate change on the quantity and quality of agricultural production, the world is facing a significant lack of food and serious problems of nutrition. Agriculture is a vital aspect of the world which plays a very important role in economic and social development programs (Adisa et al., 2019).

Rice and wheat are two major staple crops in irrigated agriculture of Pakistan. Therefore, the rice-wheat cropping system is one of the most important cropping patterns followed by maize and sugarcane. In this system, rice is grown in a warm, sub-humid, monsoonal and summer months whereas, wheat in the cooler, drier, and winter season. During the year 2020-21, the total area under rice and wheat was 3.34 and 9.18 Mha respectively (GoP 2020-21). The traditional practice of cultivating both crops is flat sowing with flood irrigation. The average yield of rice was 2.52 t/ha (GoP 2020-21) which is much lower as compared to 7.40 and 6.19 t/ha in the USA and China respectively (Soomro et al., 2015). For wheat, the yield was 2.97 t/ha as compared to 6.5 t/ha in Egypt. On an average, the world's rice fields use around 1.4 m^3 of water to produce 1 kg of rice with water productivity (WP) of 0.71 kg/m^3 whereas it is less than 0.45 kg/m^3 in Pakistan (Soomro et al., 2015). In case of basmati rice, the WP is even as low as 0.08 kg/m^3 found in the Lower Bari Doab Canal Command (Ashraf et al., 2010). For wheat, it is 0.5 kg/m^3 as compared to 1.0 kg/m^3 in India and 1.5 kg/m^3 in California (Qureshi and Ashraf, 2019). Among different factors responsible to the lower yield, shortage of water and lack of knowledge on irrigation scheduling are the major limiting factors.

In Pakistan water requirement of rice and wheat varies from 500 to 1500 mm and 353 to 562 mm respectively depending on the crop variety and agro-climatic conditions (Ashraf 2015; Soomro et al., 2018; Rao et al., 2016). However, farmers are applying 2-3 times or even more water than its actual requirements in a growing season (Ashraf et al., 2010; 2014). The conventional mindset of farming community is a major obstacle in applying more water to crop than its requirements.

Wheat is mainly sown with three different sowing methods viz. broadcast sowing, drill sowing and augmented furrow sowing and two different irrigation regimes i.e., normal irrigation and water deficit at an-thesis stage (Sharma et al., 2002). Researchers have recently developed a series of new technologies to sustain the productivity of wheat cultivation after rice, including furrow-irrigated permanent raised-bed planting systems (Singh et al., 2009), ditch-buried straw return tillage practices (Yang et al., 2019), the use of resistant strains, zero tillage with medium-sized strip seeding (Li et al., 2020, Li et al., 2021), tillage, fertilizer and seeding strategies (Ding et al., 2021) and the use of Turbo Happy Seeders (Sidhu et al., 2015). One strategy is to grow wheat in raised-bed planting (RBP) patterns (Kaur et al., 2020, Du et al., 2021b, Du et al., 2021c, Du et al., 2022). The raised-bed planting method is appropriate for wheat production and has shown to be one of the available solutions for conserving water by achieving high water usage efficiency (Sayre and Hobbs, 2004).

There are several numbers of irrigation methods, which have the potential to apply irrigation water efficiently. But each method works at its best under specific farming conditions. In irrigated areas of Punjab, the cultivated land is mostly flat, and fields are leveled where farmers grow row crops (wheat, maize, rice, sugarcane) and apply water through flood irrigation. Water losses (both conveyance and application) are high from the main source to the farmer's fields through unlined or damaged watercourses. The conventional irrigation practices are resulting in decreased water use efficiency (Mehran et al., 2017).

The best alternative could be the mix of conventional and advanced irrigation systems. The researchers have developed a basket of resource conserving technologies (RCT) and made it available to farmers for adoption. Some are based on reduced tillage for wheat, including zero tillage. Bed-planting (BP) systems are being developed to increase water productivity and when combined with reduced tillage in a permanent raised bed (PRB) system, it also provides more savings.

LASER leveling, combined with these systems, provides additional benefits as well. Most of the benefits of tillage operations for wheat are lost when rice soils are traditionally puddled (ploughed while wet). A majority of rice farmers traditionally puddle their soils to keep water ponded for reducing percolation losses and to control weeds. After a few weeks that puddled fields have more cracking and need more water once the fields dry. It is true that initial flooding is important to promote tillering and to more effectively control weeds but this practice causes a loss of precious water. Studies reveal that rice yields are similar between puddled and non-puddled situations if weeds can be controlled. The data also show that wheat yields are significantly better when wheat is planted with zero tillage after non-puddled rice than puddled rice. (Hobbs and Gupta, 2003).

The adoption of water-saving techniques that do not require continuous submergence, especially in rice fields, such as bed planting or direct seeding on beds, can support the sustainability of rice-wheat production systems. Therefore, in RCT, bed planting/furrow irrigation is one of the irrigation techniques that is used for the efficient use of water. In the bed planting technique, irrigation is applied in furrows while crops are being grown on the beds. It gives flexibility for efficient nutrient management, increases irrigation efficiency, and reduces crops lodging (Hobbs and Gupta, 2003). Borrel et al., (1997) has found that the raised-bed system saved 16% to 43% water compared with puddled transplanted rice. In wheat and rice, on-farm irrigation efficiency can be increased to 30% by minimizing water losses. It also reduces tube well-pumping costs and time of irrigation thus enabling tube wells to irrigate larger areas more efficiently (Hassan et al., 2005). Bed planting technique reduces per acre seed rate without sacrificing crop yield as compared to flat sowing. It also improves root proliferation ensuring better crop stand and yield (Peries et al., 2001). Above all, bed planting promises a considerable amount of water-saving (around 35% to 45%) as compared to the conventional sowing method as well as eliminates the formation of crust on the soil surface (Fahong et al., 2003).

It is evident by various studies that rice can be successfully grown on raised beds (Hobbs and Gupta, 2003; Soomro et al., 2018). However, in Pakistan this technology could take off due to number of misconceptions such as (i) more irrigations will be required in case of bed planting as compared to conventional, (ii) salinity may be built up thereby reducing the crop yields and (iii) overall net income will be less. To address these concerns, a study was conducted for rice and wheat sowing with conventional and bed planting during 2017-

20 at Pakistan Council of Research in Water Resources (PCRWR) Research & Demonstration (R&D) Centre, Sialmore, Sargodha in terms of irrigation scheduling, soil fertility, yield, rooting depth and behavior, lodging improve and water productivity (WP).

2 Materials and Methods

2.1 Description of Experimental Site

Pakistan's agriculture sector has been dominated by five crops: wheat, rice, sugarcane, maize and cotton. According to the newly identified agro-ecological zoning of Punjab, rice is mostly suitable in areas of upper Punjab such as Gujranwala, Sialkot and Gujrat, and in a few areas of central Punjab i.e. Sheikhupura, Sargodha and Nankana Sahib (Amin, 2020). Punjab is growing rice-wheat crop cycle on 30% of its net sown area (Aziz et al., 2019). The study was conducted from 2017-20 at PCRWR Research & Demonstration (R&D) Centre, that lies in Chaj Doab (the area between Chenab and Jhelum Rivers) located at Sialmore, district Sargodha 3 KM away from the Lahore-Islamabad motorway (M2) (Figure 1). The site represents irrigated agricultural area of central Punjab of Pakistan at 73.11 North (longitude) and 31.95 East (latitude); 189 m above mean sea level. This area is famous for mixed cropping patterns including rice, wheat, sugarcane, maize, fodder, citrus and vegetables. The major crops grown are rice (0.084 Mha), wheat (0.73 Mha), sugarcane (0.1 Mha), maize (0.012 Mha) and citrus (0.084 Mha) in Sargodha district (CRS, 2020-21). The Sargodha district is bounded on the north by Jhelum district and on the east by the districts of Mandi Bahauddin and Hafizabad separated by the Chenab River. The Jhang district lies on the south and the Khushab district on the west, separated by the Jhelum River. The field selected for this research study was rice followed by wheat.

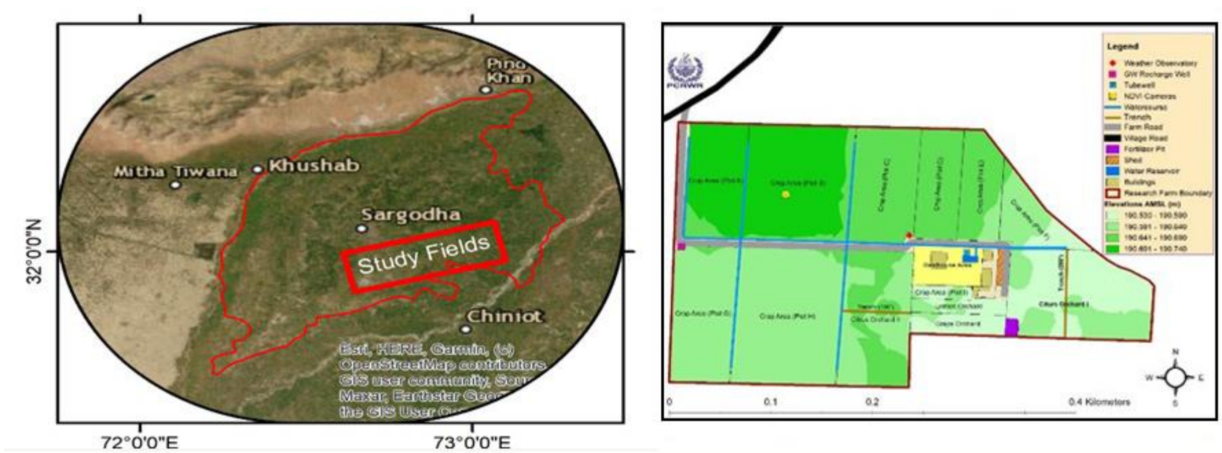


Figure 1: Location map of PCRWR R&D centre

2.2 Irrigation Source

The source of irrigation water on the site is groundwater of good quality from a shallow tubewell installed at 30 m depth. The water table depth is about 7.6 m which is continuously monitored and recorded from the piezometer installed at the center (Figure

2). The water table depth varied mainly before and after monsoon season. The tube well discharge is 40 lps which is located at a distance of 100-200 m from experimental field. Firstly, pumped water is stored in the reservoir (12 x 6.4) m then after filling it, water is applied to the fields through a network of paved watercourses. It is worthwhile mentioning that R&D centre is located on the belt of River Chenab. Therefore, quality of groundwater is good; EC was 0.74 (ds/m), pH 7.33, Sodium Absorption Ratio (SAR) 1.6 and no Residual Sodium Carbonates (RSC).

2.3 Climate

The area has a subtropical climate with an average annual temperature of 23 ^{o}C and mean annual rainfall of 400 mm, most of which falls during monsoon (June – September) in the form of medium to high intensity rainfall. The area also receives winter rainfall of lesser intensity during December – February. The average annual rainfall in monsoon period during 2018-2020 was 411 mm. The maximum temperature in summer reaches up to 44 ^{o}C in May. During winter, temperature may at times fall below the freezing point (January). Monthly reference evapotranspiration (ET_0) varies from 20 mm in December to a maximum of 164 mm in June (Table 1). Climatic data have been collected from an automated weather station installed at the centre. (Figure 2 and Table 1).

Figure 2: Climatic data observatory setup and piezometer/multi level observation well

Table 1: ETo, Rainfall, Temperature at PCRWR R&D center Sialmore, Sargodha

Month	2018				2019				2020			
	ETo	RF	Temp °c		ETo	RF	Temp °c		ETo	RF	Temp °c	
	(mm)		Max	Min	(mm)		Max	Min	(mm)		Max	Min
Jan	31	2	22	2	34	40	17	6	32	56	16	5
Feb	50	13	26	6	44	44	18	8	55	22	22	8
Mar	75	7	31	11	78	48	24	12	73	118	23	13
Apr	121	50	36	16	123	52	33	19	118	25	31	17
May	143	18	40	24	148	104	36	21	146	24	36	22
Jun	152	72	36	30	164	3	39	25	140	86	37	25
Jul	125	177	35	26	125	96	35	27	90	161	36	27
Aug	125	3	35	27	119	18	35	27	113	142	35	27
Sep	100	2	33	23	96	10	34	26	98	29	35	25
Oct	71	3	30	16	74	35	30	18	63	2	32	16
Nov	49	2	26	10	43	3	24	12	24	2	24	10
Dec	32	6	20	4	22	17	15	6	20	25	22	9

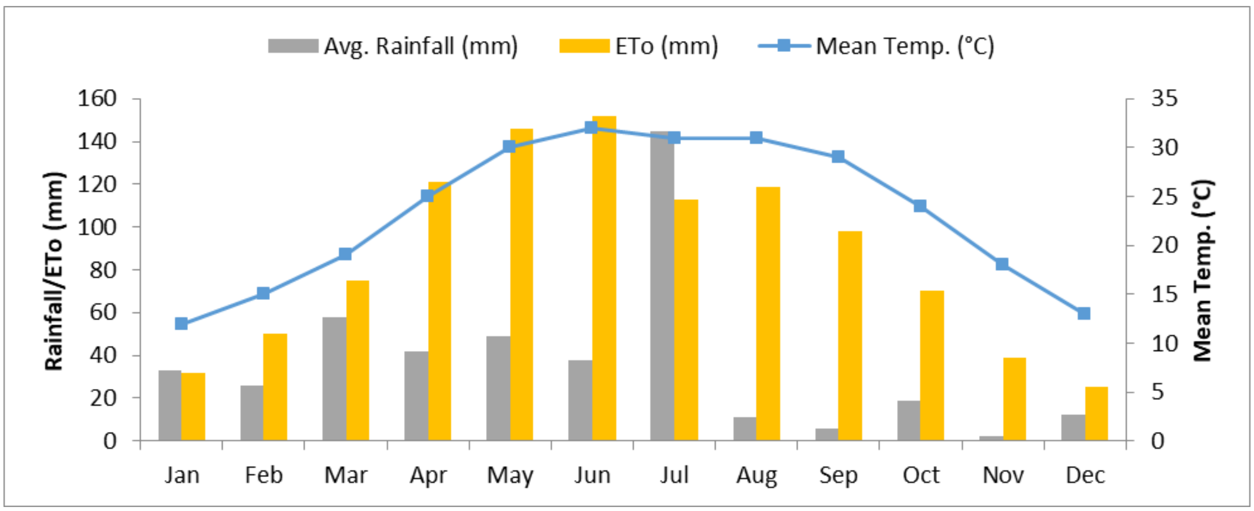


Figure 3: Monthly average rainfall, mean temperature and ETo during the study period (2018-20)

2.4 Soil Profile

The study area is the part of the Indus Plains which comprises of alluvial deposits mixed with calcareous characteristics. The soil in the area is medium texture and texturally structurally homogeneous up to a depth of 1m to 4m. These are underlain by thick sandy loam to loamy sand and highly conducive aquifer (Kelleners et al., 1999).

Topography of the study area is flat and soils are predominantly medium to moderately coarse with favorable permeability characteristics and show a similarity throughout the area. The soils are generally low in organic matter, with a pH in the range of 7 – 7.9. These soils are adoptable to a wide variety of crops (Ahmad, 2002).

2.4.1 Soil Characteristics of R&D Centre

To analyze the soil characteristics, undisturbed soils samples were taken from study field and analyzed in the PCRWR soil physics laboratory, Islamabad. Soil texture at study site is sandy loam determined by Hydrometer method with bulk density of 1.47 g/cm^3. Whereas, soil moisture retention curve was determined using Hein's apparatus and Pressure plat extractor. The field capacity of the soil is at 28%, whereas the permanent wilting point is at 7%.

Table 2: Texture analysis of soil profile

Soil Texture and Bulk Density						
Clay %	**Silt %**	**Sand %**	**Soil Class**	**Field Capacity %**	**Permanent Wilting Point %**	**Bulk Density g/cm^3**
1.12	47.95	50.93	Sandy Loam	28	7	1.47

2.4.2 Chemical Properties of Soil

For chemical analyses of the soil, samples were collected after harvesting of each crop season, from each experimental plot from same depths (0-15, 16-30 and 31-45) cm and mixed to prepare composite sample. Collected soil samples were analyzed from district soil and water testing laboratory, Agriculture Department, Sargodha. The soil samples were analyzed for Electrical Conductivity (EC_e), pH, Organic Matter (OM), Phosphorus (P) and Potassium (K).

2.5 Experimental Design

The trials were conducted to compare irrigation efficiency between raised bed irrigation application and conventional irrigation application on wheat, followed by the rice crop. The study spanned a three years period, from the Rabi 2017-18 to Kharif 2020 seasons, covering an area of 5000 m^2 (0.5 hectares). In case of wheat crop, zero tillage method was also adopted beside bed planting and broadcasting. In addition to above two treatments, the data on prescribed templates were collected from neighboring farmers as well during the three years crop seasons regarding water application, yield of crop and inputs etc. to compare it with experimental outputs. Five farmers were selected in the vicinity of Centre whose interviews were conducted on seasonal basis.

2.5.1 Land Preparation

The whole study plots were precisely LASER leveled after the harvesting of each crop. The LASER land leveling helped to save water, improve WUE, crop yields and net income of the farmers (Ashraf et al., 2017). LASER land leveling technology was introduced in Punjab during 1985 by the OFWM, Punjab. Farmer's community is now well aware of the benefits of this technology and now after harvesting of wheat crop, they have their fields LASER leveled. For wheat sowing, three ploughings were made and one plough with planking was done. The bed furrow seed drill was used to drill wheat seed and fertilizer on raised beds simultaneously.

2.5.2 Salient Features of the Bed & Furrow Shaper Cum Seed Drill Machine

The machine has been equipped with three adjustable furrow openers (Figure 4). These openers have the provision to change both the depth and the top width of each furrow, separately. The provision of this adjustment allows the user to obtain the required size of furrow considering the type of crop, soil and its seed bed preparation. The machine has also a provision of adjustable seed planting mechanism as well, which not only allows adjusting the planting depth but also permits adjusting the line-to-line distance of the crop, if required. The seed planting system consists of discs rather than the traditional tines. The disc system in comparison with the tines does not disturb the shape of bed and opens up fine channels to place the seed at proper depths. All four discs are bolted on a rectangular iron bar through spring covered iron strips, which have been fixed on the main frame from where the sowing depth can be adjusted as a whole and/or on an individual disc basis. The spring provided on the iron strip between the discs and iron bar helps to keep the proper depth of opening in the bed. There is an adjustable planer fixed on the main frame prior to the seed planting mechanism, which not only presses and levels the bed top but also flattens the surface of the bed for more precise planting. As the drill covers all three furrows and two beds simultaneously, it results showing an in-built furrow-bed system with compacted edges of the furrows. Later on, the level beds are helpful for the harvesting of crop. This seed drill machine has the provision to apply fertilizer underneath the beds. However, fertilizer is applied in the center of two adjacent rows on each side of the bed at deeper depth than the seed. Moreover, fertilizer applicators are fixed on the front side of the main frame while the seed sowing mechanism is fixed on the side of the main frame.

Figure 4: Bed planter seed drill

2.5.3 Wheat on Beds

The machine develops two beds and three furrows in a single operation. Basically, the machine has been designed to develop bed furrow system of (60 x 30) cm to sow four lines of wheat on each bed. The geometry of sowing wheat on a bed has been shown in (Figure 5) which shows that wheat is sown on both sides of the bed leaving 15 cm buffer zone in the center of four rows. The first line of wheat is sown at 7.62 cm while the second line is sown at 15 cm from the adjacent furrows.

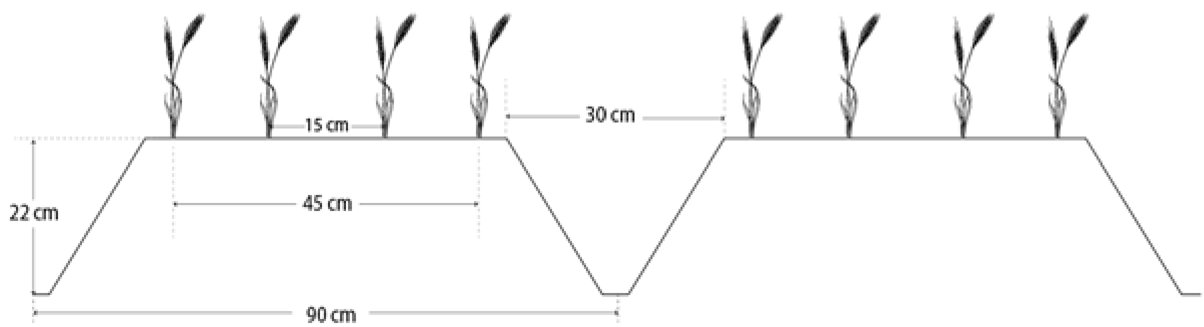


Figure 5: Geometry of bed & furrow for wheat crop

Wheat was sown in November of each study year, on flat borders using zero till drill without any cultivation and on raised beds using Bed Planting seed drill machine with seed rate of 123.5 kg/ha for all treatments. The fertilizer application to all treatments was same as recommended by the Agriculture Department of Punjab i.e. 111 kg N and 86 kg P per hectare. Farmers practiced broadcast method for sowing of wheat. Farmers applied soaking (pre-planting) irrigation before broadcasting whereas, at the R&D Centre no soaking was applied in both treatments.

2.5.4 Rice Bed Planting

On well prepared land, rice seedlings were transplanted on the beds following the pattern of wheat sowing after flooding the field (Figure 6). In this practice, bed-furrow system of 90cm (60 x 30) cm was developed adjusting the machine sowing system on wheat geometry. Following this procedure, four lines were available on each bed as a guide to transplant the rice seedlings in lines keeping plant to plant distance of 21 cm. After developing the bed-furrow system, the furrows were flooded a day before the rice nursery transplantation onto the beds. Calculation shows that there were about 202,960 plants/ha in bed-furrow system while there were 171,350 plants/ha in traditional planting of rice (farmer practice). Initially, field was kept under flooding from 10 to 15 days to control weeds and better stand of nursery seedlings. The period of flooding could be reduced using chemical control of weeds. For conventional rice transplanting, field was flooded and water standing with the continued supplement irrigation. 30 days old developed rice nursery was transplanted manually by maintaining plant to plant and row to row to distance 23 cm.

Figure 6: Bed formation, flooding in furrows and transplantation of rice nursery on beds

2.6 Data Collection

After completion of sowing, three places were selected / marked at head, middle and tail in each plot. Data regarding rice-wheat tillering were collected by counting number of tillers per plant in one square meter from each marked place in every plot. Date of sowing/transplanting, harvesting and other crop yield parameters like plant height, spike length, number of grains per spike, 1000-grain weight, grain yield were recorded as following (Tables 3 & 4).

Table 3: Agronomic parameters of wheat crop

Year	**2017-18**			**2018-19**			**2019-20**		
Sowing Method	**BP**	**ZT**	**Farmer**	**BP**	**ZT**	**Farmer**	**BP**	**ZT**	**Farmer**
Seed rate (kg/ha)	100	125	125	100	125	125	100	125	125
Variety	FSD-2008	FSD-2008	FSD-2008	FSD-2008	FSD-2008	FSD-2008	FSD-2008	FSD-2008	FSD-2008
Date of sowing	26-Nov	23-Nov	25-Nov	18-Nov	11-Nov	20-Nov	20-Nov	15-Nov	12-Nov
Date of harvesting	23-Apr	23-Apr	1-May	28-Apr	28-Apr	30-Apr	26-Apr	26-Apr	30-Apr
Plant population (plants/ha)	618,376	678,965	655,412	610,847	695,378	668,245	527,710	634,194	675,615
Average tillers per plant	16	12	9	17	11	10	16	11	10

Table 4: Agronomic parameters of rice crop

Year	**2018**			**2019**			**2020**		
Sowing Method	**BP**	**Conv.**	**Farmer**	**BP**	**Conv.**	**Farmer**	**BP**	**Conv.**	**Farmer**
Variety	Supper Basmati	Supper Basmati	Supper Basmati	Supper Basmati	Supper Basmati	Supper Basmati	Supper Basmati	Supper Basmati	Supper Basmati
Date of sowing of nursery	23-May	23-May	25-May	19-Jun	19-Jun	20-Jun	12-Jun	12-Jun	14-Jun
Date of transplantation	8-Jul	4-Jul	9-Jul	21-Jul	24-Jul	30-Jun	12-Jul	16-Jul	25-Jul
Date of harvesting	30-Oct	30-Oct	2-Nov	6-Nov	6-Nov	10-Nov	29-Oct	29-Oct	31-Oct
Plant population (plants/ha)	201,000	195,011	168,000	228,440	181,934	176,061	207,433	186,466	169,975
Average tillers per plant	17	14	15	18	16	17	22	19	18

2.7 Irrigation Scheduling

Irrigation scheduling was followed at a MAD (Management Allowed Deficit) level of 50% depletion of soil moisture in flat sowing (controlled conditions). Irrigation scheduling was done using tensiometers. The active root zone of the crops at the farm varies from 50 to 75 cm depending upon the soil type. Initially, active root zone of wheat and rice crops were chosen as 30.5 cm in sandy loam. At the time of irrigation application, available soil moisture was 6.4 cm. The first irrigation was applied at 50% MAD level i.e., 3.2 cm moisture content along with required dose of fertilizers. The relationship between amount of water applied (Q), time of application (t), area to be irrigated (A) and depth of water to applied was calculated as below.

$$QT = 27.78\ A.d \quad \ldots (1)$$

where:

T is the time of irrigation (hrs)

d is the depth of water applied (cm)

A is the area to be irrigated (ha)

Q is the discharge (lps)

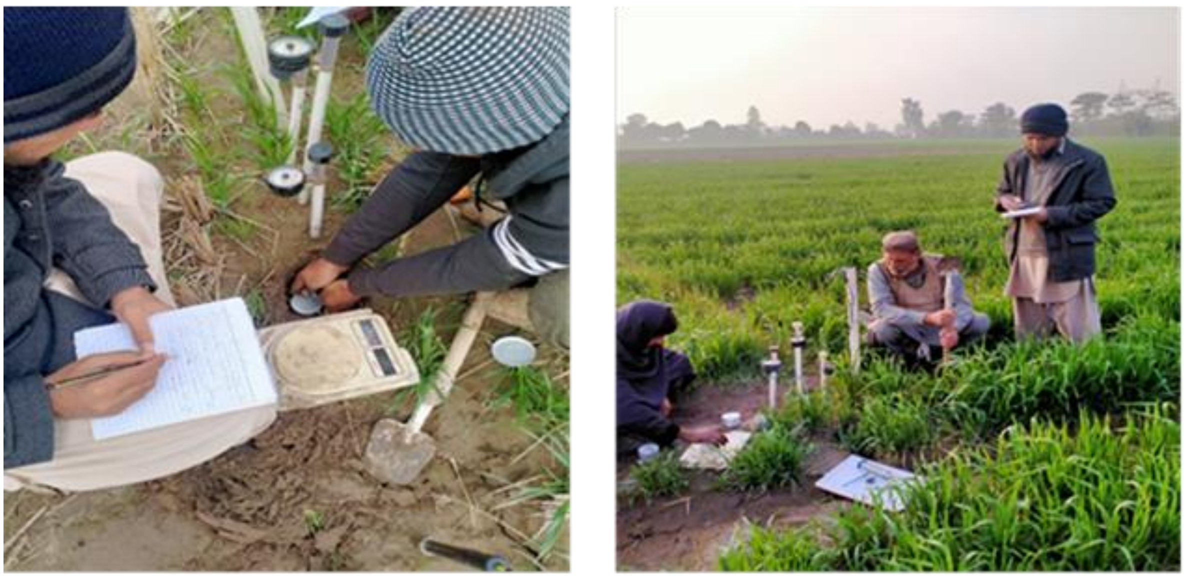


Figure 7: Soil sampling and recording tensiometer reading for soil moisture determination

2.8 Water Use Efficiency (WUE)

Water use efficiency (WUE) was computed by dividing crop yield (kg/ha) of each treatment with total volume of water applied per hectare (irrigation + rainfall). (Humphreys et al, 2008a).

Rainfall data was recorded using a rain gauge installed within the meteorological station (Figure 2). The total amount of water (input water) applied was computed as the sum of water received through irrigation (I) and rainfall (R). Fertilizer was applied following the same as in farmer's practices i.e. broadcasting of fertilizers before sowing, with first and second irrigation. The fertilizer rates were also selected based on local farmers practices i.e., one bag DAP, one bag Urea before the sowing and one bag of Urea during first irrigation or during first and third irrigation in case of wheat.

2.9 Soil Moisture Characteristics

The amount of soil water that is available to the plant from its seed germination to maturity. Available soil moisture content (ASMC) is dependent on the soil characteristics such as field capacity and wilting point. Different soils have different characteristics. These are determined by the soil characteristic curves. The soil type of study site is sandy loam. Soil samples taken from the field and developed a soil moisture characteristic curve in the PCRWR soil physics laboratory, Islamabad. By using the curve, field capacity and wilting point at suction pressure of 326 centimeter and 15300 centimeter was determined respectively (Figure 8).

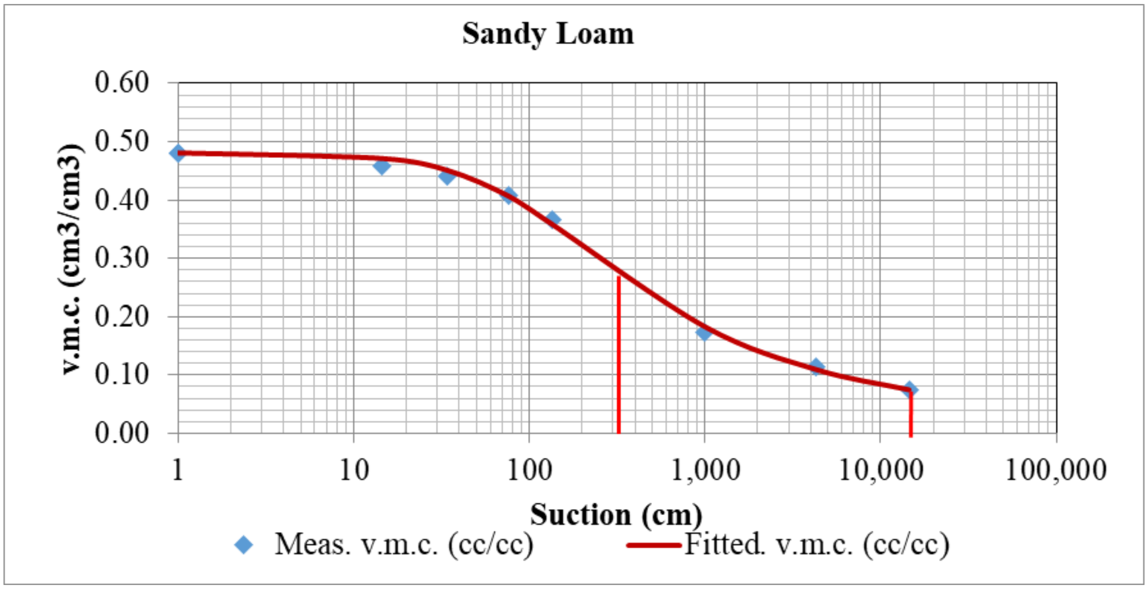


Figure 8: Soil moisture characteristic curve for Sandy Loam soil

Field Capacity at 326 cm suction = 0.28

Wilting Point at 15300 cm suction = 0.07

Available Soil Moisture (vol. %) = FC-WP= 0.28-0.07 = 0.21

Multiply ASM to desired depth i.e. 15.2 cm = 0.21x15.2 = 3.2 cm

2.10 Crop Yield

The crops under both treatments were harvested with combine harvester and the yields were measured by weighing the grains with a balance on whole plot basis and the average yield of each treatment was calculated (Figure 9). As the harvesting was done with combine harvester, there were no straw produced.

Figure 9: Harvesting of rice and wheat crops on beds

2.11 Rooting Depth

The effective root zone depth (ERZD) refers to the depth of soil that is actively utilized by plant roots for water and nutrient uptake under proper irrigation. After harvesting of each crop, lateral and vertical root lengths were measured which provides information on the distribution of roots within the soil profile. Proper management of irrigation and nutrient application based on the ERZD can improve crop growth and yield (Figure 10).

Figure 10: Measuring rooting depth (lateral) after harvesting

2.12 Economic Analysis

The cost of production and net income of each crop was calculated. The cost of production included non-water and water costs incurred from planting to harvesting were recorded. Gross income is a monetary measure for the total production and it was calculated by using the Govt. support rates for wheat grain and auction rates for rice grains during the trial years. The cost of production varied mainly due to flat and furrow fields and the amount of water used for two treatments. Cost for non-water inputs was the same for both treatments.

2.13 Statistical Analysis

All collected data on bed planting of rice-wheat was compared to traditional transplantation/sowing methods. A paired-t test was conducted at 95% significance level to determine if there was a significant difference between the two methods. The results were analyzed for statistical significance.

2.14 Farmer's Perceptions

This study focuses on evaluating the influence of raised bed planting technology. This evaluation is based on the analysis of three years' worth of field trial data and insights gathered directly from farmers. A survey was carried out to delve into farmers' viewpoints regarding the practice of bed planting for rice-wheat cultivation. The survey also encompassed details about their socioeconomic background and distinct farm attributes.

3 Results and Discussion

3.1 Crop Production Parameters

These parameters describe the growth behavior of the crop. Proper plant population, tillering and plant height are prerequisite for obtaining higher productivity, assessing growth and provide an idea of predictable biomass and crop productivity. The emergence count is also a key indicator of predicting crop productivity. Results in Table 5 show that tiller production was higher in bed planting compared to conventional methods, resulting in better plant health. Wheat and rice plants were generally sustained on the beds relative to conventional methods which could be due to rapid drying of the beds than flats, greater surface area and the greater concentration of roots in the bed tops (Singh et al., 2009). Overall performance was best with bed planting and irrigation at 50% depletion. Statistical analysis showed no significant difference in crop growth parameters, such as tiller count, plant height, spike length, grain count per spike and grain weight between different planting methods. Thus, bed planting can promote plant health without affecting crop growth.

Table 5: Crop production parameters of wheat and rice (average 2018-20)

	Wheat					Rice				
Treatments	**No. of tillers per plant**	**Plant height (cm)**	**Spike length (cm)**	**No. of grains per spike**	**1000-grain weight (g)**	**No. of tillers per plant**	**Plant height (cm)**	**Spike length (cm)**	**No. of grains per spike**	**1000-grain weight (g)**
BP	16[a]	116[a]	9[a]	60[a]	40[a]	368[a]	103[a]	27[a]	101[a]	27[a]
ZT	11[a]	106[a]	9[a]	48[a]	35[a]	-	-	-	-	-
Conventional	9[a]	111[a]	10[a]	52[a]	38[a]	355[a]	108[a]	26[a]	76[a]	25[a]
Farmer	11[a]	98[a]	11[a]	50[a]	38[a]	348[a]	99[a]	24[a]	86[a]	24[a]

***Note**: Means sharing common letters do not differ significantly at 5% probability level.*

3.2 Water Application

3.2.1 Wheat

The irrigation was done by examining the in-situ soil moisture using tensiometers that were installed in all treatments. For easy soil moisture depletion monitoring, when the pressure gauge of tensiometer reached to 40 centibar, soil moisture was at 50% of manageable allowable deficit (MAD) i.e., 3.2 cm. On an average, 19 cm water was used under bed plantation method and 28 and 34 cm in zero tillage and conventional (broad costing) method respectively whereas, farmer applied 43 cm in conventional practices (Table 6). Soil moisture deficit is the amount of water required to bring the soil moisture content back to the field capacity (Ashraf et al., 2017). According to the regular monitoring of soil moisture, only four irrigations were applied to both treatments, while farmers applied four to five. This is depicted in Figures 11 and 12 which displays the number of irrigations and water depth for the treatment with bed planting, zero tillage and the farmer's field where no irrigation scheduling was used. The straight horizontal line (red) indicates the maximum allowable deficit which was set at 50% moisture depletion. Soil moisture depletion shows that how much moisture has been dried out in soil just before irrigation. Before each irrigation, moisture content was within the limits of available moisture content in both of the treatments. Figure 11 and 12 also shows depth of water applied against the soil moisture deficit. The depth of water applied was always greater than the soil moisture deficit. It was mainly due to the non-uniformity in water application (Ashraf et al., 2002). The farmer's field received an average of 43 cm of water through five irrigations, which is nearly double the amount applied in fields with an irrigation schedule. The figure also explains the psychology of the farmers towards their old mindset that wheat crop needs 4-5 irrigations. They thought that from sowing to harvesting after every 20 to 28 days, they should apply irrigation to wheat crop irrespective of the actual condition of soil moisture.

The trends in Figure 11 show that there was less water applied in bed plantation in comparison to conventional methods. The depth of water is directly related to moisture depletion and it was higher under flat method and the lowest under bed planting. During 2017-18, total water applied was more as compared to 2018-19 and 2019-20 respectively in bed planting, zero tillage and conventional at R&D centre except farmers. So, use of water applied is in the order of soil moisture depletion. During 2017-18, total water applied was more than the second and third year mainly due to the differences in weather conditions, such as less rainfall observed in 2017-18 i.e. 4 cm while 14 and 21.6 cm during 2018-19 and 2019-20 respectively. On flat sowing, more moisture stress conditions occur due to combination of higher surface evaporation and more transpiration. Similar results have been reported by Ahmad (2002). On an average, the difference in amount of water applied is significant between conventional (farmer) and bed plantation. The difference in water applied at farmers' and experimental sites could be due to the differences in management practices. The conventional plots at R&D centre are also under controlled conditions i.e. proper LASER leveled, whereas farmer's plots do not have proper LASER leveled and they apply water according to their mindset bed planted wheat received 27, 15 and 15 cm irrigation water that was 31, 46 and 12% lower than zero tillage treatment whereas 41, 63 and 65% lower than farmer practice respectively (Table 6). The results showed that bed-planted wheat received on an average 32% lesser irrigation water in comparison to zero tillage and 56% lower than the farmer's practice, respectively (Figures 11 & 12). This indicates that the BP wheat system requires less water for irrigation, potentially making it a more water-efficient method of cultivation compared to conventional wheat sowing.

Previous research studies on evaluating the bed planting irrigation method have largely been conducted on a small scale, using experiments that followed consistent irrigation management practices (Kukala et al., 2010). These studies typically involved the application of reduced amounts of irrigation water to both flat and bed plots, through scheduling irrigation events on the same day and/or by intentionally applying less water to the beds. However, these studies did not examine the performance of conventional wheat sowing under similar conditions of reduced irrigation water application, thereby limiting the insights that can be gained from these experiments. The practicality of reducing irrigation in full-sized conventionally tilled farmer's fields may be challenged by poor/no leveling and large irrigation block size relative to flow rate. This leads to the need for a larger amount of water to cover the entire field. However, the use of furrows or beds can help mitigate this issue. By hastening the flow of irrigation water to the other end of the field, the amount of water needed can be reduced as the furrows take up less than half of the total field area. The reported irrigation water savings for wheat on beds are generally larger in farmers' fields viz. 45–54% in Haryana (Singh et al., 2002), 34% in Pakistan (Kahlown et al., 2006) than in small plot studies (0–33%) (Sharma et al., 2002; Lauren et al., 2008). In the current study, which is conducted in a larger field, showed that using laser leveling and bed planting in wheat fields resulted in significant water savings compared to traditional tillage practices. On average, laser leveling led to a 21% reduction in irrigation water use, while beds/furrows resulted in a 34 % decrease (Kahlown et al., 2006). Despite the widespread use of traditional tillage techniques by farmers, those who grow wheat using bed planting have seen an increase in yield by 8%, a reduction in irrigation water usage by 25%, and lower operational costs by 25% as compared to flat-planted wheat using conventional tillage methods (Tripathi et al., 2017).

Table 6: Comparative analysis of water applied, yield and WUE of wheat on bed planting, zero tillage, conventional and farmer field

Wheat												
Year	**Irrigation (cm)**				**Yield (Kg/ha)**				**WUE (kg/m³)**			
	BP	**ZT**	**Conv.**	**Farmer**	**BP**	**ZT**	**Conv.**	**Farmer**	**BP**	**ZT**	**Conv.**	**Farmer**
2017-18	27 [a]	39 [a]	44 [a]	46 [b]	3350 [a]	3210 [a]	3266 [a]	3318 [a]	1.24 [a]	0.82 [a]	0.74 [a]	0.72 [a]
2018-19	15 [a]	28 [a]	38[b]	41 [b]	3634 [a]	3635 [a]	3420 [a]	3390 [a]	2.42 [a]	1.30 [a]	0.90 [a]	0.83 [b]
2019-20	15 [a]	17 [a]	21 [a]	43 [b]	4360 [a]	4220 [a]	4250 [a]	3450[b]	2.90 [a]	2.48 [a]	2.12 [a]	0.80 [b]
Average	***19*** [a]	***28*** [a]	***34*** [a]	***43*** [b]	***3735*** [a]	***3688*** [a]	***3645*** [a]	***3386*** [a]	***2.19***[a]	***1.53***[a]	***1.25***[a]	***0.78***[b]

Note: *Means sharing common letters do not differ significantly at 5% probability level*

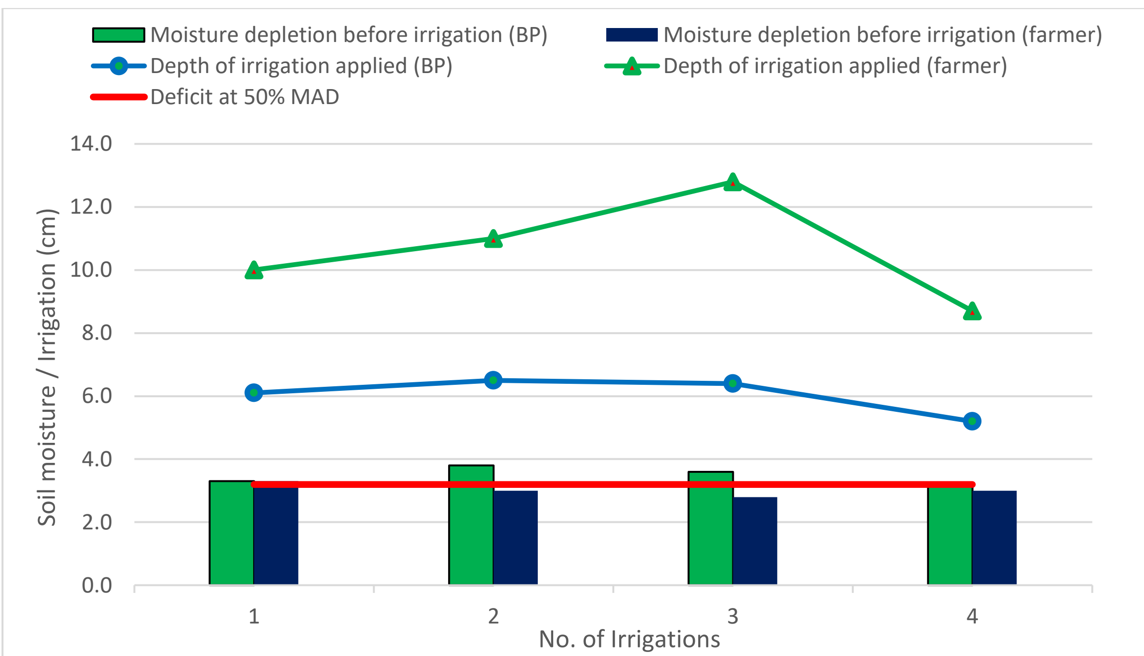


Figure 11: Moisture deficit and irrigation depth applied to wheat crop (BP & farmer)

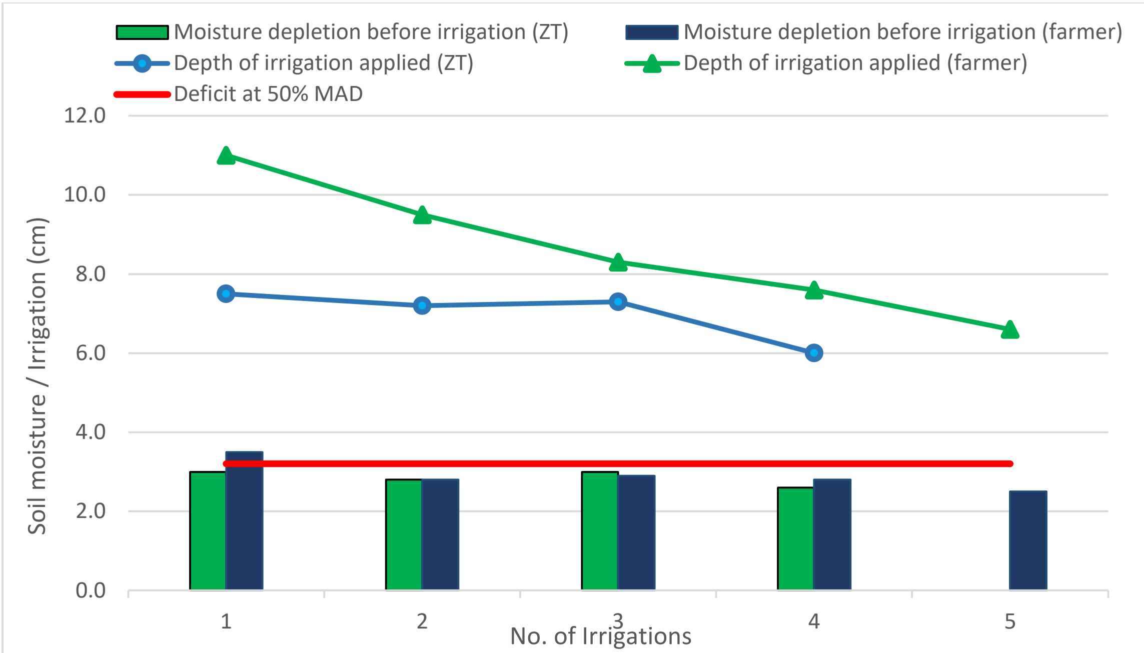


Figure 12: Moisture deficit and irrigation depth applied to wheat crop (Zero Till. & Farmer)

3.2.1.1 Yield

The grain yield of a crop is the net resultant of various factors which contribute to certain extent in determining the productivity of any system. It is valid criterion for comparing the efficiency of different treatments. Table 6 indicates that during three years of study, there was a slightly increase in grain yield under bed planting and zero till method as compared to flat sowing (BC). The average grain yields were found to be 3735, 3688 and 3386 kg/ha for bed, zero tillage and broad casting (farmers) respectively, which were in close agreement to those reported by Ahmad and Mahmood (2005). Overall, increase in grain yield for bed planting in comparison to broad casting (farmers) was found to be 10%. The results concluded that the crop under low water application in bed planting did not feel any water stress causing reduction in yield, but only reduced amount of over irrigation causing losses. These results reveal the advantages of bed planting and zero till over broad costing. The good production on raised beds resulted due to better and strong crop stand, which could be due to high fertilizer use efficiency under low intensity of weeds. Besides, there is less chance of nitrate leaching due to non-flooding irrigation under bed-furrow system (Majeed et al., 2015). Similarly, lodging reduced as a result of drainage of rainwater from the furrows and tough anchorage of plants/roots in the soil. Similar advantages of planting wheat on beds have been reported by Sayre and Moreno Ramos (1997), Hobbs et al., (1998) and Niaz et al., (2011). The differences in grain yields were found non-significant in 2018 and 19 and significant in 2020. The reason for the low yield of the farmer is that farmer applied five irrigations and last irrigation at the stage of grain ripening which is unnecessary and causing the crop lodging. Irrigation after milking stage can cause damage (Jeesica, 2017).

3.2.1.2 Water Use Efficiency (WUE)

Water use efficiency is an indicator that tells how much of the water (irrigation/rainfall) has been used for crop production. Any effort that tends to increase crop yield or reduces the amount of water needed, without reducing the crop yield, increases the WUE. Enhancing WUE will be a key pathway to future food security (Mu et al., 2009). As the soil of beds is more porous, water intake and storage in the beds was relatively higher which increased the water use efficiency of the crop.

As reported by various researchers, raised bed technology is an improved irrigation method that not only saves water and improves water use efficiency but also increases yield. The results of the study firmly confirm the findings of previous researchers. Over the three years, water savings in wheat bed plantations exceeded those of the conventional method and traditional farmer practices by 44% and 56%, respectively. Meanwhile, average water use efficiency in wheat bed plantations was 75% and 81% higher compared to conventional methods and traditional farmer practices, respectively. Additionally, the ZT method also demonstrated superior water use efficiency, surpassing the conventional method and traditional farmer practices by 22% and 96%, respectively. (Table 6). Differences among different treatments for WUE was found highly significant, with maximum WUE of 2.90 kg/m^3 in 2019-20 as least amount of water was applied. The reported average WUE of wheat in Pakistan Punjab, Indian Punjab and Imperial Valley USA is 0.45, 0.8 and 1.0 kg/m^3, respectively (Briscoe and Qamar, 2006). In this study, the average WUE of wheat grown on beds is 2.19 kg/m^3 which is better than the reported average of Pakistan, Indian Punjab and USA. Naresh et al., (2017) revealed that WUE of wheat on beds was 2.20 kg/m^3 as compared to broadcasting i.e., 1.29 kg/m^3 in India. Niaz et al., (2005) reported WUE of wheat on raised beds and flat planting were 2.35 kg/m^3 and 1.28 kg/m^3 respectively. Waraich et al., (2010) found an increase of 18–45% higher WUE (water use efficiency) without yield increase under bed planting with furrow irrigation in comparison with conventional flat planting with flood irrigation.

The higher WUE values of wheat can be explained by the lower evaporative demand from the atmosphere in winter and early spring (caused by lower temperatures and less solar radiation) when wheat was grown than in summer when rice was grown (Zwart and Bastiaanssen, 2004). Mann et al., (2003) evident that in Pakistan, wheat sown on 70 cm bed and furrow system in the rice-wheat area of Punjab produced good yields due to better spike length, number of grains per spike. Mollah et al. (2015) studied the raised bed planting method of wheat in Bangladesh and found higher wheat productivity by planting wheat on beds in the rice-wheat cropping system. Over the past 20 years, farmers in the irrigated production areas in the northwest state of Sonora in Mexico have adopted an innovative system by which wheat is planted in defined rows on top of beds with irrigation supplied in furrows between the beds. Now with more than 95% farmer acceptance of this planting method for wheat as well as all other crops in their cropping systems, dramatic improvements in irrigation water use efficiency have occurred and farmers are taking advantage of the field access provided by this planting method to improve N management (Wang et al., 2004). Results indicated that raised bed planting technology has a lot of potential to increase water productivity of wheat. Thus, it is suggested that maximum wheat area should be brought under bed planting to save irrigation water.

3.2.2 Rice

3.2.2.1 Plant Population

Plant population is one of the major concerns in the bed planting system especially in the case of rice. Efforts were made to address this concern by adjusting planting geometry of the crop lines. It was observed in experiments conducted for the evaluation of different bed-furrow systems that water saving increases with the increase of bed size; however, lateral intake of irrigation water into the bed limits the bed size (Niaz et al., 2011). Calculations indicate that 90 cm bed furrow system matches the traditionally required number of the rice lines and meet the required plant population. The average plant population used to be 200,000 and 160,000 – 175,000 per hectare for bed planting and conventional transplantation respectively. The recommended rice plant population by the Agriculture department is 200,000 per hectare. But in reality, farmers planted only 135,000 – 170,000 per hectare (Figure 13). The reason behind low population density on flat sowing is the labor planted rice nursery in flooded field without taking care of plant to plant and row to row distance whereas, in bed sowing water is standing only in furrows and top surface of bed is visible therefore, labor can easily maintain plant population. That results in higher plant population densities in bed planting compared to traditional transplantation.

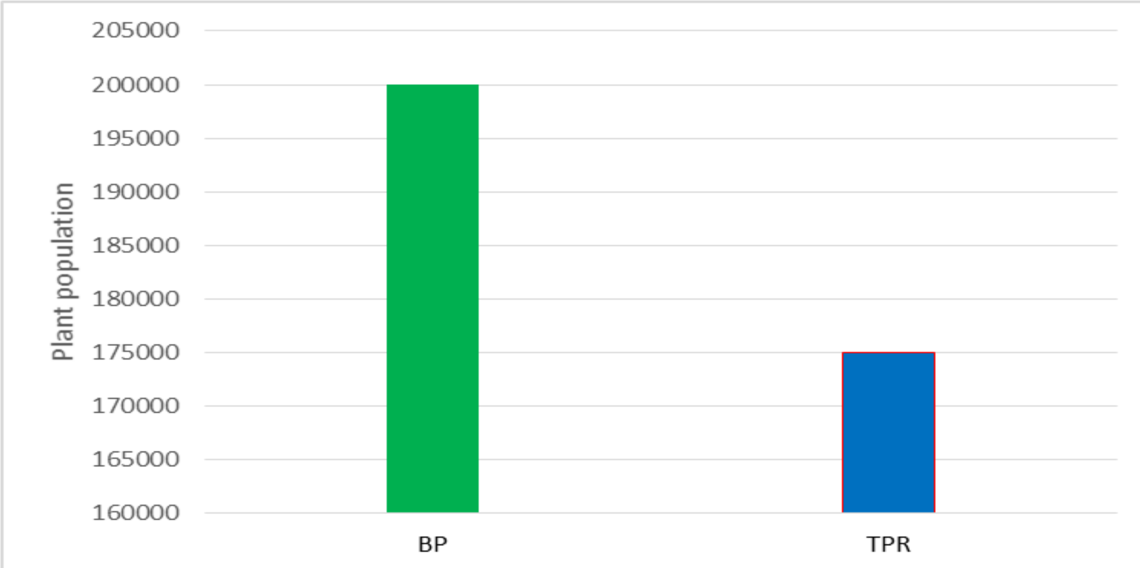


Figure 13: Average plant population on BP and TPR

3.2.2.2 Water Application

There was difference in the number of irrigations applied to the rice crop under both treatments. Initially in bed plantation, irrigation scheduling was not possible because after transplanting, 20-30 days furrows were filled with water so rice nursery roots got stable into the beds. But after 30 days irrigation scheduling was set initially 10 % MAD to 30% MAD. The frequent irrigations in furrows were applied to maintain soil moisture in beds at saturation level. Therefore, it was observed 30-32 and 45-50 days of irrigation intervals in bed planting and conventional methods respectively.

The average time of irrigation observed for one acre was 30 to 45 minutes and during the first 3 weeks after transplanting, the furrows are filled to the top every day, while after that, the furrows are filled about three-fourths of their height to ensure proper irrigation and maintain adequate moisture in the soil. However, the farmers are irrigating their fields for a longer period of time i.e., 60 to 90 minutes, almost on a daily basis to keep water standing in the field. Farmers applied irrigation daily after transplantation (20 to 30 days) as needed to keep the seedlings alive. Figure 14 shows that farmers (Transplanted Puddled rice TPR) applied abundant amount of water (302 cm) without any reason for the satisfaction of their minds that without water, rice will be ruined while BP used only 161 cm of water. However, the water applied depends on the soil type, rice variety and climatic conditions. During farmer’s interview, it was concluded that “where there is no water, no rice” but PCRWR and other research agencies proved that rice can be grown on raised beds successfully with limited water applications.

Table 7: Comparative analysis of irrigation, yield and WUE of Rice on bed planting, conventional and farmer's (TPR) field

Rice									
Year	**Irrigation (cm)**			**Yield (Kg/ha)**			**WUE (kg/m^3)**		
	Bed Plantation	**Conv.**	**Farmer (TPR)**	**Bed plantation**	**Conv.**	**Farmer (TPR)**	**Bed plantation**	**Conv.**	**Farmer (TPR)**
2018	130 [a]	261 [b]	310 [b]	3340 [a]	3430 [a]	3360 [a]	0.26 [a]	0.13 [a]	0.11 [a]
2019	179 [a]	299 [b]	296 [b]	2743 [a]	3334 [a]	3063 [a]	0.15 [a]	0.11[b]	0.10 [a]
2020	146 [a]	313 [b]	301 [b]	3970 [a]	3977 [a]	3857 [a]	0.27 [a]	0.13 [a]	0.13 [b]
Average	***161*** [a]	***291*** [b]	***302*** [b]	**3324[a]**	**3580[a]**	**3427[a]**	***0.19*** [a]	***0.13*** [b]	***0.11[b]***

Note: *Means sharing common letters do not differ significantly at 5% probability level.*

On average 161, 291 and 302 cm water were applied under bed plantation, conventional plantation and farmer field respectively (Table 7). Bed plantation used 47% less water compared to the farmer's practice. This is because the area for irrigation in bed-furrow planting is one third less than in basin flood irrigation and requires less water depth. Additionally, furrow irrigation improves the water absorption phase, reducing the irrigation time and increasing irrigation efficiency (Niaz et al., 2011). Same findings were derived Kukala et al., (2010) in 2006 when fresh beds were introduced for rice, irrigation applications to the fresh beds tended to be lower than to the TPR (by 11 and 24%), on the sandy loam and loam, respectively. Bed plantation also offers benefits such as better weed control, reduced lodging, no need for puddling and energy savings. Earlier research has shown that changing from flat to bed layouts alters the hydrology of the system and allows greater control of irrigation, better surface drainage and possibly better capture and use of rainfall. The irrigation water moves laterally from the furrow into the bed and is driven upwards towards the bed surface by evaporation and capillarity, and downwards largely by gravity. The altered hydrology affects nutrient transformations and transport compared with irrigation on the flat (Farooq et al., 2009). The rice nursery is planted on the bed surface and irrigation is applied through the furrows. The bed surface remains almost dry and the lateral water movement fulfills the crop water requirement. The infiltration rate of the furrow bottom remains almost zero due to compaction developed by tractor and machinery movement and irrigation which facilitates the lateral water movement of irrigated water into the bed area. Statistical analysis showed that the average difference in water applied between conventional and bed plantation is significant. The water depth applied was significantly higher in conventional and farmer fields compared to bed plantation. Naresh et al., (2014) evident that transplanted rice on beds resulted in 15%–24% less water application than TPR. Other evidence from the United States and Australia also indicates water savings for rice grown on beds compared with flooded rice. For example, on fine-textured soils in Missouri in the USA, furrow irrigated rice used approximately one-half the water of flooded rice (Tracy et al., 1993). Also, on fine-textured soils in subtropical Queensland, Australia, rice grown on beds with saturated soil culture used 32% less water than that on flat surfaces with permanent flood established from the three-leaf stage (Ockerby and Fukai, 2001).

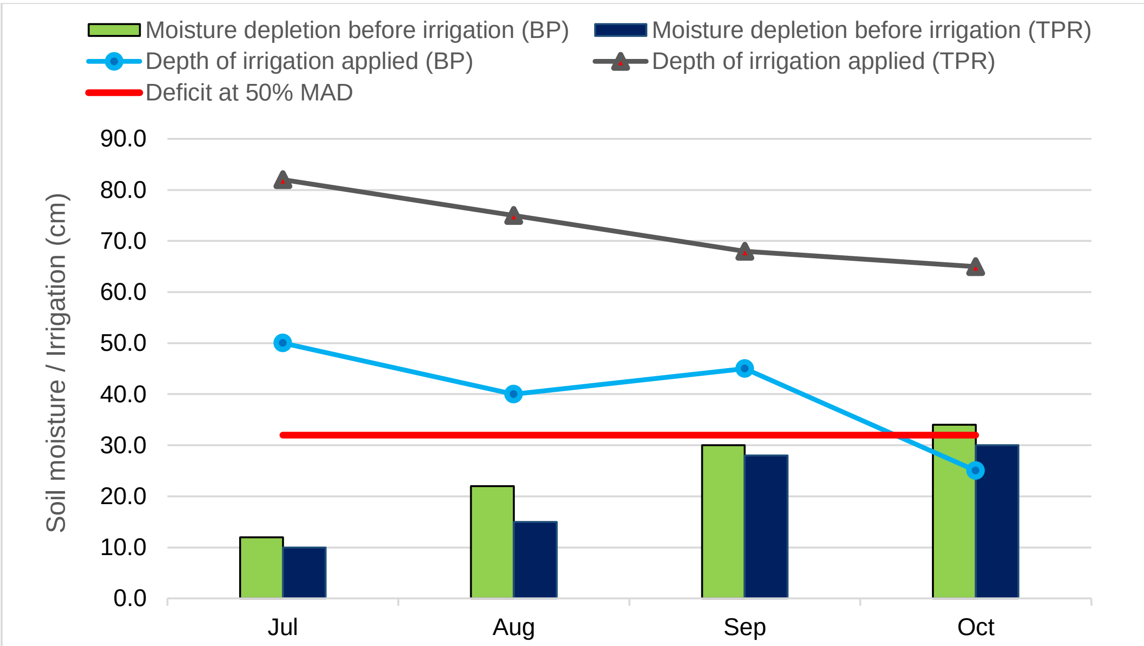


Figure 14: Moisture deficit and irrigation depth applied to rice crop (BP & TPR)

3.2.2.3 Yield

Rice on beds performed better in respect of yield components over puddled method. Manjunatha et al., (2009) also derived similar type of findings from their experiment on rice. Number of grains per panicle and test weight (1000 grains) both were found higher in transplanted rice on beds over conventional (Table 5). Same results were reported by Kahlown et al., (2007) and Naresh et al., (2014) that a higher number of panicles per square meter in BP compared to TPR and higher levels of spikelet sterility in rice planting on beds than TPR. Rice yield on raised beds that were kept around field capacity remained 3-17% lower than under conventional transplanted conditions and 0.6% lower than farmer field whereas 3% higher yield was obtained during 2020 (Table 7). The lower yield may be due to the adverse soil conditions for rice nursery growth. Moreover, in these three years severe attack of rust was observed on rice crop especially on bed planting rice which may be the cause of lesser yield. According to Naresh et al., (2014), rice grown on beds was found to be more susceptible to water stress compared to TPR, leading to lower yields. However, the water- and labor-intensive operation of puddling can be skipped without any decrease in yield for rice production. Results from Bangladesh suggest that the performance of rice on beds depends upon soil type. For example, rice used less water and had better growth on beds compared with the traditional puddled system on a fine-textured clay soil at Joydebpur, while its performance was poor on a coarse-textured soil at Nashipur. Humphreys et al., (2005) and Kukal et al., (2005) concluded from analyzing various early reports on the raised bed system in the Indo-Gangetic Plain that with transplanting on beds, rice yields were ‘‘similar or lower compared with puddled flooded transplanted rice’’.

There is no significant difference found in the yields between bed plantation, conventional and farmer practice during study period 2018-20 (Table 7). These results coincided with those obtained by Sandhua et al., (2012) that rice transplanted on fresh beds, produced statistically equal yield as produced by puddle flat. Similar result was reported by Kukala et al., (2010) that yield of rice on beds was within 7–15% of yield of transplanted rice, with no significant difference on the sandy loam. This indicates that significant amount of precious water can be saved in bed plantation without compromising the yield. More results from previous studies, it appears that the performance of rice on beds in the IGP is variable relative to conventional TPR in terms of yield and irrigation or input water use and water productivity (Balasubramanian et al., 2003; Sharma et al., 2002). Many reports show similar yields with BP and TPR, while some find that BP is inferior. Analogously, research from the United States and Australia highlights water conservation benefits for bed-planted rice compared to flooded rice. In Missouri, USA, fine-textured soils supported furrow-irrigated rice that used only half the water of flooded rice (Tracy et al., 1993). Similarly, subtropical Queensland, Australia, saw a 32% reduction in water usage for rice grown on beds with saturated soil culture, compared to flat surfaces with a continuous flood established from the three-leaf stage (Ockerby and Fukai, 2001).

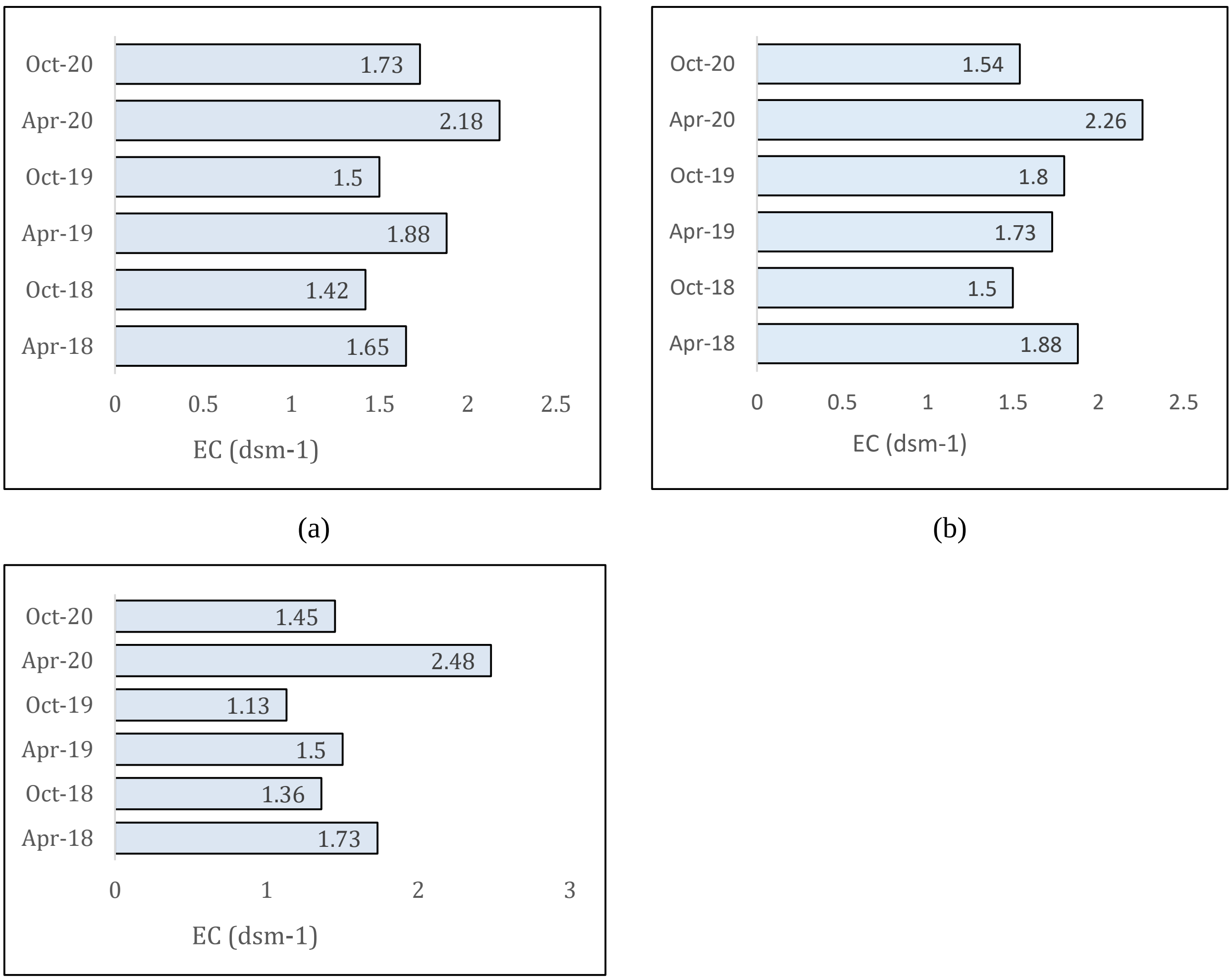
3.2.2.4 Water Use Efficiency (WUE)

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).

It was found that WUE and water saving were significantly higher in bed plantation as compared to farmer’s field. The water use efficiency of rice transplanted on beds varied from 0.15 to 0.27 kg/m^3 as in (Table 7). On an average, WUE of rice on beds was 46 & 73 % higher than the conventional and farmer practice respectively. The water saving in bed planting directly relates to water productivity. This study has shown greater water saving of 40-53% and 40-58% in bed planting as compared to conventional and farmer practice respectively. Researchers found that furrow and bed planting saved about 60 cm of irrigation water from transplanting to harvest and about 44 to 50% more water productivity than traditional plantings (Jagroop et al., 2007). In comparison with the traditional planting methods, planting rice on beds or furrows can extensively increase the productivity of irrigation water. It increased rice yields by 4%, water productivity by 66% and water savings by 38% (Meleha et al., 2008). Transplanting rice in bottom of beds significantly increased grain yield and water productivity by 3.45% and 58.1% respectively, while saved irrigation water by 35.2% as compared with traditional transplanting methods (El-Atawy, 2012). Naresh et al., (2014) showed that wide raised beds saved approximately 15–24% of irrigation water compared with continuously flooded rice. Many researchers and farmers have also shown that it is possible to grow transplanted rice on beds, but with variable performance in comparison with puddled transplanted rice in terms of yield and irrigation water amount (Humphreys et al., 2008a). The potential for conserving irrigation water through rice cultivation on raised beds is evident in multiple studies. Compared to transplanted puddled rice, savings in irrigation water ranged from 9% to 58% in various studies (Sharma et al., 2002; Balasubramanian et al., 2003; Jehangir et al., 2007; Bhushan et al., 2007), with the highest savings attributed to intermittent irrigation on beds compared to continuously flooded transplanted puddled rice (Choudhury et al., 2007; Humphreys et al., 2008b;).

3.3 Soil Health

Crop residues are an important source of soil organic matter and vital for the sustainability of agricultural ecosystems. About 25% of N and P, 50% of S and 75% of K uptake by the cereal crops is retained in crop residues, making them valuable nutrient sources (Singh, 2003). Nevertheless, the practice of retaining straw is infrequent in the rice-wheat farming systems of Pakistan. Typically, wheat and rice straw are harvested from the fields for purposes such as cattle feed and house thatching, leaving minimal residue for incorporation into the soil. This practice has led to the deterioration of soil physico-chemical properties. Consequently, it has resulted in a decline in soil organic matter levels within these cropping systems and hindered the optimization of nutrient uptake and absorption efficiency. It is, thus, necessary to manage the paddy soils with the objectives to increase soil organic matter content, increase biological activities, reduce exchangeable sodium and improve soil physical conditions for keeping lands productive on sustainable basis. The goal can be achieved with good management techniques including application of amending materials, balanced fertilization and appropriate tillage practices. Several factors affect soil salinity levels, such as quantity and quality of irrigation water, depth of water table, soil type, rainfall, etc. Figure 15 reveals that there was no fluctuation in the electrical conductivity (EC) over the course of the study. However, after rice was harvested, the EC decreased, likely because rice is a reclamative crop (Soomro et al., 2015). At the R&D Centre, the EC of the groundwater and soil is favorable, so there is no issue with soil salinity accumulation. The findings align with those of Timsina et al., (2001), who found that raised beds can help mitigate salinity issues by allowing salts to drain out through furrows. However, there is a risk of salt accumulation on the beds where evaporation occurs.



(c)

Figure 15: Soil salinity buildup in the soil profile under different treatments a) bed plantation b) zero tillage and c) conventional practice

Fertility in the soil depends on the quantity of the fertilizers applied, nutrients taken up by the crops and crops grown (Ashraf et al., 2017). Figure 16 shows that there was an upward trend in the levels of both phosphorus and potassium in a BP from 2018 to 2020. Additionally, the concentration of these elements was initially low in comparison to a conventional plot, but it gradually increased over the following years. In the BP, the fertilizer was applied directly to the beds, while in the conventional plot, it was applied through broadcasting. The gradual increase in the levels of phosphorus and potassium in the BP plot over the next years suggests that the fertilizer application method was effective in conserving the nutrients. The broadcasting method can result in wastage of nutrients, as some of the fertilizer may not be absorbed by the soil or plants, leading to a lower overall concentration of the nutrients. The higher nutrient uptake in bed planting is mainly due to less leaching loss of nutrients and availability of sufficient moisture for mineralization of native as well as applied nutrients. The higher up-take efficiency of nutrients depends on a myriad of factors including nutrient availability due to favorable soil biota under crop establishment techniques compared to conventional puddled transplanted rice (Naresh et al., 2014).

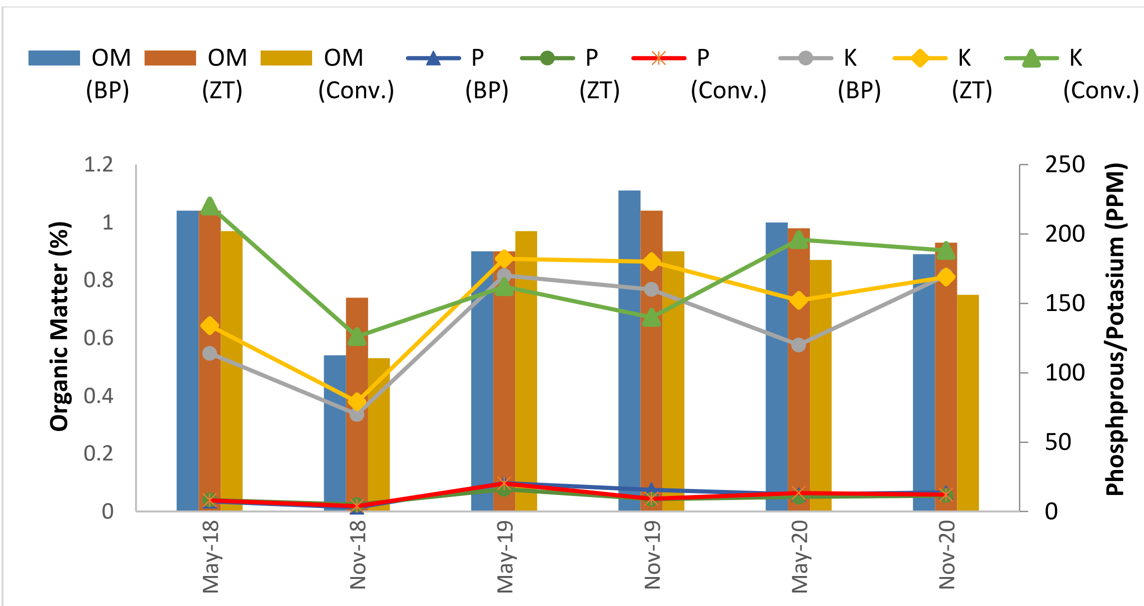


Figure 16: Organic Matter (OM), Phosphorus and Potassium concentration in soil

3.4 Rooting Behavior

The effective root zone depth is the depth of the soil used by the main body of the plant roots to obtain most of the stored moisture and plant food under proper irrigation. It is not the same as the maximum root zone depth. As a rule of thumb, about 70% of the moisture extracted by the root is obtained in the top half of the root zone; about 20% from the third quarter; and about 10% from the soil in the deepest quarter of the root zone (Ashraf, 2015). Root zone depth varies according to the effective soil depth, fertility management, and rooting characteristics of the plant. The application of irrigation water should be limited to an amount that will penetrate only to the effective root zone depth. Applications in excess of this amount will result in the wastage of water and add pumping costs. Additionally, in the light textured soils, heavy applications may cause the leaching of plant food away from the plant feeder roots. Crop production parameters are directly proportional with the development of root system and availability of nutrients to the plants (Hussain et al., 2013).

In agriculture, it is also commonly accepted that a larger root system is better for plant growth. However, to efficiently utilize below-ground resources, it is essential to have a well-developed root system that is adequately distributed in the soil to capture water and nutrients. The effectiveness of the bed planting method is evident in the root system, as it promotes optimal root development for plants. The positive effect of the bed and furrow irrigation method was also evident from the root system. The length of primary roots of the BP method was greater than those from the conventional irrigation method. The range of primary root length for BP and conventional flooding method in wheat and rice crop were 4 to 30 and 4 to 23 cm and 4 to 24 and 3 to 20 cm respectively (Tables 8 & 9). It was also evident by Humphreys et al., (2005) that in the subsurface layers, a greater number of roots were found under the bed compared to the flat. These results also coincided with the report of Romij et al., (2009) that during vegetative growth, more than 70% of the total root length was located in the top 15 cm of soil, and that the root system extends no deeper than 40 cm, with at least 90% of it being confined to this depth. These findings are consistent with the results obtained in this study. It was also observed that roots for the BP method were healthier than conventional irrigation method. The total surface area of roots was positively associated with individual root length, indicating that there are greater numbers and surface area of the root system in the B&F (17 to 35 cm) than the conventional irrigation system (14 to 30 cm) in rice crop. Whereas in wheat, it was 24 to 38 cm for BP and 20 to 30 for conventional method and in zero tillage, it was 20 to 33 cm observed. The short rooting length in TPR is due to puddling because hard surface appears in puddled field. Therefore, roots of the plant do not sink further down and they stay close to the surface in search of nutrients and water. According to Martinez et al., (2008), TPR has some drawbacks such as the formation of a hardpan at a depth of 15-30 cm, which can increase soil compaction and bulk density, resulting in hindered root growth of the crop. Consequently, farmer has to irrigate frequently. Whereas the plant roots on beds go down due the softness in bed surface and take out the food and water. Root color is also an important indicator for root vitality. It was observed that under the conventional flooding method, the root system of the paddy rice was deteriorated, likely due to the reduced conditions under long-term flooding that resulted in the depletion of oxygen. In contrast, under the permeable irrigation condition, gas conductance was high and the amount of reduced materials was low, allowing the development of a healthier root system (Chunlin He., 2010). Half-distance between rice root axes in the top 10 cm of soil range between 0.5 to 1.5 cm possibly contributing to significant interplant competition for immobile nutrient such as P and K (Craig et al., 1995). Uptake rate depends on the root surface area as photosynthetic rate depends on leaf area. The diameter of the rice root is more or less analogous to one another even though varieties are different. Cultivars also differ in their root development. Although the pattern of root length development is the same, early maturing cultivars produce less total root length than late maturing cultivars (Romij et al., 2009).

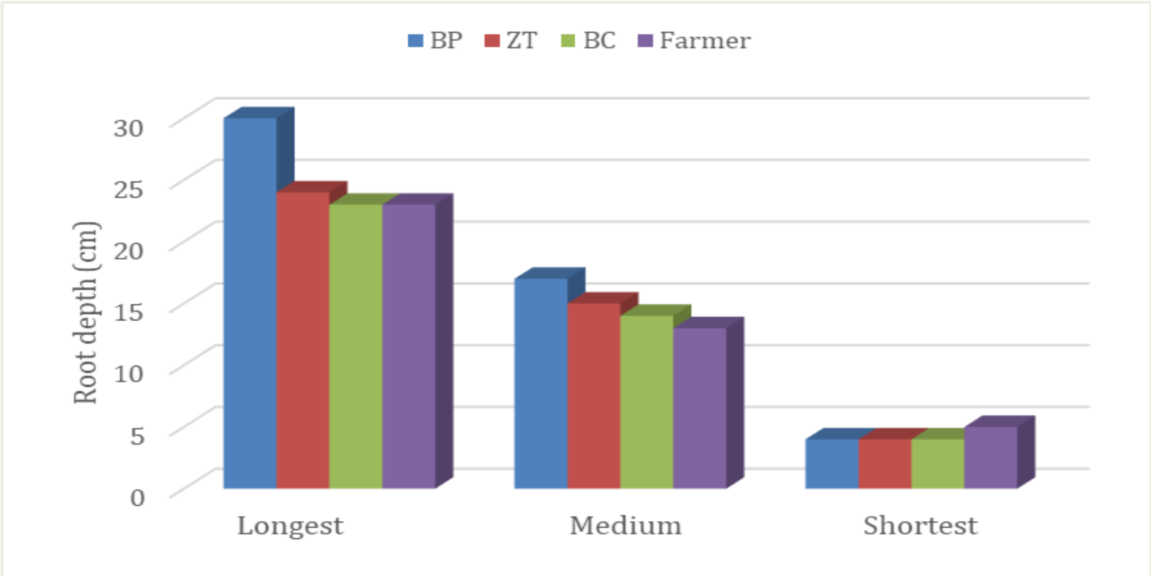


Figure 17: Average rooting depth of wheat crop (2017-20)

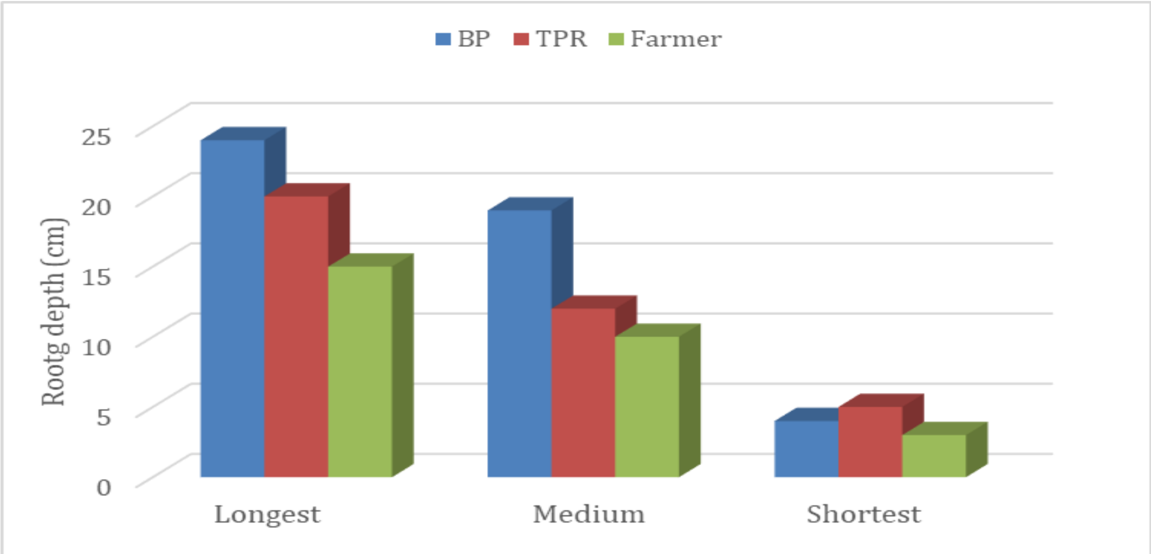


Figure 18: Average rooting depth of rice crop (2018-20)

Table 8: Average rooting depth of wheat crop (2017-20)

Method	Rooting Depth (cm)			Surface Area (cm)
	Longest	Medium	Shortest	
Bed Planting	30	17	4	24-38
Zero Tillage	24	15	4	20-33
Broadcast	23	14	4	20-30
Farmer	23	13	5	20-28

Table 9: Average rooting depth of rice crop (2018-20)

Method	Rooting Depth (cm)			Surface Area (cm)
	Longest	Medium	Shortest	
Bed Planting	24	19	4	17-35
TPR	20	12	5	14-30
Farmer	15	10	3	15-28

Figure 19: Wheat roots measurements *Beds* *Zero Tillage*

Figure 20: Wheat broad casting *Farmer field*

Figure 21: Rice on Beds *Conventional* *Farmer*

3.5 Economic Analysis

Net income/ profitability of the farmers is the most important indicator for the success of any crop or management practice. A higher gross income resulting from a high cost of production may not be an appropriate option as high portion of the income may be offset by the corresponding high cost of production (Ashraf et al., 2017).

Rice is a labor-water intensive crop. It's cost of production was 36 and 58% higher, as compared to those for wheat on beds and conventional sowing. However, there was no significant difference for cost of production, gross income and net income for wheat and rice between the two treatments.

Table 10 and 11 indicates the economic analysis of bed planting technology of per hectare rice-wheat production for cropping season 2017-20. The total production cost, gross income and net income were calculated for both crops. In the study, total cost of production includes land preparation, seed, fertilization, plant protection (pesticide and weedicide), manual labor charges, irrigation cost, harvesting and threshing.

Total cost of production of wheat on beds was 12% higher than farmer practice where as 4% lower than zero tillage method because there is no land preparation requires in zero tillage sowing method of wheat. It was also observed the large saving of inputs in bed planting cultivation which reduced per hectare cost of production. The net income of bed planting was 2% and 21% higher than that of zero tillage and broadcast methods. Similarly, Mehran et al., (2017) reported that net return for wheat crop was 48% higher in bed planting technology as compared to flat broadcast sowing. The whole picture depicted the absolute advantage of bed planting technology over traditional sowing of wheat. The statistical analysis reveals that there is non-significant difference in net income whereas differences among water cost of treatments were found significant. It means if a farmer adopts furrow irrigation method, he can save available fresh water which can be used in another field (Table 10).

For rice, on an average, under bed plantation the cost of production was 34% lesser and net income was 20% higher as compared to farmer/conventional transplantation. The basic reason of less cost of production was water cost which was 45% lesser than that of the conventional rice transplantation method. This may be answer of the question usually raised by the farmers that furrow irrigation requires a greater number of irrigation intervals. In furrow irrigation, the number of irrigations could be the same as practiced by the farmer or less with a short time duration. It is also evident that if we follow proper irrigation scheduling with the help of soil moisture instruments extra irrigation water can be saved which is being applied by the farmers without any reasoning. From statistical analysis, it was found that there was no significant difference in net income however, there was a significant difference in cost of water and production for rice between the bed and flat plantation (Table 11). Choudhury et al., (2007) reported that water inputs were reduced by 32–42% compared with flooded rice, but could also be accomplished with dry seeding on flat land with the same water management practices. Reduced water inputs and yield reductions balanced each other so that net profit was comparable among most of the treatments. Moreover, Naresh et al., (2014) reported that in rice cultivation on beds, the saving in inputs was mainly due to the reduced cost in land preparation and planting method (63%–78%), irrigation water (8%–24%), and labor.

Table 10: 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**
2017-18	58650^{a}	53870^{a}	63870^{a}	7290^{a}	10530^{a}	11880^{ba}	65940^{a}	64400^{a}	75750^{ab}	130650^{a}	125190^{a}	127374^{a}	64710^{a}	60790^{a}	51624^{a}
2018-19	62570^{a}	57260^{a}	67560^{a}	4215^{a}	7868^{a}	10678^{ba}	66785^{a}	65128^{a}	78238^{ab}	145360^{a}	145400^{a}	136800^{a}	78575^{a}	80272^{a}	58562^{a}
2019-20	70550^{a}	64850^{a}	76050^{a}	6195^{a}	7670^{a}	8260^{a}	76745^{a}	72520^{a}	84310^{ab}	200560^{a}	194120^{a}	195500^{a}	123815^{a}	121600^{a}	111190^{a}
Average	63923^{a}	58660^{a}	69160^{a}	5900^{a}	8689^{a}	10273^{ba}	69823^{a}	67349^{a}	79433^{ab}	158857^{a}	154903^{a}	153225^{a}	89033^{a}	87554^{a}	73792^{a}

Note: *Means sharing common letters do not differ significantly at 5% probability level.*

Table 11: 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**
2018	57965^{a}	82540^{a}	82890^{b}	35100^{a}	70470^{b}	71650^{b}	93065^{a}	153010^{b}	153100^{b}	173680^{a}	230360^{a}	230800^{b}	80615^{a}	77350^{a}	77850^{a}
2019	64830^{a}	75837^{b}	78658^{a}	50299^{a}	84019^{b}	85300^{b}	115129^{a}	159856^{b}	159967^{b}	145379^{a}	176702^{b}	176920^{a}	30250^{a}	16846^{a}	16975^{a}
2020	70475^{a}	95440^{a}	96365^{b}	51035^{a}	92335^{b}	92850^{b}	121510^{a}	187775^{b}	188050^{b}	166320^{a}	222712^{a}	222800^{b}	44810^{a}	34937^{a}	35200^{a}
Average	***64423***^{a}	***84606***^{b}	***85971***^{b}	***45478***^{a}	***82275***^{b}	***83267***^{b}	***109901***^{a}	***166880***^{b}	***167039***^{b}	***161793***^{a}	***209925***^{a}	***210173***^{a}	***51892***^{a}	***43044***^{a}	***43342***^{a}

Note: *Means sharing common letters do not differ significantly at 5% probability level.*

4 General Discussion, Conclusions and Recommendations

4.1 The Potential of Raised Beds

Changing from flat to bed layouts alters the geometry and hydrology of the system and offers greater control of irrigation, drainage and its effects on the transportation and transformation of nutrients and possibly better capture and use of rainfall. During irrigation of bed and furrow systems, water moves horizontally from furrows into the beds (subbing), pulled upward towards the soil surface by evaporation, transpiration, and capillarity, and downward largely by gravity.

4.2 Education and Social Dynamics

Education is an important factor as it broadens farmers' intelligence and enables them to perform the farming activities accurately and efficiently. Moreover, better educated farmers tend to be more innovative and can use the resources efficiently (Fakoya et al., 2007). One major hurdle in acceptance is changing the mind-sets of farmers concerned since the phrase 'the more you till, the more the yield' is stubbornly adhered to and difficult to overcome. Technically, adoption in Pakistan is hindered by uneducated forefather's mindset that rice-wheat cannot be grown on beds. Especially rice crop cannot grow without standing water. Their thinking alone does not accept this method of cultivation. Lack of awareness is another reason of non-adoptability of BP. The need of the time is to allocate more resources and efforts to divert media towards creation of awareness among young farming community about conservation of natural resources. Mehran et al., (2017) found that young and educated farmers are more likely to adopt bed planting technology as compared to old aged farmers. Sajida et al., (2013) concluded that more access to education and other social indicators increases the chances of adoption of new technologies in the farming community. However, the small farmers can also be benefited with the technology with proper education regarding the technology in the area with good social mobilization for the conservation of scarce and valuable farm resources.

4.3 Adoption of Rice Bed Planting–Farmers Views

The performance of transplanted rice on beds was evaluated in district Toba Tek Singh during 2017-18. PCRWR played a major role, and best efforts were made to introduce bed-planting of rice using a newly developed bed-planting machine or ridger in close collaboration with the Agriculture Extension Department. A total of 155 and 137 farmers adopted bed and ridge planting, respectively, representing a significant increase compared to the previous year when only 6 farmers practiced it in tehsil Kamalia. The area under bed and ridge transplantation was about 110 and 102 hectares, respectively.

We interviewed 114 farmers and visited their fields, which revealed significant variation in rice nursery transplanted on beds/ridges compared to flat sowing. On average, there were 247,000 and 111,150 to 136,000 plants per hectare for bed/ridge planting and conventional transplantation, respectively.

There was a slight difference in the number of irrigations applied to the rice crop between bed/ridge planting and the conventional method. In bed/ridge planting, more irrigations were used, but the average time for each irrigation was shorter, typically ranging from 110 to 150 minutes. During each irrigation, the furrows were filled to about three-fourths of their height. In contrast, with the conventional method, farmers irrigated their fields for 220 to 300 minutes (almost daily) to maintain standing water in the field. Farmers reported a 50% reduction in irrigation water usage and a 20-30% decrease in fertilizer consumption with bed/ridge plantation. They also acknowledged that bed/ridge planting offered better control over weeds, prevented lodging, eliminated the need for puddling, and conserved their energy.

The experiences of farmers and researchers in western Uttar Pradesh, Punjab, and Haryana, India, provide further evidence of the water-saving potential of rice cultivation on beds. Based on pumping time, rice on beds utilizes 25–50% less water, while still achieving comparable growth and yield to traditional cultivation (Connor et al., 2003).

4.4 Benefits of the Resource Conservation Technologies (RCTs) in Terms of Water Use and Crop Lodging

A review of the studies conducted by Sajida et al., (2013) and Mehran et al., (2017) shows that farmers are adopting the new RCTs quickly. Adoption of RCTs could be even faster if it is possible to have sufficient machinery available from small-scale manufacturers. Farmer feedback on water savings with these new technologies essentially says that they save water. For zero tillage, farmers report about 25–30% savings. This comes in several ways. First, zero tillage is possible just after rice harvest and any residual moisture is available for wheat germination. In many instances, where wheat planting is delayed after rice harvest, farmers have to pre-irrigate their fields before planting. Zero tillage saves this irrigation. Savings in water also come from the fact that an untilled soil has less infiltration than a tilled soil and so water flows faster over the field. That means farmers can apply irrigation much faster. Because zero tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cutting down on subsequent irrigation, water use is reduced by about 10 cm/ha, or approximately 1 million/ha. An additional benefit is less waterlogging and yellowing of the wheat plants after the first irrigation, which are common occurrences on normal ploughed land. In zero tillage, less water is applied in the first irrigation and this yellowing is not seen.

Farmers also report water savings in bed planting. Farmers commonly mention 30–50% savings in this system. Farmers also indicate that it is easier to irrigate with bed planting. Obviously, around half the field space is used for water and so less water is used. The question is whether farmers need to apply more frequent turns of irrigation with this system. Planting rice on beds, farmers estimated that they used 50–65% less water than on the flat. They kept the beds flooded for the first week, but were then able to cut down on irrigation frequency later on.

BP offers scope for use of even saline water. When saline water is applied in a raised-bed–furrow land configuration, it permits salt movement to the top of the raised beds, keeping the root zone relatively free of salts below the furrow. This improves the ability of the plants to avoid early salt injury at seedling stage and subsequently improves the salt tolerance of the crop due to crop ontogeny. When combined with mulching or residue retention, bed planting has the potential to reduce evaporation losses from the soil surface and salinization and to further improve crop productivity in saline environments.

BP and ZT can be more beneficial in levelled fields. This is being promoted in Pakistan as a means of improving water efficiency. However, when this is combined with zero tillage, bed planting and non-puddled rice culture, plant stands are better, growth is more uniform and yields are higher. The use of permanent-bed systems and zero tillage results in less soil disturbance and reduces the need for future levelling. Laser land leveling technology was introduced in Punjab during 1985 by the OFWM, Punjab and since then is struggling to introduce this technology to the farmers. About 10,000 LASER units have been provided to the farmers and imparted training to 6,000 farmers/service providers/LASER operators in Punjab during (2015-18) under the development project "Provision of LASER land levelers to farmers/service providers on subsidized cost" through OFWM Department.

One of the most chronic constraints to crop production is the grain yield reduction near the crop harvest stage by lodging worldwide. This is more prevalent in cereal crops, particularly in wheat and rice. Studies proved that bed planting is to be useful to control lodging of crop. This method ensures easy drainage of excessive water from the field after heavy rain which leaves the plants less likely to be lodged. Furthermore, if lodging occurs, the lodged rice-wheat on beds revived its stand after few days, which did not happen in conventional sowing method.

4.5 Constraints in the Adoption of Bed Technology

A question also arises that if bed planting has so much benefits, then why it is not being adopted by the farmers, at large scale? Major reason for non-adoption of this technology is non-availability of bed planting machinery and farmer's capacity to use it. Another reason is the lack of awareness about bed planting especially at Gujranwala, Hafizabad, Sheikhupura, Sialkot, and Sargodha districts. Other reasons pointed out by the farmers were that they don't need it because they are abundant with canal water, more time and cost required in the land preparation especially in Sialkot district. As mentioned by 80% of farmers, availability of labor force is also big hurdle in adoption of this technology. This method of plantation is new and laborer don't cooperate with them. They are facing problem at the time of sowing and harvesting. About 25% respondents were of the view that there is need to create further awareness among the farmers regarding sustainable adoption of these technologies. It was suggested by 90% respondents that Government should provide subsidy on bed planting machinery and easy loans for the sustainable adoption of Raised Bed planting and other water saving methods. Another adopting farmer's views that combine harvesting on beds/ridge is an issue and service providers avoid those fields because of fear to damage their combine harvesters. In this process, service providers delay the harvesting of these fields and usually agree for harvesting at the end of season with higher charges (Imtiaz et al., 2018). However, this study shows that technically combine harvester does not face any hassle while harvesting in bed planting fields. During the turning of the machine after each round, a problem was raised that due to the beds, there was not enough space for it to turn. The solution we came up with was to make horizontal beds instead of a vertical at the front and back of the field. Now there is no problem in turning the combine harvester.

4.6 Prospects for Raised Beds

There are additional benefits, including solutions to

Current and impending water scarcity—bed culture promotes the possibility (i) to grow rice/wheat with intermittent irrigation to save water and (ii) to diversify crops to other less water-demanding crops.

Environmental pollution—it can be hypothesized that both groundwater pollution and methane emissions from non-puddled intermittently irrigated rice on beds would decrease compared with those from puddled rice on flat surfaces. (Conversely, leaching of pollutants in the absence of puddling and emissions of nitrous oxides may increase (Connor et al., 2003).

4.7 Conclusions

This study provides compelling evidence of the potential benefits of resource-conserving technologies, particularly the bed planting system, in improving water productivity, enhancing net income and mitigating the negative impacts of conventional rice-wheat production methods. The adoption of bed planting technology could be a promising approach for rice-wheat cultivation in the region. The farmers need to be encouraged to embrace the bed planting system due to its numerous advantages, including water conservation, reduced production costs and increased net income. By utilizing this technique, farmers can address the challenges associated with conventional flat planting methods, such as low irrigation water use efficiency, inefficient fertilizer utilization, soil crusting and crop lodging. However, adaptability and scalability of the bed planting technology across different agro-ecological zones is still a challenge.

4.8 Recommendations

Based on the study, the following recommendations can be made:

1. Educate the farmers with sizable landholdings and tubewells as potential adopters of bed planting technology. Demonstrate the benefits of bed planting through active involvement of the Department of Agriculture Extension Punjab in the cotton-wheat and rice-wheat agro-ecological zones.

2. The government to providing subsidies for field implements like rice-wheat bed planters and drills to encourage adoption of raised bed technology. However, more awareness and capacity building are needed through agricultural extension to promote this important technology in Pakistan.

3. To ensure the success of resource-conserving technologies, a partnership approach with expanded stakeholders and participatory approaches is essential. Farmers should be allowed to experiment and provide feedback to facilitate accelerated adoption of raised bed technology.

4. Raised bed technology can help combat the devastating effects of natural disasters like high winds and rainfall, which are leading cause of crop lodging. Enhancing anchorage strength through bed planting can help improve plant anchorage.

By implementing these recommendations, farmers can benefit from the cost savings, increased income, and water conservation advantages of raised bed technology, leading to sustainable food production, improved farmer livelihoods, and reduced negative effects on the environment.

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Annexure-I

Questionnaire for Data Collection at Farmers' Fields Regarding Rice-Wheat Crop for Water and Crop Productivity

Location: Latitude___________________ Longitude_________________________

1. Name of the Farmer:____
2. Secondary occupation if any:____
3. Village_____________________Tehsil _______________ District ______________
4. Education of the respondent: (i) Primary____(ii) Middle_____(iii) Matric _________ (iv) FA____ (v) Graduate______(vi) Postgraduate_________ (vii) Illiterate __________
5. Land tenure (i) Self __________(ii) Share crops__________ (iii) On lease_________
6. Total farm size ___________ acres
7. Cultivated ________________acres
8. Area under Rice/Wheat Crop_______________ acres
9. Date of Nursery Sowing_____________________________
10. Date of transplantation________________________
11. Variety of Rice/Wheat______________________________
12. Irrigation method: Border________ Furrow ______ Basin______ Other___________
13. Sources of irrigation: (i) Canal______ (ii) Tubewell _______ (iii) Both______________
14. Distance of farm from the canal outlet ___________ft.
15. After how many days, you apply irrigation___________ days
16. How many hours you apply irrigation __________________hours
17. Number of irrigations during the crop season_________________
18. Discharge: Canal (measurement by flume)_________ cusecs; tubewell _____ cusecs
19. Delivery Size _________________________ inches

20. Pump Size ____

21. Total water depth being applied ____ mm

22. Share of irrigation water: Canal______________mm, Tubewell_______________ mm

23. Fertilizer being applied____

24. How much fertilizer being applied: DAP____,Urea_,______SoP________(kg/acre)

25. When and how many times of fertilizer application:_____________________________

26. Spray application: Weedicide_______,Herbicide_________, Pesticide________

27. Total crop period/ time__________________________ (days)

28. Plant population _______________________ (plants/acre)

29. Crop Yield _________________________ (mound/acre)

30. Did you receive any training or extension advice?_______If yes from where________

31. Would you like any training?____

32. Do you ever have visits from irrigation/Agri-extention Dept.? (i) Once a month?_____

(ii) Once a quarter____________ (iii) Never ________

33. Would you like to adopt high efficiency irrigations systems? (i) Yes __________

(ii) No __________ (iii) Don’t know __________

What are the constraints to crop productivity?

1. Inadequate water supply ______
2. Inequity in water distribution ______
3. Unreliable water supply ______
4. Warabandi system ______
5. Improper irrigation scheduling ______
6. Maintenance of irrigation system w/c, field channels ______
7. Drainage problem ______
8. Poor water quality ______
9. Waterlogging ______
10. Salinity ______
11. Improper field layout ______
12. Levelling of fields ______
13. Traditional irrigation system ______
14. Growing of high delta crops ______
15. Labour shortage ______
16. High cost of water ______
17. High diesel price ______
18. Difficulty in renting machinery ______
19. Small land holdings ______
20. Fragmented land holdings ______
21. Low yield of crops ______
22. Others ______