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IMPACT OF PUDDLING ON WATER PRODUCTIVITY OF RICE UNDER RAISED BED TECHNOLOGY

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Rice production in Asia needs to increase to feed a growing population. Though a complete assessment of the level of water scarcity in Asian rice production is still lacking, there are signs that declining quality of water and declining availability of water resources threatening the sustainability of the irrigated rice-based production system. In this research work, rice on bed-furrow planting (Raised Bed Technology) was evaluated for water productivity and irrigation water saving. The water balance approach was carried out for different levels of puddled soil with careful measurements of irrigation depth, variation in evapotranspiration, percolation rate and runoff etc. The five treatments i.e. T_o=No puddling, T_2=2 passes of puddler with self-propelled puddler, T_4=4 passes of puddler with self-propelled puddler, T_6=6 passes of puddler with self-propelled puddler, T_c =conventional with three replications of each treatment were used. Finally, the total water applied for each level of puddled soil was calculated. More percolation losses were observed in T_c (991mm) and less in T_6 (734.5mm). Seepage losses were more in T_c (695.5mm) and minimum in T_4 (223.9mm). Maximum rice yield (653.16 g/m^2) was recorded inT_6 and minimum (450.5 g/m^2) in Tc. Maximum water productivity of 0.56 Kg/m^3 was achieved in T_6 and minimum water productivity of 0.25Kg/m^3 in T_c due to more consumption of irrigation water. Thus, puddling in furrows for rice on beds should be adopted to reduce water losses and increase water productivity.
Keywords: Water productivity, water balance, bulk density, grain yield.

INTRODUCTION

In Pakistan, agriculture sector is moving toward an alarming situation due to water shortage, over population and reduced size of land holding. It is worth mentioning that total cropped area in Pakistan is 23.13 million hectares, while 8.22 million hectares is cultural waste and 6.47 million hectares is current fallow (Anonymous, 2017). Rice (*Oryza sativa* L.) is major crop after wheat and is valuable. Pakistan is also an exporter of rice. But its average yield in our country is low than potential yield.

Pakistan grows adequate amount of elevated quality rice to meet the demand of both domestic and international market. Cultivated area under rice is estimated to be 2963 thousand hectares, 17.8 percent more than the last year. The size of the crop is predicted as 7202 thousand tons, 3.3 percent less than the last year (Anonymous, 2019). It may also determine the quantity of water essential for land preparation. Puddling causes destruction of soil structure in rice, which results in a decrease in soil water transmission (Bhaduri *et al.,* 2018; Behera *et al.,* 2003). Consequently, puddling decreases percolation and therefore results in longer standing water in the field, which decreases the irrigation requirement (Patel, 2019; Aimrun *et al.,* 2010). That is how puddling is almost necessary part for sowing of rice crop. Generally, puddling is more advantageous for rain fed area, because it progresses the water holding capacity of soils (Tegenu, 2019; Lathuillière *et al.,* 2018; Aslam *et al.,* 2002). Moreover, under steady water condition, puddled soil can support the rice crop better than non-puddle soil (Ajay and Dewangan, 2006; Arora, 2006). By increasing the strength of puddling, it effects significantly on the depth of puddled layers. This is due to the superior input of energy for higher puddling intensity and result rousing of soil for deeper depths. Puddling is practiced by farmers most probably to minimize weeding intensity or density, create a circumstance suitable for rapid transplanting of rice seedlings and to reduce water and nutrient losses caused throughout percolation (Behera *et al.,* 2003, 2007; Belder *et al.,* 2002, 2004).

The research introduces principles that govern technologies and systems for reducing water inputs and increasing water productivity and assesses the opportunities of such practices for their adoption by the farmers from micro to macro scale (Pearson *et al.,* 2018; Bhushan *et al.,* 2007). Raised bed technology is getting place in agriculture because of saving water on one hand and resulting in increased crop yield on other hand (Bakker *et al.,* 2005, 2007). The practice is useful for rice as well. However, puddling in furrow needs to be evaluated for further improvement in yield and better water productivity (Bouman and Toung, 2001). The main objectives of the study were to compare conventional puddling method with self-propelled puddler in furrows for water saving and water productivity of rice and to compare water productivity of rice in bed furrow system treated with different puddling intensities.

MATERIALS AND METHODS

***Site description*:** The field experiments were carried out on rice during the Kharif season of 2014 in the Khurianwala distributary canal command in province Punjab. The total discharge capacity of the system was about 8143 cusecs, which was being conveyed to its command area through 449.01 Km length of main canal, 2323.9 Km of distributaries / minors and about 4000 outlets.

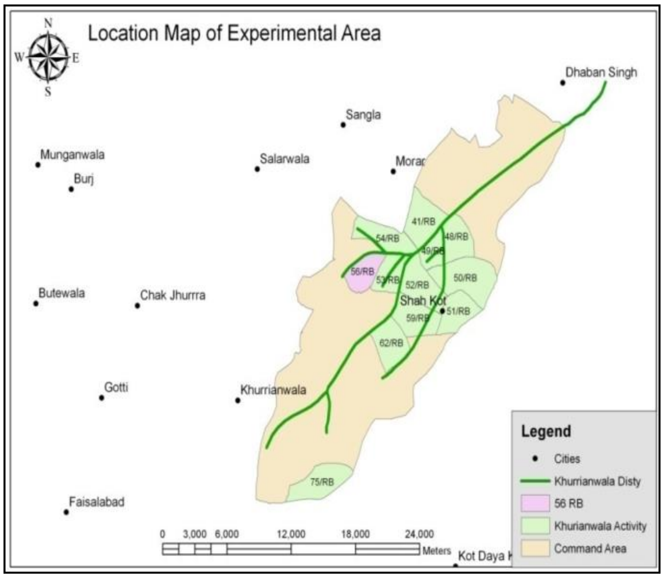

Figure 1. Site map of the experimental area.

Figure 2. Self-propelled puddler.

The extent of Gross Command Area (GCA) was about 2.36 M acres, while the Culturable Command Area (CCA) was about 160 M acres. The total design discharge was 216 cusec and canal command area (CCA) was 46641 acres whereas, total length of the distributary was 37.72 Km. The experimental site was located on the middle of the distributary where both the canal and tube well water were available to conjunctively irrigate the experimental area.

***Experimental design*:** Puddling in furrow was made by self-driven puddler under flooded condition and fresh raised beds were prepared by University bed planter. The beds of 60 cm wide separated by furrows 30 cm wide and 22.8 cm deep were developed. The experiment was laid out in a Randomized Completely Block Design (RCBD) and the five puddling treatments i.e.. T_o=No puddling, T_2=2 passes of puddler with self-propelled puddler, T_4=4 passes of puddler with self-propelled puddler, T_6=6 passes of puddler with self-propelled puddler, T_c =conventional with three replications of each treatment were conducted. The meteorological data during the period of experiment was obtained from weather station of University of Agriculture Faisalabad. Moreover, data regarding depth of rainfall and evaporation were collected at the site by installing rain gauge and pan evaporator and from Pakistan Meteorological Department (PMD) office. Soil texture was determined by using Bouyoucos hydrometer method and Soil bulk density was determined by core method.

***Water balance*:** The water balance of the root zone of a cropped field was calculated in millimeter (mm) by using the water balance equation.

$$I + R = ET + DP + S + R_{off} + dW \qquad \text{Eq.1}$$

Where, I is irrigation applied, R is rainfall, ET is evapo-transpiration, DP is deep percolation below root zone, Sis seepage, R is runoff and dW is change in the soil water storage in root zone, all are in millimeter.

***Plant growth parameters*:** The number of plants m^{-2} was calculated from randomly selected sites from each treatment. The number of tillers per hill was recorded on dates of 15 and 30 at flowering and at harvesting, respectively. On each date the same randomly selected hills were taken for recording the number of tillers. The plant height was recorded at maturity with the help of a meter rod. The height of twenty randomly selected plants per plot was measured from soil surface to the tip of the panicle and then averaged. After harvesting of crop root length was taken for each treatment from randomly selected sites and plants. Rice crop was harvested at maturity, tied into bundles and kept in the field for sun drying. The sun-dried bundles were weighed with the help of balance to record the dry matter production comprising stem leaves etc., straw yield of each plot. The crop yield was later converted into tons /ha. At the time of harvesting, crop was manually harvested from three locations (1 m^2 each) under each treatment. The crop yield calculated using the equation 2.

$$Y = W_g /(A \times 100) \qquad \text{Eq.2}$$

Where; Y is Crop grain yield (tons / ha), W_g is Grain weight (g) and A is Area (m^2).

***Measurement of applied water*:** Irrigation was applied to maintain an average depth of water in each treatment. Irrigation was applying after every second day. The quantity of irrigation water applied was measured by using 8" x 3' cut throat flume.

***Water productivity assessment*:** The water productivity (kg/m^3) is defined as agricultural production produced by consuming a unit volume of water. It was calculated using Eq.3.

$$Water\ Productivity = \frac{Crop\ Yield}{Total\ Volume\ of\ water\ applied} \quad \text{Eq-3}$$

RESULTS AND DISCUSSION

***Soil textural analysis*:** The results shown in Table 1 indicate the percentage of sand, silt and clay found in the soil samples collected at a depth of 0–45.72 cm. The result indicated that the textural class of soil was sandy loam in all depth ranges.

Table 1. Soil textural analysis at depth of 0 – 45.72 cm.

Sr.	Depth (cm)	% sand	% silt	% clay	Texture
1	0.00-15.24	55.17	25.00	18.80	Sandy Loam
2	15.24-30.48	53.23	28.00	18.24	Sandy Loam
3	30.48-45.72	53.72	34.06	13.71	Sandy Loam
	Average	54.04	29.02	16.91	Sandy Loam

***Bulk density*:** The fluctuating pattern of bulk density at 0-30cm depth of soil under different treatments is presented in Figure 3. It was observed that bulk density increased with increasing the puddling intensity and significant difference was observed before and after the puddling. The bulk density before and after puddling was calculated as 1.54 and 1.572 gcm^{-3}, respectively. Results indicated that when puddler was passed six times, it compacted the soil more than conventional method of puddling; bulk density of six passes of puddling was 1.572 gcm^{-3} and 1.568 gcm^{-3} in conventional method. When we compared six passes of puddling with four and two passes of puddling, it decreased by 1.567 and 1.552 gcm^{-3}, respectively.

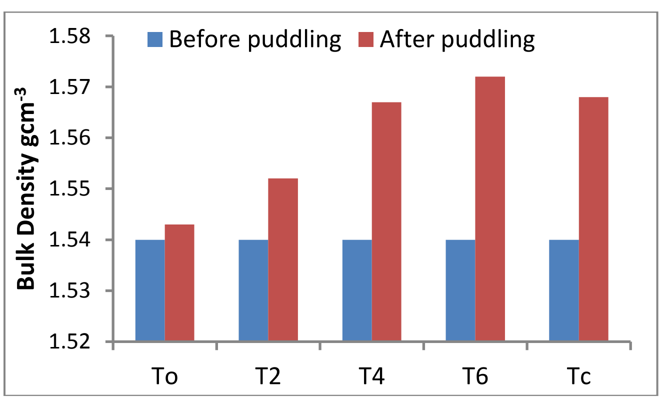

Figure 3. Bulk density of different treatments

***Measurement of water balance*:** Water balance study was conducted to know the total inflow and out flow of the water utilized by each treatment.

***Plant growth parameters*:** Figure 4 represents that T_6 treatment recorded higher number of plants as compared to other treatments while, the lowest treatment was T_c; as the puddling intensity increased, the compaction of soil became less which results in more growth of plants because of improved growth environment in soil; however, high compaction the plants growth. Therefore, the highest production of rice plants was calculated as 17 plants per m^{-2} in T_6 while in T_c average production was 12.33 plants m^{-2}. The remaining treatments; T_o, T_2, and T_4 were at 13.67, 14.55 and 15.22 plants per m^{-2}, respectively. The bar graph also represented that more number of tillers (27) were recorded in T_6 while, least in T_c (17).The number of tillers relates to environmental conditions such as availability of sufficient water, nutrient availability, aeration and irradiation. These all conditions are supposed to enhance in T_6 as compared to other treatments.

Similarly, the highest shoot and root length was measured in T_6 as 143.89 and 34.44 cm, respectively. In contrast, the lowest values were observed as 118.67 and 26.78cm in control method. This is probably associated with anaerobic conditions of the soil in combination with irrigation water. The plant water requirement was almost entirely met by irrigation in 6 passes of puddling and the use of subsoil water stored was limited in less puddled or no puddled soil. In T_1, restriction of root growth was due to less soil water uptake and this water uptake rate enhanced as the puddling intensity increased. The most critical stage for root penetration can be expected at and after the crop establishment phase where roots grow into, and possibly through the puddled layer to tap subsoil water for future growth.

***Straw yield*:** Straw yield is total biomass produced by a crop from a unit area. The straw yield of crop obtained under various treatments is represented in Figure 5. The straw yield due to puddling and 6 passes of roller were significantly greater than other puddling intensities. It is indicated that the treatment T_6 produced maximum straw yield (25.20 tons/ha) while, the treatments under no puddling (20.23 tons/ha) and 2 passes of puddling (21.91 tons/ha) were insignificant.

***Grain yield*:** The efficiency and effectiveness of irrigation and other inputs is reflected by the level of grain yield per hectare. The treatment of 6 passes of puddling treatment produced maximum grain yield 6.53 tons/ha followed by treatment under 4 passes of puddling (6.15 tons/ha), 2 passes of puddling (5.89 tons/ha) and no puddling (5.12 tons/ha). While, minimum grain yield was recorded under control treatment as 4.47 tons/ha. The more passes of puddling make the mud softer and hence the germination of rice transplanting is increased. These results are supported by Aimrun *et al.* (2010) who calculated irrigation water percolation rates and

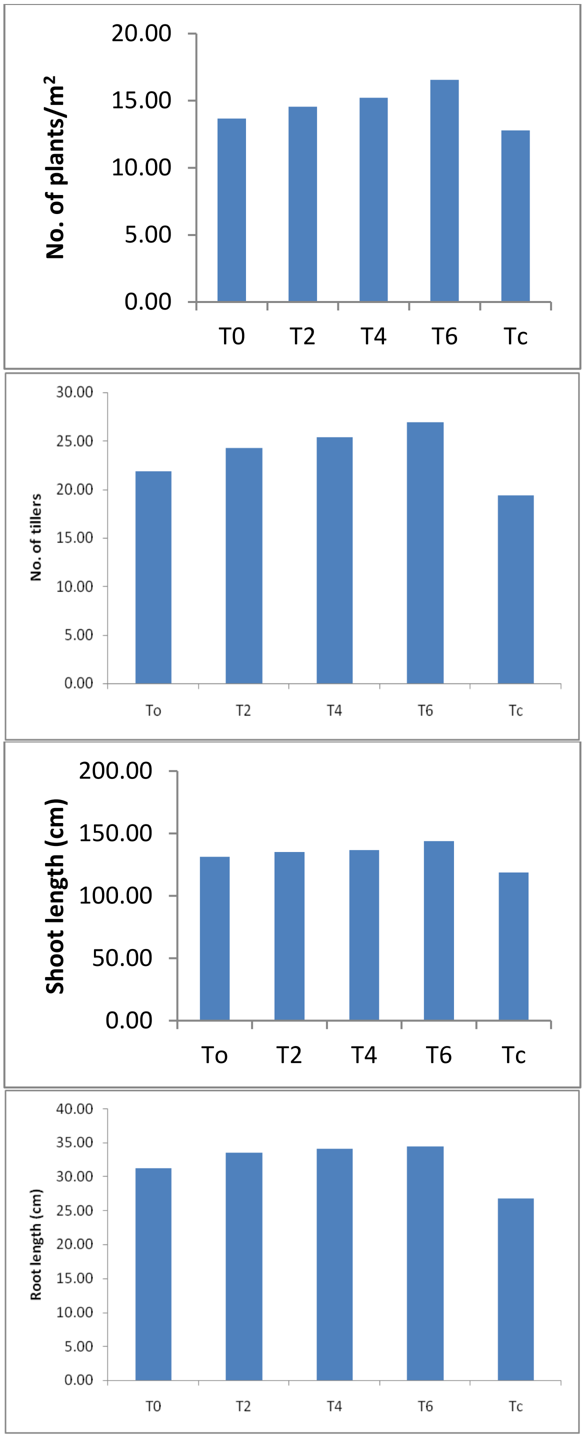

Figure 4. Plant growth parameters achieved under different treatments.

its relation to rice productivity. These results also coincide with Won *et al.* (2005).

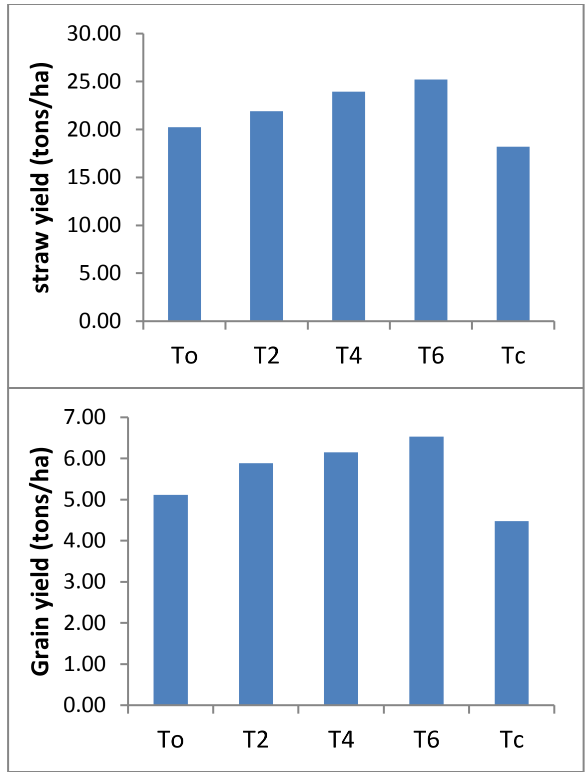

Figure 5. Straw and grain yield achieved under different treatments.

***Depth of water applied*: ** The depth of water applied in each treatment was measured with the help of an 8x3 cut throat flume and an average of 11,050 m^3/ha water was used in treatment under 6 passes of puddling followed by treatment 4 passes of puddling (11,514m^3/ha), 2 passes of puddling (11,990 m^3/ha), no puddling in furrows (12560 m^3/ha) and control (18,424 m^3/ha). , , . Minimum amount of water was applied in T_6 to achieve maximum water productivity while, T6 and T_4 both showed significant results but 2 passes of puddling treatment and no puddling treatment were insignificant. The loss of water by percolation is reduced because of structure less soil and the formation of tillage pan. These results are also supported by Choudhury *et al*. (2007) and Wang *et al.* (2004).

***Water productivity*: ** Water productivity indicates that how efficiently water was used by crop. The maximum water productivity was obtained by 6 passes of puddling treatment as compared to T_4 (0.51 kg/m^3), T_2 (0.49 kg/m^3) and T_o (0.41 kg/m^3). The higher water productivity in T6 is due to multiple factors such as higher germination rate, less percolation losses and increase in availability of nutrients, especially phosphorus, iron and manganese. These results are supported by Belder *et al.* (2004), who observed similar results for increase in water productivity by increasing puddling intensity. These results are also supported by Cabangon *et al.* (2004) and Belder *et al.* (2002).

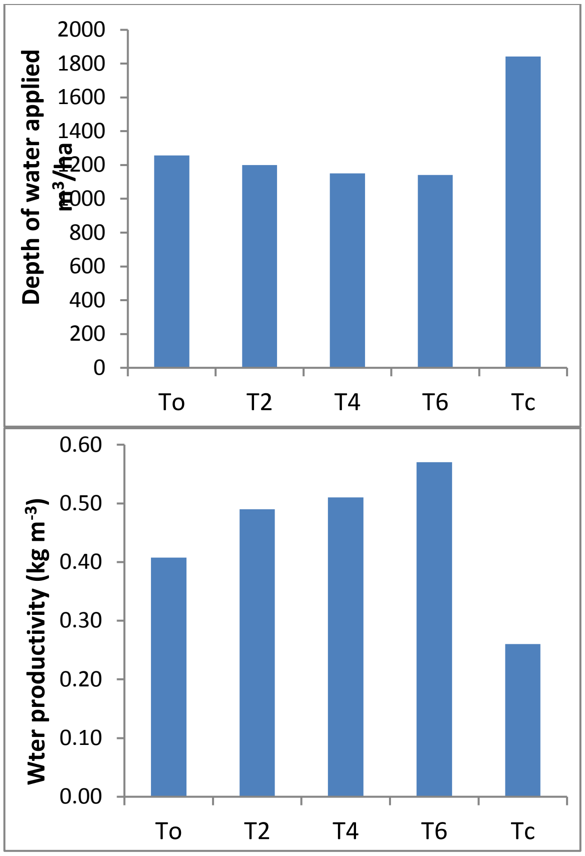

Figure 7. Depth of water and water productivity achieved under different treatments.

***Conclusions*:** Soil bulk density increased significantly within the treatments of increasing passes of puddling i.e. 1.42 g/cm^3 to 1.51 g/cm^3. Density of 1.54 g/cm^3 saved 38.2% of water as compared with densities 1.49 g/cm^3, 1.46 g/cm^3 and 1.4 g/cm^3 which saved 36%, 34.3% and 31.8% water, respectively. Water loss through seepage plus percolation was significantly higher for the unpuddled soils as compared to the puddled and it increased with the increasing intensity of puddling i.e. 976mm to 1098.6mm. Infiltration rate of soil significantly decreased with the increasing intensity of puddling in furrows. Maximum passes of puddling in furrows gave maximum amount of yield i.e. 653.2 g/m^2 as compared to 450.5 g/m^2 under control treatment. Maximum water productivity (0.5724 kg/m^3) was obtained under six passes of puddling whereas minimum water productivity (0.26 kg/m^3) was obtained in control treatment.

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