Research Article

Improving Water use Efficiency Through Various Planting Techniques in Winter Wheat (*Triticum aestivum* L.)

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Abstract | Water scarcity across the globe greatly emphasizing agriculture sector to adapt such practices that have more water use efficiency in the context of seasonal variability and climate change. Hence it is crucial to explore useful techniques in crop production that utilize less water without compromising yield, sacrificing income of the farming community and evidencing sustainability in production systems. Thus, a two years field study (during 2017-18 and 2018-19) was conducted at research area of Agronomic Research Station Khanewal, Punjab, Pakistan to compare the existing traditional winter wheat (*Triticum aestivum* L.) planting techniques (broadcast and drill) with the water efficient planting techniques (ridge and bed planting) to evaluate their water use efficiency and their economic feasibility. Results of this study revealed that sowing of wheat on ridges and beds gave higher productive tillers (384 ha^{-1} and 401 ha^{-1}, respectively), grains per spike (47 and 47, respectively), 1000-grains weight (43 and 44 g, respectively) and ultimately higher grain yield (4492 kg ha^{-1} and 4761 kg ha^{-1}, respectively) than broadcast and drill planting techniques (conventional techniques). Likewise, it was figured out that minimum water was required in wheat planted at ridge (47266 m^3 ha^{-1}) and bed (40772 m^3 ha^{-1}) techniques than with broadcast (65347 m^3 ha^{-1}) and drill sown (57498 m^3 ha^{-1}) wheat. Similarly, higher water use efficiency was recorded in ridge (0.10 kg/m^3) and bed (0.13 kg/m^3) sown wheat followed by the drill (0.08 kg/m^3) and broadcast (0.05 kg/m^3) methods. Moreover cost benefit ratio of ridge (1:1.15) and bed (1:1.25) planting techniques was higher than drill (1:0.93) and broadcast (1:0.44) techniques. In conclusion, it is recommended that wheat may be planted on ridges and raised bed to have more yield, high water use efficiency and sound financial return to farming community.

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Introduction

Climate change is obvious and alarming to the future crop production. The assessment of its impact showed significant decline in yield of cereals (Ullah *et al*., 2019a) importantly wheat crop (Hussain *et al*., 2020) in arid and semi-arid regions. Many scientists proposed different adaptation strategies to combat climate change adverse effects. The replacement of conventional techniques in crop production to innovative was identified as resource efficient practices (Ullah *et al*., 2019b). These identified practices responded positively in studying the future impacts of climate in different scenarios. The role of water in adaptation is worth mentioning in addition to adapting crop production techniques (Ullah *et al*., 2017). How-

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ever, water is becoming finite source due to changing climate. Its judicious use through synchronizing its utilization with techniques is necessary to minimize the adverse impacts on seasonal variability and climate change (Ullah *et al*., 2018).

The per capita, per annum availability of water in Pakistan was 5300 m^3 in 1950, which is now a day reduced to 1000 m^3 (Usman *et al*., 2015). It is expected to go down to 800 m^3 during 2025 (Qureshi, 2011) due to increasing population and lack of water smart techniques. Judicious use of water and efficient management are the main challenges and significant needs of the current situation in all parts of the world and in Pakistan for safeguarding the food security which is directly linked with water availability (Saeed *et al*., 2017). This situation is emphasizing on the shift in agricultural management practices (OECD, 2014) such as; adapt varieties which are drought resistant, re-optimize sowing techniques to attain benefit from longer growing seasons, incorporate those crops in crop rotation which are less sensitive to drought conditions, adapt conservation tillage and increase irrigation efficiency.

Enhancing irrigation efficiency means minimize the usage of irrigation water in agriculture for crop production without compromising the profitable yield (Farooq *et al*., 2009). Wheat (*Triticum aestivum* L.) is a staple crop in Pakistan and grows on 8825 thousands hectares in Pakistan (GoP, 2019-2020). In most of the areas of Pakistan wheat is broadcasted and in some areas sown by drill (Byerlee *et al*., 1986; Khan, 2003; Hussain *et al*., 2012). Wheat crop grown by these methods is irrigated through flood irrigation system (Khan, 2003) and irrigation efficiency of this irrigation system is 30-50%, which means 50-70% water is lost at each irrigation. Despite of this, furrow irrigation raised bed / ridge technology is an irrigation efficient technology in which water only moves in furrows (Hussain *et al*., 2018). In most of the countries farmers have shifted from broadcast to bed / ridge and furrow system for sowing of wheat owing to current water shortage situation (Tripathi *et al*., 2002).

Despite the loss of water, unsuitable planting technique also results in wheat yield reduction (Maleha *et al*., 2020). Adoption of suitable planting technique like ridge and raised bed techniques enhance the yield of wheat (Sweeney and Sisson, 1988) due to their major effect on growth and development of root system of plant (Khan *et al*., 2012a). As compared with flat sowing (broadcast and drill planting) where soil is compact due to use of heavy farm machinery, the rhizosphere soil of ridges/raised bed is loose and fertile which is a desirable character for the development of healthy and extensive root system. The improved root morphology ultimately results into proper uptake of water and nutrients from soil hence augments the plant growth and enhance its productivity (Bengough *et al*., 2011; Khan *et al*., 2012a). Nonetheless, compacted soils are more vulnerable to water logging due to heavy rains and results in hypoxia limiting root growth (da Silva *et al*., 1994: Khan *et al*., 2012a). Mechanical impedance also reduced leaf expansion in hard soils due to direct signaling between root and shoot growth (Masle and Passioura, 1987; Young *et al*., 1997; Khan *et al*., 2012a). But in case of ridges or raised bed, soil being loose as well as creates a better environment for aeration, light penetration, water movement, and root development which results in more yield (Roth *et al*., 2005; Khan *et al*., 2012a).

In addition to the previously described benefits of ridge/bed planting; these techniques also result in better management of irrigation and nutrients, better crop stand and less lodging (Meleha *et al*., 2020) by providing easy drainage in water logged fields. Chaudhry *et al*. (2015) conducted a field trial and found that sowing of wheat on beds resulted in higher plant height, productive tillers, spikelets per spike, 1000-grains weight and water productivity. To the best of our knowledge and according to the survey of the area the farmers are still practicing flat sowing but due to prevailing water shortage conditions there is a dire need to shift the farmers towards water saving techniques that not only enhance the yield but also minimize the usage of water. Hence this study was designed to compare the sowing methods of wheat that use less water and provide profitable yield.

Materials and Methods

Site description: This field trial was conducted during winter season 2017-18 and 2018-19 at Agronomic Research Station, Khanewal, Punjab, Pakistan, which was geopositioned at latitude; 30°18' 35.95" N, longitude; 71°59' 40.14" E and elevation of 454 m (Figure 1). The texture of the soil was sandy loam (alluvial). The classification of the region is arid according to the weather indicators.

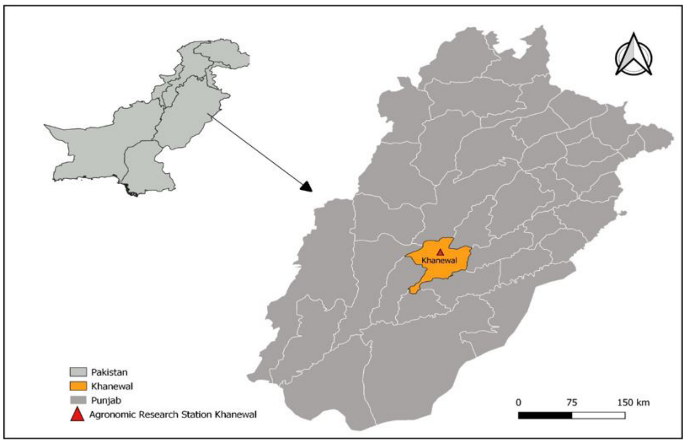

Figure 1: *Geo-graphic location of experimental site.*

Weather conditions: The maximum temperature prevailed 40°C during the last week of the crop season in year 2017-18 as compare to 2018-19 (37°C). While minimum temperature of (4.9°C) was observed in crop season 2018-19 as compare to 2017-18 (7°C). Total rainfall was received quite higher (127 mm) in crop season 2018-19 while 39 mm in first year of study (2017-18). It can be figured out that the first year of study was dry and hot as compare to second year (2018-19) of study. The weekly weather indicators are presented in Figure 2.

Design and treatments: The Experimental treatments were comprised of different wheat planting techniques to explore and compare the usage of water viz; broadcast on flat soil (conventional technique), drill planting on flat soil, ridge planting and bed planting. Experiment was laid out in randomized complete block design with three replications and net plot size of 3.15 × 6.00 m.

Crop husbandry: Winter wheat variety Jauhar-16 (commonly grown wheat variety of the area) was used as test variety in this study. The fertilizer was applied @ 120-90-62.5 NPK kg ha^{-1}, respectively and the crop was sown with seed rate of 120 kg ha^{-1}. Urea, DAP and SOP were used as source of nitrogen (N), phosphorous (P) and potassium (K), respectively. After picking of cotton, the cotton sticks were rotavated and field was levelled with laser. The seed bed was prepared by one pass of cultivator followed by planking. The basal dose of 90 kg P and 35 kg N ha^{-1} was applied at the time of land preparation. Remaining N was applied in 2 splits, ½ at 1st irrigation (tillering stage) and ½ at 2nd irrigation (booting stage).

The wheat crop was broadcasted manually in the field as a treatment and the seed were covered with cultivating the soil following by planking, which is a conventional method. Secondly, the wheat was sown in lines through drill using rabi drill with row to row distance of 22.5 cm, as the plot size was 3.15 × 6.00 m hence 14 rows of wheat were planted in each repeat of drill planting technique. The ridge planting technique was executed by preparing ridges by ridger after broadcasting the seed manually in the field. The wheat crop was planted on beds, (45 cm bed top + 30 cm furrow) which were made with the help of bed shaper and three rows of wheat crop (one row at each corner of bed top while one at the center keeping row to row distance 22.5 cm at top of the bed) were sown (in total 12 rows of wheat were sown in each plot of bed planted wheat) with the help of manual drill. Wheat was sown on 16.11.2017 and 15.11.2018 during 2017-18 and 2018-19, respectively.

1st irrigation was applied at 30 days after sowing (DAS). First irrigation in ridge planting was applied as the irrigation water may not cross half depth of the furrow to avoid crust formation at ridge. 2nd irrigation was applied at booting, 3rd irrigation was applied at anthesis while 4th was applied at grain filling stage. At tillering stage weedicide (Pallas 75 WG: active ingredient Pyroxsulam developed by Dow Agrosciences) 150 ml per acre was applied. Fungicide (native 75 WG: active ingredients Tebuconazole 50%+ Trifloxystrobin 25% w/w) 126 g / 100 L water per acre was also applied at anthesis stage to control rust. Wheat was harvested on 14.04.2018 and 15.04.2019 during 2017-18 and 2018-19 respectively.

Water measurement and use efficiency

Cutthroat flume: Irrigation water applied at each irrigation was measured using cutthroat flume, which was named by the developers (Skogerboe *et al*., 1973). The water was measured using float method as described by Hossain *et al*. (2014). Flume was installed in water channel and sealed from each side so that water can only pass through the flume. When the depth of flume was constant the upstream flow depth "h a " and downstream flow depth "h b" was measured in meter with the help of a measuring scale. The condition of flow was identified by dividing h b /h a (h b /h a ≤0.65 for free flow). After identifying the upstream flow condition discharge was calculated with the value of h a and h b for the flume size 122×92 cm. Stop-watch was used to record time taken to fill each plot.

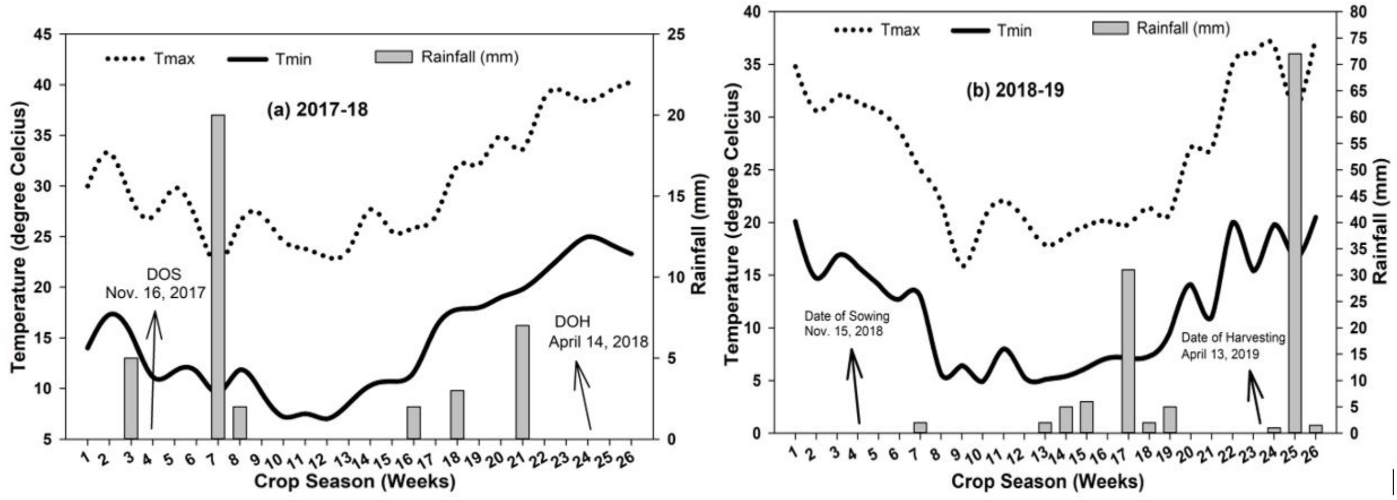

Figure 2: *Weather of experimental site during the study.*

Then discharge (Q) and amount of irrigation water was measured using following formula:

Discharge (Q)=2.858 × Hu × 1.826........(1)

Where;
Q: Discharge (m^3 Sec^{-1}); Hu: Upstream head reading of cutthroat flume.

Volume of irrigation water applied (V) = Q x T.....(2)

Where;
V: Volume (m^3); Q: Discharge (m^3 Sec^{-1}); T: Time taken in seconds to fill the field in seconds.

Water use efficiency: Water use efficiency which defined as the "economic yield per unit water applied" was measured according to procedure followed by Neal *et al*. (2011);

$$Water\ use\ efficiency\ \left(\frac{kg}{m^3}\right) = \frac{Economic\ yield\ \left(\frac{kg}{ha}\right)}{Total\ water\ applied\ \left(\frac{m^3}{ha}\right)} \ldots (3)$$

Observations

Yield and yield components: At maturity 10 plants from each plot were tagged to collect data regarding yield components. Plant height in centimeter (cm) of these tagged plants was measured using meter rod and averaged to get average plant height. Ten spikes from these tagged plants were harvested, length of these spikes were measured with the help of scale to record spike length. Spikelets per spikes were counted from the same spikes to record spikelets pes spike. These spikes were threshed manually and counted individually then averaged to get average grains per spike. Total number of tillers and productive tillers were counted with the help of quadrate which was placed at random places in each treatment to count total and productive tillers from each treatment. To record biological yield and grain yield, the entire plot of each treatment in each repeat was harvested manually, and dried under sunlight on threshing flour for a week and weighted using weight balance to record biological yield per plot and then converted into biological yield per hectare using unit method (Ullah *et al*., 2020). These plants were threshed manually and weighted to record grain yield per plot and then converted into grain yield per hectare using unit method (Ullah *et al*., 2020). To record 1000-grains weight in grams (g), 1000 grains from each treatment were counted and weighted using weight balance (Model GT-500 manufactured by A&E labs, Guangzhou, China).

Economic analysis

Economic analysis was performed following procedure designed by Byerlee (1988) as:

Cost of production (Rs./ha) = Permanent cost (Rs./ha)+varriable cost (Rs./ha)

Where;
Permanent cost = expenses (Rs./ha) incurred in all field operations which were uniform in each treatment while Variable cost = expenses (Rs./ha) incurred on each treatment.

Gross icome (Rs./ha)= Yield (Kg/ha)×markete rate of wheat (Rs./kg)..(5)

Net income (Rs./kg)= Gross income (Rs./kg)- Cost of production (Rs./kg)..(6)

$$Benefit\ cost\ ratio\ (BCR) = \frac{Net\ income}{Cost\ of\ production} \ldots (7)$$

Table 1: *Effect of planting techniques on yield components of wheat.*

Planting techniques	Plant height (cm)			Total tillers (m^{-2})			Productive tillers (m^{-2})			Spike length (cm)			Spikelets per spike		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean
Broadcast planting	86	106	96	379 c	409 c	394	293 c	326 c	310	9	11	10	16	19	17
Drill planting	91	101	96	415 b	434 bc	423	343 b	362 b	353	9	11	10	16	19	18
Ridge planting	87	104	96	466 a	460 ab	463	376 a	392 a	384	9	10	10	16	20	18
Bed planting	87	106	97	488 a	489 a	488	401 a	405 a	401	9	10	10	16	21	19
LSD at p 0.05	14	7		28	35		26	25		1	2		2	4	

Mean sharing same letter do not differ significantly at $p \leq 0.05$.

Table 2: *Effect of planting techniques on yield components of wheat.*

Planting techniques	Grains per spike			1000-grains weight (g)			Grain yield (kg ha^{-1})			Biological yield (kg ha^{-1})		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean
Broadcast planting	43 b	40 c	41	39 c	39 c	39	3383 d	2417 b	2900	10367 c	10833 b	10600
Drill planting	44 b	44 b	44	41 b	40 bc	41	4483 c	2767 b	3625	13517 b	12000 a	12758
Ridge planting	47 a	47 a	47	44 a	42 ab	43	5433 b	3550 a	4492	15633 a	12667 a	14150
Bed planting	47 a	47 a	47	44 a	43 a	44	5889 a	3633 a	4761	16050 a	12933 a	14491
LSD at p 0.05	3	2		1	2		395			1815	940	

Mean sharing same letter do not differ significantly at $p \leq 0.05$

Results and Discussion

Planting techniques significantly affected total number of tillers m^{-2}, productive tillers m^{-2} at maturity, grains per spike, 1000-grains weight and grain yield (Table 1 and 2) in both years *i.e.* 2017-18 and 2018-19.

During 2017-18, higher number of total tillers were recorded in bed planted (488 m^{-2}) and in ridge planted (466 m^{-2}) wheat as compared with broadcast technique (379 m^{-2}), while during 2018-19, higher number of total tillers were recorded in bed planted wheat (489 m^{-2}) which was statistically at par with the number of total tillers of ridge planted wheat (460 m^{-2}) than broadcast planted wheat (409 m^{-2}) (Table 1). Likewise in case of productive tillers, higher number of productive tillers were recorded in bed planted (401 and 405 m^{-2} during 2017-18 and 2018-19 respectively) and ridge planted wheat (376 and 392 m^{-2} during 2017-18 and 2018-19 respectively) than number of productive tillers (293.33 and 325.67 m^{-2} during 2017-18 and 2018-19 respectively) in broadcast planted wheat (Table 1).

Higher number of grains per spike was recorded in bed planted (47 and 47 during 2017-18 and 2018-19 respectively) and ridge planted wheat (47 and 47 during 2017-18 and 2018-19 respectively) than broadcast planted wheat (43 and 40 during 2017-18 and 2018-19 respectively). Whereas in case of 1000-grains weight during 2017-18, higher 1000-grains weight was recorded in both bed planted (44 g) and ridge planted (43 g) wheat than broadcast planted wheat (39 g) (Table 2), however during 2018-19, higher 1000-grains weight was recorded in bed planted wheat (43 g), which was also statistically at par with ridge planted wheat (42 g), than broadcast planted wheat (39 g) (Table 2).

Regarding grain yield, during 2017-18, higher grain yield was recorded in bed plated wheat (5889 kg ha^{-1}) than broadcast planted wheat (5433 kg ha^{-1}) (Table 2) while during 2018-19, higher grain yield was recorded in both bed planted (3633 kg ha^{-1}) and ridge planted wheat (3550 kg ha^{-1}) than broadcast planted wheat (2417 kg ha^{-1}) (Table 2). Likewise during 2017-18, higher biological yield was recorded in both bed planted (16050 kg ha^{-1}) and ridge planted wheat (15633 kg ha^{-1}) than broadcast planted wheat (10367 kg ha^{-1}), while during 2018-19, all treatments i.e. bed, ridge and drill planting (12933, 12667 and 12000 kg ha^{-1} respectively) gave higher biological yield than broadcast planted wheat (10833 kg ha^{-1}) (Table 2).

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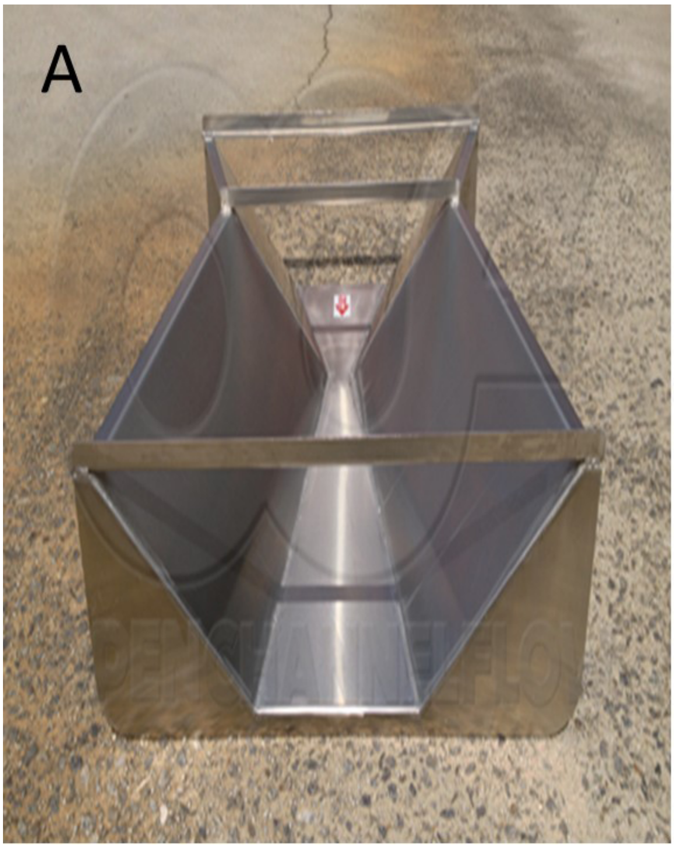

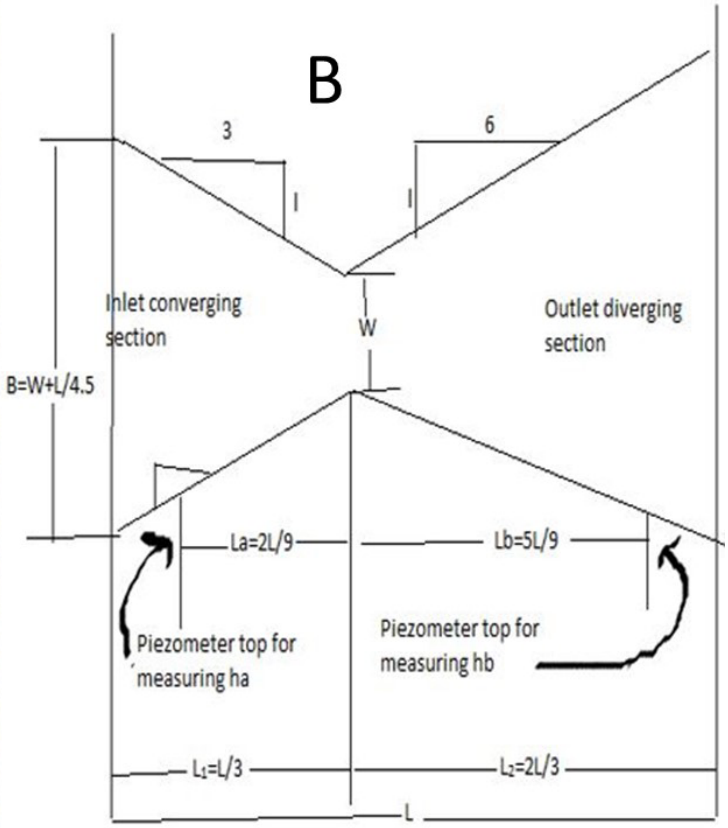

Figure 3: *Side (a) and top (b) view of a cutthroat flume.*

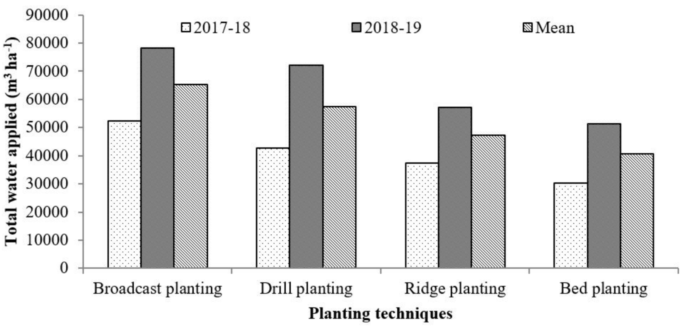

Figure 4: *Total water applied to wheat crop sown by various planting techniques.*

Regarding amount of water required to irrigate field, it is obvious from the data shown in Figure 4 that higher amount of water was required to irrigate wheat sown with broadcast as well as drill planning techniques while minimum water was required to irrigated field sown with ridge planting technique followed by bed planning technique. Moreover, water use efficiency (WUE) of broadcast planting and drill planting techniques were less as compared with ridge and bed planting techniques; however, ridge planting technique had slightly more WUE than bed planting technique (Figure 5).

Higher cost of production and gross income were recorded in bed planting followed by ridge planting techniques as compared with drill and broadcast planting techniques (Table 3). Whereas net income of bed and ridge planting was higher than broadcast and drill planting techniques (Table 3). Likewise higher cost benefit ratio was recorded in bed and ridge planting techniques as compared with drill and broadcast planting techniques (Table 3). However higher cost benefit ratio was recorded in bed planting technique (1:1.25) than ridge planting technique (1:1.15) (Table 3).

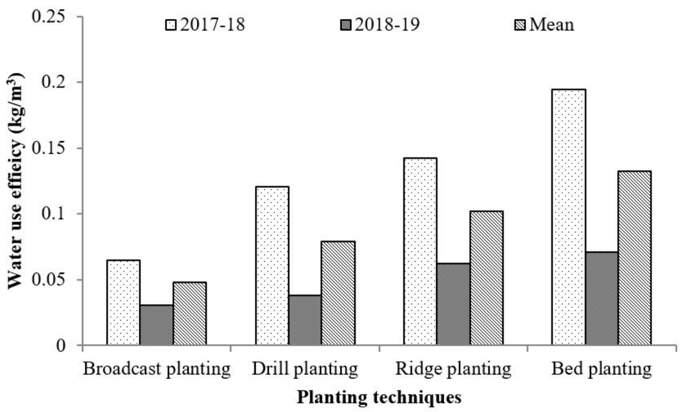

Figure 5: *Water use efficiency of various planting techniques of wheat.*

The present study revealed the scope of ridge as well as bed planting techniques for saving water and improving productivity of wheat. Bed planting and ridge

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planting techniques resulted in higher number of total as well as productive tillers than broadcast and drill planting techniques. This might be the result of well-developed and extensive root system, which eventually resulted in better crop stand establishment (Khan *et al*., 2012a). In arable systems, soil compaction is caused by the use of heavy farm machinery which is among the main factors that badly affect root growth and development (Bengough *et al*., 2006). Compact soil hinders the extension of root in soil to explore more volume of soil hence the roots only remain near the surface of soil and can uptake water and nutrients from upper layer of soil only while longer roots can explore more volume of soil and can uptake water and nutrients from deeper layers of soil (Chassot and Richner, 2002). Longer roots are also a desirable character under limited supply of water and nutrients because it enables plant to survive and maintain adequate growth under limited resources (Horst *et al*., 2001).

Table 3: *Economic analysis of various planting techniques of wheat.*

Sowing methods	Cost of production (Rs./ha)	Gross income (Rs./ha)	Net income (Rs. /ha)	Cost benefit ratio
Broadcast planting	65289	94250	28961	1:0.44
Drill planting	66765	128646	61881	1:0.93
Ridge planting	67265	144354	77089	1:1.15
Bed planting	68789	154736	85947	1:1.25

The effect of soil compaction on root growth can be tackled by adoption of better sowing method than broadcast and drill planting techniques such as ridge and raised bed planting techniques (Khan *et al*., 2012a; 2012b) that not only improve the productivity of crop but also use less water. Soil in ridge and bed planting techniques is loose which augment root system growth enabling plant to uptake water and nutrients from large area of soil (Khan *et al*., 2012a); owing to direct effects of availability of water and nutrients on root morphology (Bucher, 2007; Ao *et al*., 2010). These sowing techniques also aid in attaining optimum plant population due to better germination as well as better utilization of light, land and other resources (Quanqi *et al*., 2008).

Continual decline of water resources necessitates the adoption of water wise cultivation, which is possible by shifting from high water consuming sowing techniques to water efficient sowing techniques that have more water use efficiency (WUE). Choosing an efficient sowing technique improves WUE by better utilization of rain as well as irrigation water (Hussain *et al*., 2010). These sowing techniques not only perk up the WUE but also advance water application efficiency. Similar findings were also reported by Khan *et al*. (2012a; 2012b) in maize crop in which productivity and WUE was enhanced by sowing of maize crop in ridges/raised bed as compared with flat sowing owing to loose/fertile soil of ridge/raised bed which augmented the root development (Khan *et al*., 2012a).

Grains per spike and 1000-grains weight were also higher in ridge and bed planting techniques than broadcast and drill planting techniques as soil condition and optimum supply of nutrients are crucial to attain higher number of grains per spike and 1000-grains weight in wheat (Hong-zhu *et al*., 2019). These factors, soil condition and uptake of nutrients are better in ridge/bed planting techniques hence higher number of grains and 1000-grains weight was recorded in these treatments. Eventually improvement of yield contributing trains in ridge/bed planting techniques resulted in higher biological and grain yield of wheat.

Moreover, increase in yield in ridge and bed planting techniques was also owing to less lodging in these planting techniques (Ahmad and Mahmood, 2005). Choosing an appropriate irrigation technique is one of the major management techniques that are employed to minimize lodging (Ahmad and Mahmood, 2005). In flood irrigation method which is used to irrigate fields that are sown by broadcast or drill planting techniques the binding of soil and plant is reduced due to wet soil owing to excess water near roots (Hobbs and Morris, 2011). Whereas in furrow irrigation technique used to irrigated field that are sown either by ridge or raised bed sowing techniques, the soil near root remains dry because the excess water remain in furrows hence the plant is tightly held with soil surface which is a desirable character under windy conditions which cause lodging.

Water use efficiency of ridge and bed planting techniques were also higher as less time was required to fill the furrows between ridges and beds as compared with flat surfaces in broadcast and drill planting techniques. These results are also in line with study of Maleha *et al*. (2020) that 29.5% water was saved when wheat was planted on raised beds than broadcast and drill planting techniques. Aboelsoud *et al*. (2020) also reported that more water is required to irrigated flat sown field than ridge/raised bed sown field. Similarly, it was also reported that WUE of furrow irrigation technique is 30% higher than flood irrigation (Fahong *et al*., 2004).

Consequently, more yield with minimal increase in cost of production in ridge and bed planting techniques resulted in higher benefit cost ration of these planting techniques.

Conclusions and Recommendations

This study was comprised of comparison of wheat planting techniques which use less water without compromising the ultimate productivity of crop to grow a beneficial crop under limited water resources in changing climate. Drill, ridge and bed planting techniques were compared with commonly practiced broadcast technique for their consumption of water, water use efficiency and yield. Ridge and bed planting techniques resulted in higher yield, water use efficiency and less consumption of water than broadcast planting technique of wheat. Hence in conclusion, it is recommended that wheat may be planted on ridges and raised bed to have more yield, high water use efficiency and sound financial return to farming community.

Novelty statement

Under scare water resources there is a dire need to shift from traditional to innovative planting techniques that not only use less water but also more profitable in the sense of productivity and profitability specifically in the context of future climate shift.

Author's Contribution

Saba Iqbal and Asmat Ullah: Conducted the experiment, monitoring and execution.
Muhammad Luqman: Helped in data analysis.
Hafiz Muhammad Akram: Supervised the experiment
Muhammad Kashif Munir: Edited draft of the paper
Nawal Zafar: Helped in format setting of the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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