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EVALUATION OF DIFFERENT SOWING METHODS FOR ENHANCING PRODUCTIVITY AND WATER USE EFFICIENCY OF WHEAT UNDER LIMITED WATER CONDITIONS

[a]Atif Riaz, [a]Mudassir Aziz*, [a]Abdul Ghaffar, [b]Wazir Ahmed, [a]Khuram Mubeen, [a]Muhammad Usman

[a] Department of Agronomy, MNS University of Agriculture, Multan (Punjab), Pakistan.

[b] Department of Soil and Environmental Sciences, MNS University of Agriculture, Multan (Punjab), Pakistan.

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ABSTRACT

The selection of appropriate sowing methods is very important for improving water use efficiency. A field trial was conducted in the winter season of 2018-19 to investigate the impact of different sowing methods on the water use efficiency of spring wheat exposed to water deficit at anthesis. Wheat was 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 anthesis stage. All agronomic practices were kept uniform throughout the experimental duration. Different sowing methods and irrigation regimes significantly affected the grain and straw yield of wheat. Among different sowing methods, the wheat crop was sown with augmented furrow method substantially produced maximum plant height (111 cm), no. of tillers per m^2 (427), 1000 grain weight (37.93 g), grain yield (4.73 t ha^{-1}) and straw yield (4.24 t ha^{-1}). Whereas, statistically maximum irrigation water use efficiency (17.72 kg ha^{-1} mm^{-1}) and benefit-cost ratio (1.34) was recorded in the augmented furrow method of sowing of wheat exposed to water deficit at the anthesis stage. Farmers can sow wheat by using the augmented furrow method to improve grain yield and irrigation water use efficiency under water deficit at anthesis as compared to conventionally used drill and broadcast sowing methods.

Corresponding Author: Mudassir Aziz

Email: mudassiraziz@hotmail.com

INTRODUCTION

Wheat is the leading cereal crop and staple food of the majority of the population of Pakistan. Although, Pakistan is the 8th largest wheat producer in the world the country's wheat productivity is less than that of other countries in the region like China, India and Bangladesh (Ahmad *et al.*, 2021). Water use efficiency is becoming a serious concern for agriculture particularly in arid and semi-arid areas (Bhattacharya, 2019). The scarcity of water is further aggravating the situation in these areas by threatening crop productivity (Qasim *et al.*, 2019). Food shortage is a major issue in many regions of the world including Asia and Africa (Aziz *et al.*, 2015). Improving irrigation water use efficiency under the current scenario is becoming a serious global food security concern. Wheat is the leading cereal crop around the globe which is severely affected by different abiotic stresses (Bali and Sidhu, 2019). Water deficit is most destructive in terms of decreasing overall crop yield as compared to any other kind of stress like extreme temperature, cold and salinity (Noorka and Heslop-Harrison, 2014). Shortage of water not only results in variation in crop morphology but also severely disturbs the plant metabolism. Moreover, changes in crop morphology are closely linked with variety, growth period, interval and intensity of water shortage (Sánchez-Díaz *et al.*, 2002; Tester and Bacic, 2005). Water deficit significantly reduced biological yield, tillering capacity, grains per spike and grain size in wheat (Wang *et al.*, 2005). Water shortage at various critical stages of crop growth is closely associated with a reduction in yield. Water deficit at the anthesis stage resulted in reduced pollination and thus, fewer grains spike^{-1} and less grain yield (Ashraf, 1998). Due to a shortage of water, yield losses of wheat crops ranged from 17 to 70% (Nouri-Ganbalani *et al.*, 2009).

Among different strategies which are predominantly utilized under limited water conditions include the use of osmoprotectants and efficient water management practices (Aziz *et al.*, 2018). Water conservation techniques are very helpful for enhancing crop productivity under limited water conditions (Fang *et al.*, 2021). The use of inappropriate sowing methods under shortage of water is one of the important issues for less crop productivity (Semenov *et al.*, 2007). Sikander et al. (2003) highlighted the importance of using appropriate sowing methods for improving grain yield in wheat. Planting methods play the most crucial role in appropriate growth, development and production of grains in wheat (Ata-Ul-Karim *et al.*, 2015). The superiority of sowing methods is evident in terms of less weed density, efficient water management, low crop lodging risk and more fertilizer use efficiency in wheat (Sayre and Moreno, 1997). Non-uniformity of seed emergence in wheat was reported by Liu *et al.* (2017) in broadcast and drill sowing. Moreover, Ahmad and Mahmood (2005) reported an increment in wheat yield up to 11.2% with 40-50% water saving in improved sowing methods as compared to flat sowing. Chauhdary *et al.* (2016) also recorded 35% water saving in resource-conserving improved methods of sowing like bed sowing of wheat as compared to conventional methods. Root penetration in deeper soil with improvement in water and nutrient use efficiency was reported by (Govaerts *et al.*, 2006) by using improved sowing methods as compared to traditional crop sowing methods. Hence, there is a dire need to focus on the latest irrigation techniques for improvement in water use efficiency in field crops (Bhattacharya, 2019) under a limited water supply. Improvement in the sowing technique of wheat may result in better crop management through efficient utilization of limited resources (Sayre and Moreno, 1997; Malik *et al.*, 1998). Keeping in view the increasing population pressure and shrinking water resources, there is a dire need to find out the most efficient resource-conserving methods of wheat sowing leading to water-saving and improvement in overall wheat productivity. The present investigations were done to find out the most efficient improved sowing method of wheat under limited water conditions.

MATERIALS AND METHODS

The field experiment was conducted at the research farm of MNS-University of Agriculture, Multan (30.1575° North, 71.5249° East) Punjab, Pakistan during the winter season 2018-19 on loamy soil. The climate of the experimental site was arid. Soil samples at depth of 0-15 cm were analyzed before starting the experiment. The pH 8.4, EC 1.56 dS/m, P 6.8 mg kg^{-1}, K 230 mg kg^{-1} of soil extract was recorded. The proposed study was laid out in Randomized Complete Block Design (RCBD) with a split-plot arrangement having 3 replicates. Net plot size was kept 20 m × 5 m. Different sowing methods including S1 = broadcast sowing, S2 = drill sowing and S3 = augmented furrow sowing was kept in the main plot while different irrigation regimes i.e. I1 = normal irrigation and I2 = water deficit at anthesis stage were kept in a subplot. In case of water deficit, irrigation was skipped at the anthesis stage (90 days after sowing). In drill sowing, the distance between rows was kept at 22.5 cm. In the augmented furrow method, the seed was broadcasted on a well-prepared seedbed and then the furrow was made 60 cm apart with the help of potato ridger.

The wheat cultivar "Galaxy-2013" was planted in the first week of December with a seed rate of 120 kg ha^{-1}. Half of the recommended dose of N (60 kg ha^{-1} of total 120 kg ha^{-1}) and full doses of P (90 kg ha^{-1}) and K (60 kg ha^{-1}) was applied at the time of sowing. The remaining N (60 kg ha^{-1}) was applied at first irrigation. All other management practices were kept the same throughout the conduct of the experiment. Cutthroat flume was used to measure the quantity of water applied during the entire growth period. Discharge for submerged conditions was calculated by the formula proposed by Skogerboe *et al.* (1972).

$$Q = \frac{Cs(Ha - Hb)^n}{(-logS)^{ns}}$$

The depth of irrigation water was computed by the formula

QT = AD

Where Q = discharge (m3 ha^{-1}), T = Time (h), A = Area (hectare), D= Depth (mm). The total quantity of water applied to different treatments was computed by multiplying discharge at the field outlet with a time of application. Irrigation water use efficiency (WUEi) (kg ha^{-1} mm^{-1}) was computed by the formula;

$$WUEi = \frac{Yield\ (kg\ ha^{-1})}{Total\ quantity\ of\ water\ applied\ (mm)}$$

Different yield and yield traits including plant height, tillers per m^2, spike length, grains $spike^{-1}$, spikelets per spike, thousand-grain weight, grain yield, straw yield, harvest index were recorded by applying standard protocols and procedures. Tukey's honest significant difference (HSD) test for mean comparison was used to distinguish differences between treatment means at a 5% probability level (Steel et al., 1997). The benefit-cost ratio for different treatments was calculated by the procedure described by CIMMYT (1988).

RESULTS

Yield and yield components

Plant height was not influenced significantly by both irrigation regimes while it was significantly influenced by various methods of sowing (Table 1). Maximum plant height was noted in S3 (augmented furrow sowing) it was statistically similar to plant height recorded in S1 (broadcast sowing). Statistically similar plant height was achieved in S1 (broadcast sowing) and S2 (drill sowing). Under S2 (drill sowing) plant height of wheat was 101 cm while in S1 (broadcast sowing) plant height was 103 cm. Minimum plant height (101 cm) was recorded in plots where wheat was sown with a drill (S2).

Tillers per m^2 were statistically the same under both irrigation regimes (Table 1). However, different sowing methods significantly influenced tillers per m^2 of wheat. Maximum tillers per m^2 (427) was recorded in augmented furrow sowing. It was statistically different from both other methods of sowing. A minimum number of tillers per m^2 (303) was observed in drill sown wheat (S2). Interaction between different irrigation regimes and sowing methods was non-significant regarding tillers per m^2 of wheat.

Spike length is an important yield contributory parameter. The Spike length of wheat was statistically influenced by different irrigation regimes (Table 1). Maximum spike length (11.81 cm) was noticed under normal irrigation while minimum (10.93 cm) was recorded underwater deficit at anthesis. Spike length was non-significantly influenced by different sowing methods. The interactive effect of different sowing methods and irrigation regimes was non-significant regarding spike length.

Spikelets per spike were significantly affected by different irrigation regimes (Table 1). Maximum spikelets per spike (18.33) were observed under normal irrigated conditions while minimum spikelets per spike (16.89) were recorded underwater deficit at the anthesis stage. Data showed that various sowing methods non-significantly influenced spikelets per spike of wheat.

Under normal irrigation, grains per spike were 10.46% more than the recorded underwater deficit at anthesis (Table 1). Grains per spike were statistically similar in different wheat sowing methods.

Data showed that the thousand-grain weight of wheat was statistically similar under different sowing methods (Table 2). But the thousand-grain weight was influenced by different irrigation regimes. Maximum grain weight (36.79 g) was noted under (I1) normal irrigation, while minimum thousand-grain weight (32.08 g) was recorded in (I2) water deficit at anthesis.

The significant effect of different irrigation regimes and sowing methods was recorded on the grain yield of wheat (Table 2). Grain yield was recorded maximum i.e., 4.09 tonnes per ha (t ha^{-1}) under (I1) normal irrigation while minimum grain yield (3.53 t ha-1) was noticed under water deficit at anthesis. However, maximum grain yield (4.73 t ha^{-1}) was recorded under S3 (augmented furrow sowing) while, minimum grain yield (3.07 t ha^{-1}) was recorded in S1 (broadcast sowing) which was statistically similar to grain yield recorded in S2 (drill sowing). Interaction between irrigation regimes and different sowing methods was non-significant regarding grain yield. The positive linear association was recorded between the number of tillers (m^{-2}) and grain yield of wheat (Figure 1).

Table 1. Effect of different sowing methods and irrigation regimes on plant height, tiller number, spike length, spikelets and grains per spike of wheat.

Irrigation regimes/ sowing methods	Plant Height (cm)	Tillers per m^2	Spike length (cm)	Spikelets per spike	Grains per spike
Irrigation regimes					
I_1= Normal irrigation	106	354	11.81 a	18.33 a	59.47 a
I_2= Water deficit at anthesis stage	104	336	10.93 b	16.89 b	53.84 b
Sowing methods					
S_1= Broadcast sowing	103 ab	305 b	11.25	17.50	55.10
S_2= Drill sowing	101 b	303 b	11.40	17.33	55.25
S_3= Augmented furrow sowing	111 a	427 a	11.47	18.00	59.62

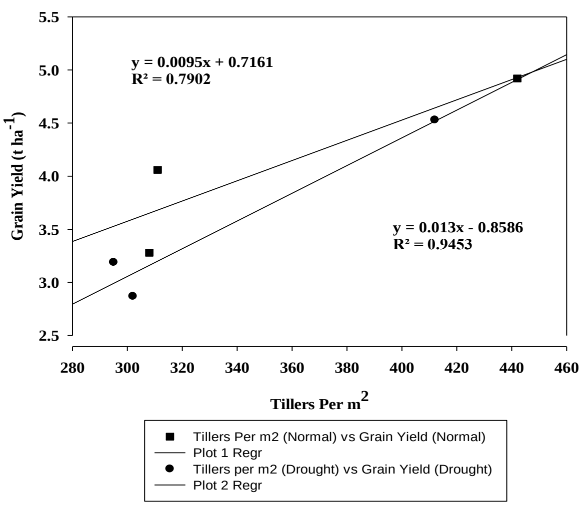


Fig. 1. Relationship between tillers m^{-2} and grain yield (t ha^{-1}) of wheat under normal irrigation and water deficit at anthesis stage.

The straw yield of wheat was statistically different under different irrigation regimes and sowing methods (Table 2). Maximum straw yield (3.73 t ha^{-1}) was noticed under normal irrigation (I1) while minimum straw yield (3.39 t ha^{-1}) was recorded underwater deficit at anthesis stage (I2).

However, maximum straw yield (4.24 t ha^{-1}) was observed in S3 (augmented furrow sowing). while minimum straw yield (2.97 t ha^{-1}) was noticed under S1 (broadcast sowing) which was statistically similar to straw yield recorded in S2 (drill sowing) wheat. Harvest index was significantly influenced by different irrigation regimes (Table 2). The maximum harvest index (52.03%) was noted under I1 (normal irrigation) while the minimum harvest index (51.10%) was recorded underwater deficit at the anthesis stage. However, the harvest index was non-significantly affected by different sowing methods.

Irrigation water use efficiency

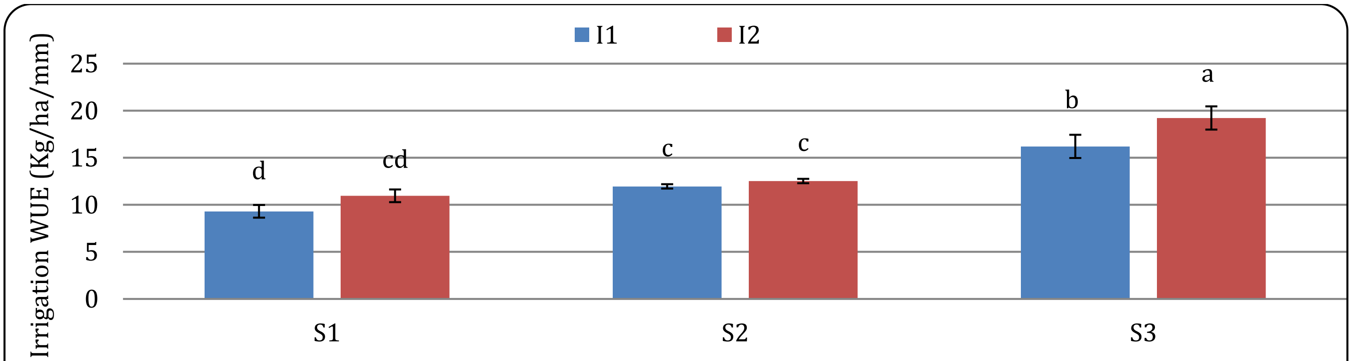
Interaction between different sowing methods and irrigation regimes was significant regarding WUEi (Fig. 2). Maximum WUEi (19.23) was recorded in S_3 (augmented furrow sowing) under (I2) skipped irrigation at anthesis stage while minimum WUEi (9.31) was noticed in S_1 (broadcast sowing) under I1 (normal irrigation) which was at par with S_1 (broadcast sowing) under I2 (water deficit) at anthesis stage.

Table 2. Effect of different sowing methods and irrigation regimes on thousand-grain weight, grain yield, straw yield and harvest index of wheat.

Irrigation regimes/ Sowing methods	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Irrigation regimes				
I_1= Normal irrigation	36.79^{a}	4.09^{a}	3.73^{a}	52.03^{a}
I_2= Water deficit at anthesis stage	32.08^{b}	3.53^{b}	3.39^{b}	51.10^{b}
Sowing methods				
S_1= Broadcast sowing	30.5	3.07^{b}	2.97^{b}	51.06
S_2= Drill sowing	34.88	3.62^{b}	3.48^{ab}	50.91
S_3=Augmented furrow sowing	37.93	4.73^{a}	4.24^{a}	52.72

Table 3. ANOVA table representing the p values obtained for different treatments.

Treatments	P-values									
	Plant Height	Tillers per m^2	Spike length	Spikelets per spike	Grains per spike	1000 grain weight	Grain yield	Straw yield	Harvest index	iWUE
Sowing methods	0.0*	0.0**	0.8671^{NS}	0.4081^{NS}	0.2473^{NS}	0.0623^{NS}	0.0028**	0.0118*	0.2477^{NS}	0.0010**
Irrigation regimes	0.1^{NS}	0.1^{NS}	0.0006**	0.0018**	0.0038**	0.0054**	0.0028**	0.0037**	0.3099^{NS}	0.0013**
Sowing methods × Irrigation regimes	0.6^{NS}	0.5^{NS}	0.7305	0.8502^{NS}	0.2100^{NS}	0.7615^{NS}	0.1970^{NS}	0.7082^{NS}	0.2539^{NS}	0.0483*



S_1= Broascast sowing, S_2= Drill sowing, S_3= Augmented furrow sowing, I_1=Normal irrigation, I_2= water deficit at anthesis stage

Figure 2. WUEi (kg/ha/mm) of wheat as influenced by different sowing methods and irrigation regimes.

Economic analysis

Economic analysis revealed a positive effect of augmented furrow method of sowing of wheat exposed to normal irrigation and skipped irrigation at anthesis stage as the data depicted in Table 4 shows. The drill sowing method was beneficial under normal irrigation only. Net return ranged from 272-792 US $ (ha^{-1}) under different sowing methods of wheat with different irrigation regimes. The maximum benefit-cost ratio was recorded 1.42 and 1.34 in augmented furrow sowing under normal and water deficit at anthesis stage, respectively in wheat.

Table 4. Benefit-cost ratio as influenced by different sowing methods and irrigation regimes in wheat.

Treatments	Total cost	Gross income	Net benefit	Net return	BCR
	US $ ha^{-1}				
S_1I_1	545	925	875	379	0.69
S_1I_2	528	805	773	277	0.52
S_2I_1	554	1137	1080	584	1.05
S_2I_2	537	900	858	362	0.67
S_3I_1	558	1350	1288	792	1.42
S_3I_2	541	1271	1225	729	1.34

BCR = Benefit cost ratio, S_1 = Broadcast sowing, S_2 = Drill sowing, S_3 = Augmented furrow sowing, I_1 = Normal irrigation, I_2 = water deficit at anthesis stage, 1US $ = Rs. 138

DISCUSSION

The present investigation regarding wheat sowing with improved methods for enhancing performance and water use efficiency under different irrigation regimes suggests that improved sowing methods may enhance yield and yield traits of wheat as well as water use efficiency under water deficit at the anthesis stage. Because of the results of the current study, the plant height of wheat is similar under normal irrigation and water deficit at anthesis due to attaining a full height of stem before the imposition of drought. However, our findings match with results reported by Abbas *et al.* (2009), who also concluded that planting methods affect plant height. Similarly, Jakhar *et al.* (2005) and Singh *et al.* (2005) also reported that there was maximum plant height under raised bed sowing in comparison to other methods of sowing. Exploiting the full height potential in wheat is associated with proper planting geometry. The number of tillers per unit area depends upon the availability of irrigation water to wheat. Under normal irrigation conditions more than 400 tillers m^{-2} was recorded by Musaddique *et al.* (2000) and Sharif (1999). McDonald *et al.* (1984) also associated more tillers production with increasing irrigation frequency. Sowing methods significantly affected the number of tillers per m^2 in wheat (Khatri *et al.*, 2019). Under the augmented furrow method of sowing, plants on top of raised ridge resulted in an increase in productive tillers on a unit area basis due to proper support per plant. An increase in spike length and spikelets per spike under normal irrigation is due to more translocation of assimilates from source to sink in the presence of optimum moisture supply. A decrease in spike length under water deficit in wheat was reported by (Dalvandi *et al.*, 2013). Shpiler and Blum (1990) also stated that midseason drought resulted in a reduction in spikes per meter square and spikelet per spike due to more sensitivity to water deficit during the period from double ridge to anthesis. Denčić *et al.* (2000) and Shehzadi (1999) also reported a reduction in spikelets per spike in the case of different cultivars of wheat exposed to water deficit at water sensitive stages. A decrease in grains per spike is due to the effect of water deficit at anthesis on pollination. These findings are also in conformity with results reported by Kilic and Yagbasanlar (2010) who stated that reduction in grains per spike in wheat exposed to deficit irrigation at various water-sensitive stages of crop growth. 1000 grain weight is less due to limited moisture supply at anthesis. Many researchers reported that water deficit significantly affected 1000 grain weight (Denčić *et al.*, 2000; Oladir *et al.*, 1999; Shehzadi, 1999). Ashraf (1998) highlighted the important role of productive spikes per plant in enhancing the yield under water deficit. Reduction in grain and straw yield under water deficit at anthesis is due to reduced pollination and less biomass production. However, more tillers per unit area under the augmented furrow method of wheat sowing is the main reason for improved grain yield. Bakhsh *et al.* (2018) validated the finding who also reported an increase in the number of tillers and grain yield in wheat under bed sowing of wheat as compared to flat planting. These findings also match with the results revealed by Solomon *et al.* (2003), Ozturk and Aydin (2004) who concluded that grain yield in wheat was reduced by inducing drought stress at different growth stages as compared to normal irrigated conditions. Maximum improvement in straw and grain yield due to augmented furrow method as compared to other methods is due to maximum water use efficiency in augmented furrow method. These results are in agreement with findings reported by Ali *et al.* (2016) and Mollah *et al.* (2016) who also reported that more straw yield under bed sowing method as compared to wheat sown by traditional methods. Liu *et al.* (2020) also associated an increase in wheat grain yield in ridge and furrow sowing with an increase in soil moisture contents. Variation in the harvest index of wheat is due to its varied response to moisture availability and differences in partitioning of assimilates. Islam et al., (2018) also reported similar findings as the harvest index of wheat was much improved with increasing the number of irrigations up to 4 as compared to the condition where irrigation was less or not applied. Our findings are in accordance with the results reported by Rajput *et al.* (1994). Who concluded that maximum spike length, tillers plant^{-1}, grain yield and harvest index were recorded with 4-5 irrigations as compared to 3 irrigations in wheat. However, our findings are similar to findings reported by Islam *et al.* (2018) who recorded an increase in spike length, tillers per plant, number of grains per spike, 1000 grain weight, grain yield and straw yield of wheat up to 3 irrigations as compared to no irrigation. However, it was found that the number of grains per spike, 1000 grain weight, grain yield and straw yield of wheat was decreased when fourth irrigation was applied to wheat as compared to third irrigations. It may be due to the application of irrigation water other than the water-sensitive stage of wheat with less impact. Improved irrigation water use efficiency under the augmented furrow method is due to more grain yield under a limited supply of irrigation water. These findings are in accordance with results reported by Aguilar-Arevalo *et al.* (2007) as they linked improvement in WUE under water deficit with the selection of the appropriate method of sowing.

CONCLUSION AND RECOMMENDATIONS

The augmented furrow method of wheat sowing resulted in 30.66% and 54.07% more grain yield as compared to drill and broadcast methods of sowing, respectively. Irrigation water use efficiency was 53.47% and 75.45% more in augmented furrow method of wheat sowing under water deficit at anthesis as compared to drill and broadcast sowing, respectively. The augmented furrow method of wheat sowing can be effectively and economically utilized by the farmers not only for increasing wheat yield but also for enhancing irrigation water use efficiency under a limited supply of water at the anthesis stage. Farmers can sow wheat by using the augmented furrow method to improve grain yield and irrigation water use efficiency as compared to conventionally used drill and broadcast sowing methods. However, farmers must be educated by extension workers of government institutes and adoptive research farms for understanding and adopting this approach. Future research is needed to check the efficacy of the augmented furrow method of wheat sowing for various soil types under farmer field conditions for improvement in grain yield and irrigation water use efficiency.

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