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POTENTIAL EFFECT OF BED-FURROW PLANTING IMPROVED THE WHEAT GRAINS PRODUCTIVITY UNDER DROUGHT STRESS

*Javaiz ALAM[1], Hamid NAWAZ[2], Haseeb-ur-REHMAN[1], Malik Muhammad YOUSAF [3], Nazim HUSSAIN[1]**

[1]Bahauddin Zakariya University, Multan Pakistan, Faculty of Agricultural Sciences & Technology, Department of Agronomy, PAKISTAN
[2]The Islamia University of Bahawalpur, Department of Agronomy, PAKISTAN
[3]Pakistan Agricultural Research Council, Arid Zone Research Institute, Bahawalpur, PAKISTAN
**Corresponding author: nazimhussain@bzu.edu.pk*

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ABSTRACT

Limited water availability in future due to climate change may impact wheat yield and the food security. Therefore, it is necessary to find out the agronomic solutions to reduce the drought induce yield losses in wheat. Planting method affects wheat yield by changing the soil water status and root growth. This 2-year study (2019-2020 and 2020-2021) was designed to evaluate the impact of various planting methods along-with water irrigation deficit regimes at different growth stages on wheat yield and net returns. The experiments were conducted in a randomized complete block design with three replications using two-way factorial arrangements. The experiment consisted of five planting methods (PM) viz. conventional broadcasting-PM, ridge-PM, bed-furrow-PM, gap-chat-PM and line-PM; and three water regimes viz., well-watered condition, mild and severe-terminal drought stress (TDS). The results revealed that wheat crop grown under bed-furrow-PM had better morphological growth under well-watered condition, and the crop grown under the same planting method performed better for morphological traits under mild-TDS and severe-TDS during both years. Irrometer Tensiometer was used to check the moisture stress level during terminal drought conditions. Better performance of wheat under mild-TDS and severe-TDS in bed-furrow-PM was the outcome of better antioxidants enzymatic and non-enzymatic activities which was later translated into better wheat yield and high net returns under water stress than other planting methods. In conclusion, bed-furrow-PM is the most suitable method for profitable wheat production in arid and semiarid region under water limited scenarios.

Keywords: Antioxidants, grains yield, planting methods, terminal drought stress, wheat

INTRODUCTION

Sudden climate fluctuations and increasing food prices are having a detrimental effect on human food consumption and ensuring the food security is at the top of agenda to sustain the world's rapidly growing population (Madani et al., 2010). Wheat grains are used a staple food to feed more than a one-fourth of the human population and provide >20% calories and proteins around world (Yasmeen et al., 2013).

Field crops grown-up in the natural environments are constantly facing the various stress challenges including water stress (humidity, waterlogged or flooding or deficit), light stress (UV-radiations and Ozone), salt stress (sodic or acidic soil), and heavy metal stress (ionic or toxic or metalloids) etc. Drought stress is one of the most drastic limiting abiotic factor for sustaining the crop production and it causes 1-30% yield losses (Farooq et al., 2009). Wheat is a determinant crop and it requires water application during the various critical phenological growth phases; however its deficiency at terminal stages termed as "terminal drought stress (TDS)" especially at grains formation and milking duration severely declines the grain yield (Dhanda and Sethi, 2002). The observations revealed that the restrictions in the grain development processes are due to the inhibition of photosynthetic mechanisms; condensed grain-sink potential; augmented leaf senescence process and poor source-sink relationships during the drought stress conditions. Majid et al. (2007) illustrated terminal drought stress into two subcategories {mild terminal drought stress (Mild-TDS) and severe terminal drought stress (Severe-TDS)} based on its severity in declining the grains yield as pre-anthesis (18–53%), post-anthesis (13–38%), and flowering and grain filling (58–92%).

The excessive production of reactive oxygen species (ROS) such as free radical species {superoxide anion ($^{\bullet}O_2^{-}$), singlet oxygen ($^{1}O_2$), per-hydroxyl radical (HO_2)} and non-radical species {hydrogen peroxide (H_2O_2), reactive hydroxyl radical (•OH) creates the oxidative damage at cellular level in the plants induced with terminal drought stress condition (Gill and Tuteja, 2010). The symmetrical production of ROS and antioxidant defense contents sustain the healthy plant production in aerobic condition. Plants pretend to show tolerance mechanisms by ROS scavenging mechanism with activation of antioxidant defense system {enzymatic: superoxide dismutase-SOD, peroxidase-POD, catalase-CAT and non-enzymatic: total soluble protein-TSP, ascorbic acid-AsA} which mitigate the injurious effect of oxidative stress (Ma et al., 2006).

Planting method (PM) triggers the crop performance under field condition. Various studies revealed the different types of wheat planting methods as conventional broadcasting-PM, ridge-PM, bed-furrow-PM, gap-chat-PM and line-PM affects the water use efficiency, and nutrient availability (Freeman et al., 2007). Planting of wheat crop in bed-furrow-PM is newly emerged technique in improving the crop yield and productivity (Shahrokhnia and Sepaskhah, 2016; Asseng et al., 2011; Karim et al., 2000). Therefore, this research project was initiated to compare the effects of various planting methods on the grains yields and antioxidants behaviour of wheat crop under subjected terminal drought stress conditions.

MATERIALS AND METHODS

Two years of field experiments were conducted in Agronomic Research Area, Department of Agronomy, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University Multan, Pakistan during the winter's season of 2019-2020 and 2020-2021. The climate of the Multan Region is semi-arid and subtropical. Meteorological data during the crop phenological growth stages are shown in the Figure 1. The experimental soil was observed as silty clay loam with average sand 24.09%, silt 60.01%, clay 18.04%, organic matter 0.65%, saturation 40%, total Nitrogen 0.06%, available phosphorus 5.75 ppm, available potassium 302 ppm, EC 2.99 dS m^{-1}, pH 7.89, zinc 0.38 ppm, $CaCO_3$ 8.99% during the both years of trials.

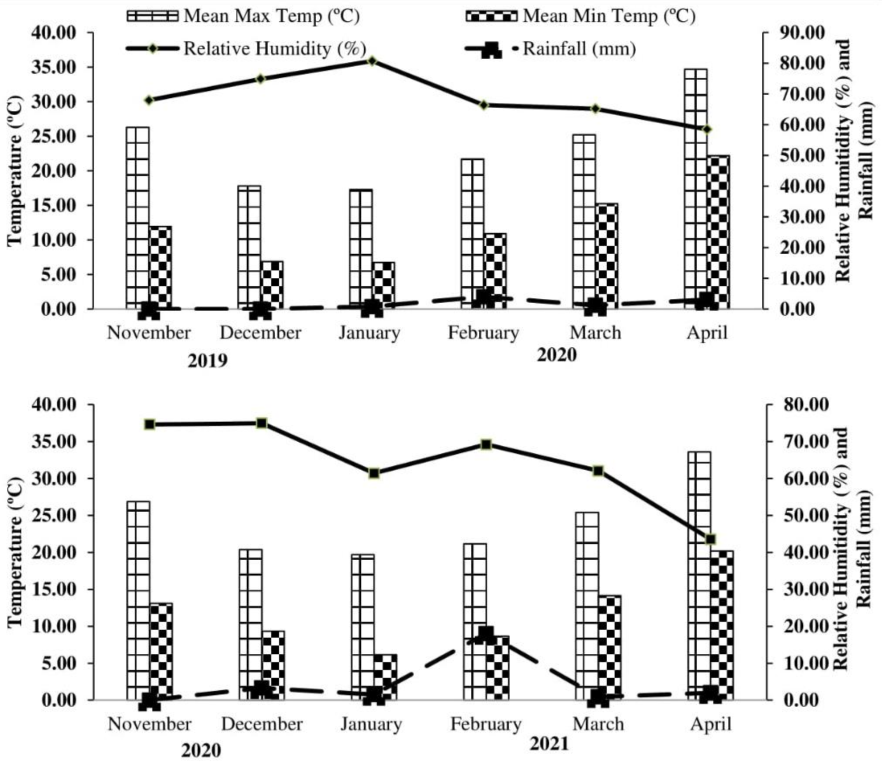

Figure 1. Meteorological data during wheat phenological growing seasons of 2019-2020 and 2020-2021 Metrological department, Central cotton research institute (CCRI) Multan, Pakistan

The experiment consisted of five planting methods (PM) viz. conventional broadcasting-PM, ridge-PM, bed-furrow-PM, gap-chat-PM and line-PM; and three water-irrigation regimes viz., well-watered condition, mild and severe-terminal drought stress (TDS). The irrigations were applied at tillering, booting, heading and milking stages in well-watered condition, in mild-TDS, drought stress was applied at milking stages while in severe-TDS, drought stress was applied at heading and milking stages. During both years, the experiment was conducted in randomized complete block design (RCBD) with two factors arrangements and replicated thrice. The details of planting methods used in the trials were as Broadcast-PM: Healthy seeds were carefully planted as broadcast, Ridge-PM: 13 uniform ridges were prepared by tractor mounted ridger planter machine at the distance of 1.5 feet and seeds were planted at the distance of 22 cm lines by using handmade drilled machine. Bed-furrow-PM: 8 uniform beds were prepared by tractor mounted bed planter machine at the distance of 2.5 feet and seeds were planted at the distance of 22 cm lines by using handmade drilled machine. Gap-chat-PM: Seeds were broadcasted at wet soil after rouni irrigation during seedbed preparation. Line-PM: Seeds were planted at the distance of 22 cm lines by using handmade drilled machine. The recommended wheat seed rate was used 125 kg ha^{-1} and fertilizers viz., urea (Nitrogen, N), single super phosphate (Phosphorus, P) and potassium sulfate (Potash, K) were applied @ 120−100−63.5 kg ha^{-1} respectively. Wheat cultivar Ghazi-2019 was planted on 1st fortnight of November during the first year and 2nd fortnight of November during the second year of trials. All the agronomic intercultural practices were applied uniformly as per need of the crop growth and development. The mature crop was harvested in the 2nd fortnight of April during the both years of trials. Hunt (1978) and Nawaz et al. (2017) described the protocol and formulas to measure leaf area index (LAI), seasonal leaf area duration (SLAD), crop growth rate (CGR) and net assimilation rate (NAR). On the other-hand, yield and yield related attributes including's fertile tillers, grains per spike, 1000-grains weight, biological yield, grains yield and harvest index were measured by following the standard procedure (Nawaz et al., 2017).

The standard protocols were used to determine the enzymatic and non-enzymatic antioxidants contents by following the procedure described by Bradford (1976) for total soluble proteins−TSP, Giannopolitis and Reis (1997) for superoxide dismutase−SOD, Chance and Maehly, (1955) for peroxidase−POD and catalase−CAT, Ainsworth and Gillespie (2007) for ascorbic acid−AsA, Waterhouse (2001) for total phenolic contents−TPC, Nagata and Yamashita (1992) for leaf chlorophyll−*a* & *b*, and Rashid, 1986 for potassium−K^+. Total expenditure, gross income, net income and benefit-cost ratio (BCR) were determined by using the formulas described by Nawaz et al. (2020).

Data was arranged and analysed by using the technique of Fisher's analysis of variance. Duncan's multiple range tests were applied to compare the treatments means differences at ≥ 5 % probability level (Steel et al., 1997). Furthermore, Microsoft Excel Program-2013 was used for making graphs and charts.

RESULTS

The applied severe-TDS had reduced LAI at 75 DAS compared with well-watered condition followed by mild-TDS; but the plants planted with bed-furrow-PM have significantly higher LAI under terminal drought stress conditions during both the years 2019-2020 and 2020-2021 (Figure 2). Among various planting methods, SLAD was obtained higher in bed-furrow-PM during all the intervals (30, 40, 55, 75 DAS) of determination and the least was recorded in conventional broadcasting-PM under severe-TDS and mild-TDS than well-watered condition shown in the figure 2 during the year-I & II. While CGR and NAR were progressively increased up till 55 DAS and then declined, however, plants showed better results in bed-furrow-PM after ridge-PM in well-watered condition as well as severe-TDS and mild-TDS during both the years of trials as presented in the figure 2.

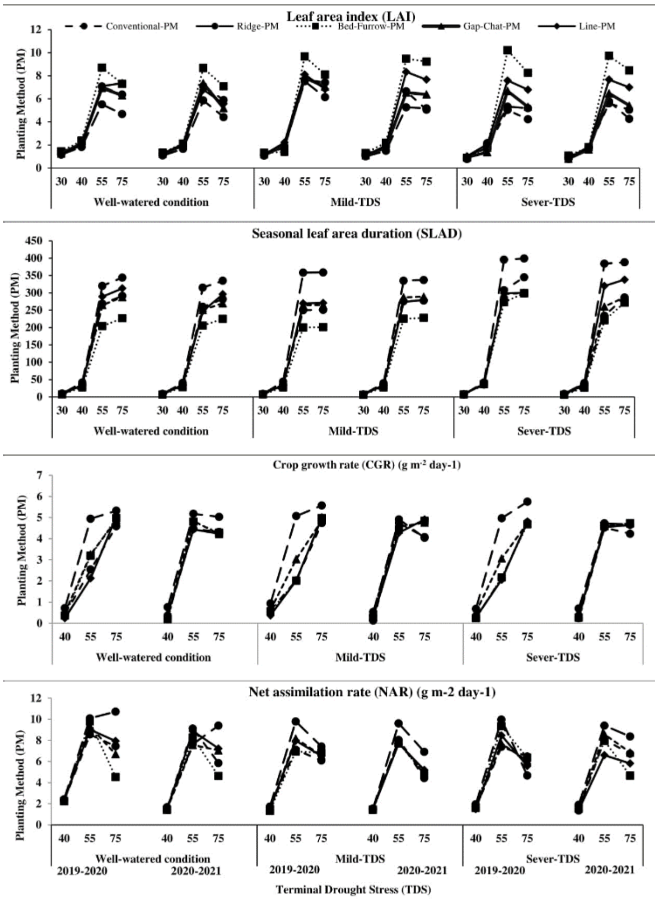

Figure 2. Impact of various planting methods on growth morphological parameters of wheat crop under terminal drought stress

The enzymatic antioxidant contents, total soluble protein (TSP) were higher in the wheat plants under severe-TDS followed by mild-TDS against well-watered condition treatment during both the years of study. Performances of TDS plants in in terms of TSP generation were significantly maximum under bed-furrow-PM as compared to others during both the years of trials (Table 1). The wheat crop with bed-furrow method under induced severe-TDS and mild-TDS had better production of SOD and POD contents (Table 1). CAT contents were also higher in the plants under induced terminal drought i.e. sever-TDS followed by mild-TDS compared with well-watered condition under bed-furrow-PM during the year-II while during the first year of trials, maximum CAT contents were noted in well-watered condition and least in sever-TDS (Table 1). The use of bed-furrow-PM under severe-TDS favoured the plants in producing the higher levels of AsA contents during both the years of trials but the highest contents were observed in year-II than year I (Table 1). TDS also impacted the plants thus affecting the TPC contents during the various planting methods but bed-furrow-PM encouraged the TPC generations in severe-TDS followed by mild-TDS when compared to well-watered condition and achieved maximum during the year-II as per year-I (Table 1). Highest K^+ contents was observed in bed-furrow-PM followed by gap-chat-PM under mild-TDS and severe-TDS after well-watered condition during the year-I and also maximum in line-PM after bed-furrow-PM in mild-TDS and least in severe-TDS as compared to well-watered condition (Table 1). It was observed that plants in bed-furrow-PM obtained significantly higher leaf chlorophyll "*a*" and "*b*" in the well-watered condition followed by mild-TDS and severe-TDS during the year-II than year-I and chlorophyll "*b*" was non-significant during the year-II (Figure 3).

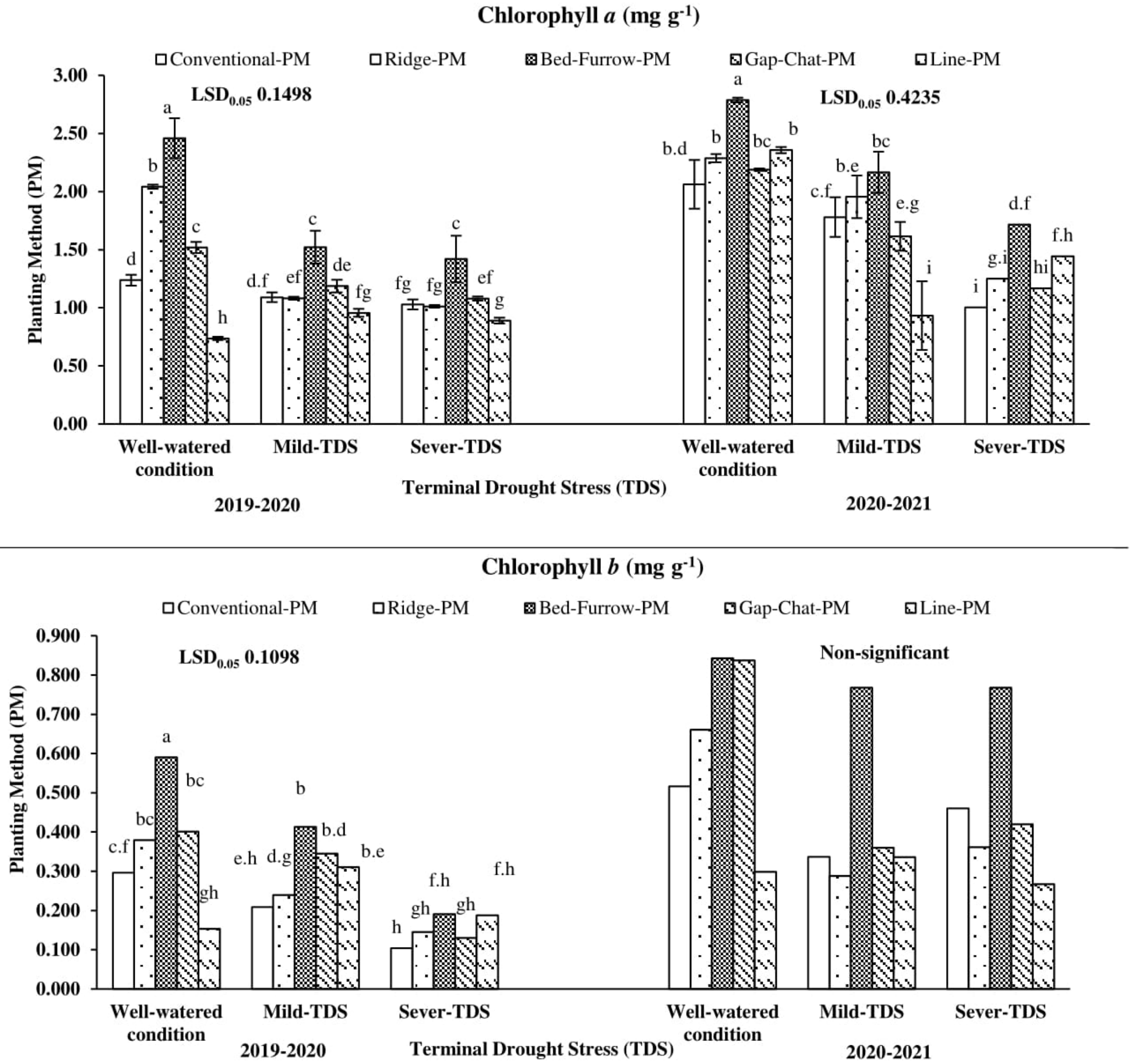

Figure 3. Impact of various planting methods on chlorophyll contents of wheat crop under terminal drought stress

Severe-TDS and mild-TDS decreased the number of fertile tillers, while maximum fertile tillers were received in bed-furrow-PM followed by ridge-PM and minimum in conventional broadcasting-PM under both TDS conditions after well-watered condition during the year-II than year-I shown in the table 2. It was observed that severe-TDS substantially hampered the production of number of grains per spike as per well-watered condition but bed-furrow-PM notably had maximum grains per spike during the year-I after year-II. The highest 1000-grains weight was recorded from wheat sown in bed-furrow-PM under to mild-TDS and severe-TDS after well-watered condition during both years of exploration (Table 2). TDS reduced the grains yield during both years of trials, but plants planted in bed-furrow-PM had significantly good trend in increasing the grains yield under induced mild-TDS followed by severe-TDS during both the years of trials. Less grain yield was observed in line-PM and conventional-PM in severe-TDS and mild-TDS conditions during both the years of trials (Table 2). Similar trend was also observed for biological yield under applied TDS conditions along-with various planting methods and maximum was obtained in bed-furrow-PM in well-watered condition followed by mild-TDS and severe-TDS during the year-II as compared to year-I. On the other hand, harvest index (HI) was non-significant (Table 2).

The economic analysis of the experiments indicated that bed-furrow-PM was the comparatively the most cost effective method to obtain the maximum benefit cost ratio with mild-TDS and severe-TDS after well-watered condition (Table 3).

Table 1. Impact of various planting methods on antioxidants of wheat crop under terminal drought stress

Planting Method (PM)	2019-2020 Terminal Drought Stress (TDS)				2020-2021 Terminal Drought Stress (TDS)			
	Well-watered condition	**Mild-TDS**	**Severe-TDS**	**Mean**	**Well-watered condition**	**Mild-TDS**	**Severe-TDS**	**Mean**
	Total Soluble Protein (mg g^{-1})							
Conventional-PM	1.24f±0.08	1.83d±0.06	2.02bc±0.06	***1.69B***	1.41ef±0.02	1.82cd±0.03	2.18b±0.13	***1.80B***
Ridge-PM	1.03g±0.15	1.53e±0.22	2.04b±0.03	***1.53C***	1.50.f±0.03	1.69c.e±0.02	2.30b±0.03	***1.83B***
Bed-Furrow-PM	1.49e±0.07	1.95b.d±0.03	2.24a±0.03	***1.89A***	1.70c.e±0.02	1.99bc±0.35	2.72a±0.04	***2.13A***
Gap-Chat-PM	1.23f±0.04	1.85cd±0.11	2.01bc±0.02	***1.70B***	1.21f±0.03	1.82cd±0.07	2.01bc±0.03	***1.68BC***
Line-PM	1.37ef±0.03	1.78d±0.11	1.95b.d±0.02	***1.70B***	1.40ef±0.04	1.73c.e±0.22	1.50d.f±0.51	***1.54C***
Mean	***1.27C***	***1.79B***	***2.05A***		***1.44C***	***1.81B***	***2.14A***	
Year		***1.70B***				***1.80A***		
LSD@0.05	Interaction 0.1796, PM 0.1037, TDS 0.0803, Year 0.0694				Interaction 0.3301, PM 0.1906, TDS 0.1476			
	Superoxide dismutase (IU min^{-1} mg^{-1} protein)							
Conventional-PM	28.59fg±0.89	36.66f±1.22	38.31ef±0.70	***34.51D***	16.78i±0.06	58.12d±1.15	31.96fg±0.72	***35.62C***
Ridge-PM	40.03ef±0.23	67.06c±1.00	106.64a±1.30	***71.24A***	35.66e.g±0.74	94.62b±1.38	104.93a±0.38	***78.40A***
Bed-Furrow-PM	22.35gh±0.34	50.36de±0.84	61.68cd±1.63	***44.79C***	20.54hi±0.13	41.25ef±0.28	38.80ef±1.96	***33.53C***
Gap-Chat-PM	35.41f±1.18	56.47cd±1.50	85.39b±1.26	***59.08B***	26.28g.i±0.78	68.93c±0.73	56.99d±0.06	***50.73B***
Line-PM	14.79h±0.87	58.04cd±0.95	28.46fg±0.49	***33.76D***	19.04hi±0.18	28.67gh±0.37	45.56e±1.11	***31.08C***
Mean	***28.23C***	***53.71B***	***64.09A***		***23.65B***	***58.31A***	***55.65A***	
Year		***48.68***				***45.87***		
LSD@0.05	Interaction 12.931, PM 7.4657, TDS 5.7829, Year Non-significant				Interaction 10.097, PM 5.8293, TDS 4.5153			
	Peroxidase (mmol min^{-1} mg protein^{-1})							
Conventional-PM	5.19i±0.68	12.21de±0.26	35.18c±0.64	***17.53C***	6.54h±0.20	18.88f±1.21	37.44c±0.21	***20.95C***
Ridge-PM	5.72i±0.69	10.76fg±0.29	35.54c±0.59	***17.34CD***	7.03gh±0.20	23.71de±0.22	37.80c±0.20	***22.84B***
Bed-Furrow-PM	7.95h±0.12	13.13d±0.21	43.30a±1.00	***21.46A***	9.13g±0.03	25.71d±0.05	45.57a±0.33	***26.80A***
Gap-Chat-PM	5.96i±0.61	11.17ef±0.15	40.07b±0.52	***19.07B***	7.23gh±0.18	22.0e±0.27	42.34b±0.17	***23.87B***
Line-PM	4.98i±0.32	9.71g±0.71	35.26c±0.95	***16.65D***	6.36h±0.09	23.79de±0.04	37.52c±0.32	***22.55B***
Mean	***5.96C***	***11.39B***	***37.87A***		***7.25C***	***22.82B***	***40.13A***	
Year		***18.41B***				***23.40A***		
LSD@0.05	Interaction 1.2090, PM 0.6980, TDS 0.5407, Year 0.4642				Interaction 2.3155, PM 1.3369, TDS 1.0355			
	Catalase (µmol min^{-1} mg protein^{-1})							
Conventional-PM	6.07h±0.27	12.13ef±0.06	34.13b±0.37	***17.44B***	8.06hi±0.35	21.56ef±0.74	34.33bc±0.16	***21.32C***
Ridge-PM	6.71h±0.26	12.89e±0.13	33.13b±0.50	***17.58B***	8.63hi±0.34	17.62g±0.79	21.66ef±0.42	***15.97D***
Bed-Furrow-PM	8.64g±0.05	14.93d±0.10	39.29a±0.04	***20.95A***	11.48h±0.06	26.50d±0.88	44.75a±0.90	***27.58A***
Gap-Chat-PM	7.11h±0.24	14.43d±0.09	30. 63c±0.11	***17.39B***	9.79hi±0.33	24.65de±0.50	37.69b±0.43	***24.04B***
Line-PM	5.92h±0.14	11.35f±0.28	30.79c±0.29	***16.02C***	7.24i±0.16	20.47fg±1.09	33.03c±1.11	***20.24C***
Mean	***33.59A***	***13.15B***	***6.89C***		***9.04C***	***22.16B***	***34.29A***	
Year		***17.88B***				***21.83A***		
LSD@0.05	Interaction 1.4724, PM 0.8501, TDS 0.6585, Year 0.7530				Interaction 3.9120, PM 2.2586, TDS 1.7495			
	Ascorbic acid (m mole g^{-1})							
Conventional-PM	54.40k±0.46	89.45fg±0.28	92.47cd±0.24	***78.77C***	71.12j±0.39	97.38de±0.84	101.17b±0.09	***89.88BC***
Ridge-PM	54.61k±0.46	90.38ef±0.08	96.71b±0.12	***80.57B***	71.33j±0.38	98.31d±0.24	98.67cd±0.12	***89.43C***
Bed-Furrow-PM	61.78i±0.45	92.28c.e±0.24	99.16a±0.30	***84.41A***	78.50g±0.36	100.21bc±0.71	106.52a 0.12	***95.07A***
Gap-Chat-PM	59.45j±0.06	87.59gh±0.67	94.12c±0.13	***80.38B***	76.17h±0.18	95.53ef±0.01	101.02b±0.09	***90.90B***
Line-PM	57.50j±0.54	86.45h±0.08	91.57de±0.12	***78.50C***	74.21i±0.63	94.38f±0.24	100.95b±0.11	***89.84BC***
Mean	***57.55C***	***89.23B***	***94.81A***		***74.2C***	***97.16B***	***101.67A***	
Year		***80.53B***				***91.03A***		
LSD@0.05	Interaction 1.9886, PM 1.1481 , TDS 0.8893, Year 0.4775				Interaction 1.8587, PM 1.0731, TDS 0.8313			
	Total phenolic contents (mg g^{-1})							
Conventional-PM	0.87gh±0.02	1.37c±0.12	1.38c±0.01	***1.20B***	1.15hi±0.01	1.59e.g±0.04	2.13bc±0.29	***1.62BC***
Ridge-PM	0.92f.h±0.03	0.99e.g±0.09	1.13d±0.01	***1.01C***	1.32f.i±0.07	1.66d.f±0.04	2.30b±0.23	***1.76B***
Bed-Furrow-PM	1.08de±0.01	1.44c±0.12	1.94a±0.03	***1.49A***	1.48e.h±0.03	1.96cd±0.02	2.66a±0.12	***2.03A***
Gap-Chat-PM	1.04d.f±0.11	0.92f.h±0.09	1.69b±0.01	***1.21B***	1.27g.i±0.16	1.71de±0.06	2.05bc±0.01	***1.68BC***
Line-PM	0.88gh±0.08	0.85h±0.03	0.96e.h±0.02	***0.89D***	1.32f.i±0.30	1.03i±0.33	2.21bc±0.03	***1.52C***
Mean	***0.96C***	***1.11B***	***1.42A***		***1.31C***	***1.59B***	***2.27A***	
Year		***1.16B***				***1.72A***		
LSD@0.05	Interaction 0.1387, PM 0.0801, TDS 0.0620, Year 0.0640				Interaction 0.3368, PM 0.1944, TDS 0.1506			
	K^+ contents (mg g^{-1})							
Conventional-PM	1.39b.e±0.02	1.19e.h±0.04	1.08gh±0.18	***1.22B***	1.36fg±0.04	1.53de±0.02	1.21h±0.03	***1.37CD***
Ridge-PM	1.52bc±0.02	1.09f.h±0.04	1.11f.h±0.17	***1.24B***	1.30gh±0.04	1.66cd±0.02	1.05i±0.03	***1.33D***
Bed-Furrow-PM	1.89a±0.04	1.59b±0.02	1.38b.e±0.24	***1.62A***	1.95b±0.04	2.55a±0.05	1.76c±0.26	***2.09A***
Gap-Chat-PM	1.42b.d±0.02	1.29d.g±0.04	1.31c.f±0.21	***1.34B***	1.47ef±0.54	1.54de±0.02	1.28gh±0.04	***1.43C***
Line-PM	1.22d.g±0.08	0.99hi±0.04	0.85i±0.03	***1.02C***	1.80bc±0.04	1.75c±0.02	1.54de±0.09	***1.69B***
Mean	***1.49A***	***1.23B***	***1.14B***		***1.58B***	***1.80A***	***1.37C***	
Year		***1.29B***				***1.58A***		
LSD@0.05	Interaction 0.2237, PM 0.1292, TDS 0.1001, Year 0.0476				Interaction 0.1500, PM 0.0866, TDS 0.0671			

Means sharing the same letter(s), within a row or column, for each trait do not differ significantly at $p \leq 0.05$

Table: 2. Impact of various planting methods on the yield and yield related parameters of wheat crop under terminal drought stress

Planting Method (PM)	2019-2020 Terminal Drought Stress (TDS)				2020-2021 Terminal Drought Stress (TDS)			
	Well-watered condition	Mild-TDS	Severe-TDS	Mean	Well-watered condition	Mild-TDS	Severe-TDS	Mean
	Fertile Tillers (m^{-1})							
Conventional-PM	354.00c±0.98	295.00e±0.72	258.00h±0.54	302.33D	369.33cd±2.20	308.33gh±0.57	291.00i±1.25	322.89C
Ridge-PM	374.67b±0.68	299.00e±0.47	271.67g±1.13	315.11B	388.67b±0.87	321.00f±1.96	274.33j±1.03	328.00B
Bed-Furrow-PM	390.33a±1.75	327.33d±1.81	286.67f±0.42	334.78A	403.67a±0.83	337.33e±2.64	266.00kl±0.82	335.67A
Gap-Chat-PM	368.33b±0.96	297.00e±1.96	261. 67h±1.10	309.00C	375.00c±0.98	315.67fg±0.57	270.33jk±0.96	320.33C
Line-PM	356.33c±0.68	282.00f±1.70	255.33h±0.87	297.89E	366.33d±0.63	304.33h±0.42	261.33l±0.42	310.67D
Mean	368.73A	300.07B	266.67C		380.60A	317.33B	272.60C	
Year		311.82B				323.51A		
LSD@0.05	Interaction 7.3537, PM 4.2457, TDS 3.2887, Year 1.8814				Interaction 7.7204, PM 4.4574, TDS 3.4527			
	Grains $Spike^{-1}$							
Conventional-PM	54.70c ±0.64	49.73d.f ±0.87	45.46fg ±0.25	49.96C	58.90c ±0.93	54.53c.f ±0.43	47.80hi ±0.31	53.74BC
Ridge-PM	60.03b ±0.72	51.70c.e ±0.53	46.80fg ±0.85	52.84B	64.10b ±0.38	53.40d.g ±0.97	49.40g.i ±0.75	55.63B
Bed-Furrow-PM	67.46a ±0.90	52.10c.e ±0.97	48.76e.g ±0.92	56.11A	70.93a ±0.45	59.10c ±0.80	51.10e.i ±0.78	60.37A
Gap-Chat-PM	55.26c ±0.59	48.93ef ±0.69	46.66fg ±0.76	50.28C	56.10cd ±0.83	52.96d.g ±1.16	50.13f.i ±0.44	53.06BC
Line-PM	53.93cd±0.23	47.30fg ±0.42	44.50 g ±0.89	48.57C	55.80c.e ±0.72	51.90d.h ±1.07	46.90i ±1.01	51.53C
Mean	58.28A	49.95B	46.44C		61.16A	54.38B	49.06C	
Year		54.87B				51.55A		
LSD@0.05	Interaction 4.2980, PM 2.4815, TDS 1.9221, Year 1.1350				Interaction 4.8334, PM 2.7906, TDS 2.1616			
	1000-Grains Weight (g)							
Conventional-PM	40.28bc ±0.87	38.01c.e ±0.14	33.62fg ±0.41	37.30B	39.39cd ±0.28	37.21ef ±0.05	29.75ij ±0.36	35.45C
Ridge-PM	42.21b ±0.78	39.54b.d ±0.59	30.92gh ±0.62	37.56B	37.56ef ±0.25	32.51h ±0.35	28.25j ±0.34	32.77D
Bed-Furrow-PM	47.38a ±0.44	41.91b ±0.40	36.95de ±0.21	42.08A	46.36a ±0.08	40.21c ±0.09	36.48fg ±0.28	41.01A
Gap-Chat-PM	37.38c.e ±0.46	35.91ef ±0.12	31.62gh ±0.45	34.97C	43.69b ±0.46	38.31de ±0.07	30.71i ±0.06	37.57B
Line-PM	35.51ef ±0.34	29.81h ±0.37	30.72gh ±0.33	32.01D	35.09g ±0.19	±32.51h 0.40	30.55i ±0.12	32.71D
Mean	40.55A	37.03B	32.76C		40.42A	36.15B	31.15C	
Year		36.78A				35.90B		
LSD@0.05	Interaction 2.9447, PM 1.7001, TDS 1.3169, Year 0.6026				Interaction 1.6565, PM 0.9564, TDS 0.7408			
	Grain Yield (t ha^{-1})							
Conventional-PM	6.49c ±0.48	4.92ef ±0.47	3.94hi ±0.26	5.122CD	6.98c±0.44	5.62e±0.40	4.27g±0.25	5.62C
Ridge-PM	7.15b ±0.32	5.41de ±0.45	4.46f.h ±0.58	5.674B	8.31b±0.40	5.62e±0.43	4.28g±0.43	6.07B
Bed-Furrow-PM	8.49a ±0.57	5.64d ±0.48	4.62fg ±0.55	6.254A	9.37a±0.15	6.31d±0.56	4.61fg±0.20	6.76A
Gap-Chat-PM	6.90bc ±0.58	4.93ef ±0.49	4.19g.i ±0.41	5.341BC	6.86cd±0.43	5.51es±0.50	4.57fg±0.29	5.65C
Line-PM	6.45c ±0.29	4.49f.h ±0.19	3.83i ±0.34	4.926D	6.49cd±0.52	5.02ef±0.40	3.99g±0.32	5.17D
Mean	7.10A	5.08B	4.21C		7.60A	5.62B	4.34C	
Year		5.54				5.46		
LSD@0.05	Interaction 0.6043, PM 0.3489, TDS 0.2546, Year NS				Interaction 0.6444, PM 0.3720, TDS 0.2882			
	Biological Yield (t ha^{-1})							
Conventional-PM	13.50cd±0.65	11.57ef±0.31	9.11hi±0.13	11.39CD	15.69c±0.47	11.81d±0.14	8.98fg±0.15	12.16C
Ridge-PM	17.43b±0.43	12.04d.f±0.21	9.65g.i±0.30	13.04B	19.61b±0.25	12.04d±0.29	9.19e.g±0.32	13.61B
Bed-Furrow-PM	19.88a±0.33	13.43cd±0.39	10.87e.h±0.37	14.73A	22.09a±0.17	14.48c±0.44	9.43e.g±0.17	15.33A
Gap-Chat-PM	14.48c±0.12	11.23e.g±0.27	9.38g.i±0.26	11.70C	15.47c±0.33	10.78de±0.46	9.72ef±0.27	11.99CD
Line-PM	12.46de±0.66	10.21f.i±0.10	8.68i±0.21	10.45D	14.92c±0.39	10.37d.f±0.32	7.75g±0.23	11.01D
Mean	15.55A	11.70B	9.54C		17.55A	11.90B	9.01C	
Year		12.26B				12.82A		
LSD@0.05	Interaction 1.8547, PM 1.0708, TDS 0.8295, Year 0.4532				Interaction 1.7725, PM 1.0234, TDS 0.7927			
	Harvest Index (%)							
Conventional-PM	39.50±2.01	39.03±0.29	39.02±0.41	39.18	39.65±0.78	41.21±0.65	42.72±1.27	41.19
Ridge-PM	39.43±0.49	39.19±0.57	38.37±0.63	38.99	37.37±0.14	41.67±0.19	41.63±0.16	40.22
Bed-Furrow-PM	38.84±0.98	39.05±0.29	39.72±0.25	39.20	37.41±0.09	38.63±0.07	41.03±0.57	39.03
Gap-Chat-PM	39.82±1.54	39.65±0.41	38.29±0.53	39.25	39.36±0.24	41.16±1.26	42.16±0.94	40.89
Line-PM	40.16±2.52	39.20±0.57	38.97±0.77	39.44	38.49±0.20	41.24±0.53	40.56±0.69	40.09
Mean	39.55	39.22	38.87		38.45	40.78	41.62	
Year		39.21B				40.28A		
LSD@0.05		NS				NS		

Means sharing the same letter(s), within a row or column, for each trait do not differ significantly at $p \leq 0.05$ *NS=Non-significant

Table: 3. Economic analysis for the impact of various planting method in wheat crop under terminal drought stress

Terminal Drought Stress	Planting Method	Total expenditure (US$ ha^{-1})		Gross Income (US$ ha^{-1})		Net Income (US$ ha^{-1})		Benefit Cost Ratio	
		2019-2020	2020-2021	2019-2020	2020-2021	2019-2020	2020-2021	2019-2020	2020-2021
Well-watered condition	Conventional-PM	395.54	395.54	955.24	888.94	559.69	493.39	1.41	1.25
	Ridge-PM	404.11	404.11	1308.59	1243.11	904.48	838.99	2.24	2.08
	Bed-Furrow-PM	421.26	421.26	1480.27	1433.32	1059.01	1012.06	2.51	2.40
	Gap-Chat-PM	389.83	389.83	1034.27	1038.91	644.44	649.08	1.65	1.67
	Line-PM	395.54	395.54	819.40	814.40	423.86	418.86	1.07	1.06
Mild-TDS	Conventional-PM	386.97	386.97	907.01	811.90	520.04	424.93	1.34	1.10
	Ridge-PM	389.83	389.83	904.32	875.57	514.49	485.74	1.32	1.25
	Bed-Furrow-PM	412.69	412.69	1061.81	970.15	649.12	557.46	1.57	1.35
	Gap-Chat-PM	395.54	395.54	859.82	780.19	464.28	384.65	1.17	0.97
	Line-PM	386.97	386.97	781.45	707.89	394.48	320.92	1.02	0.83
Severe-TDS	Conventional-PM	378.40	378.40	705.37	660.12	326.97	281.72	0.86	0.74
	Ridge-PM	386.97	386.97	708.79	732.18	321.82	345.21	0.83	0.89
	Bed-Furrow-PM	404.11	404.11	852.47	853.37	448.36	449.26	1.11	1.11
	Gap-Chat-PM	381.26	381.26	708.17	656.56	326.91	275.30	0.86	0.72
	Line-PM	378.40	378.40	661.62	640.18	283.22	261.78	0.75	0.69

DISCUSSION

Final wheat grain production is the collective outcome of various morphological, biochemical and yield related attributes like number of fertile tillers, grains spike^{-1}, 1000-grains weight etc. established during the certain period of crop husbandry (Nawaz et al., 2021). Terminal drought stress (TDS) abridged the yield and yield related parameters (grains spike^{-1} and 1000-grains weight) by using the crop under various planting methods during both the years of trials. Wheat crop exhibited the sensitive nature at its critical growth stages to drought stress especially at post-anthesis; mild-TDS conditions reduced the yields by 10-40% and severe-TDS by 50-90% (Farooq et al., 2014). The observations proved that maximum plants received stunted growth and development during the applied TDS at heading and milking stages. The substantially cut in the number of fertile tillers, grains spike^{-1} and 1000-grains weight of wheat crop are found due to the highly sensitivity under induced treatment severe-TDS and mild-TDS (Nawaz et al., 2019). The diminished grain production during the severe-TDS at heading and milking growing periods with condensed grains formation due to lower photo-activity, augmented leaf senescence and sink restrictions might be the reason for less grains production and count under terminal drought stress conditions (Ma et al., 2006). The cutback in harvest index under terminal drought stress conditions revealed that it might be due to the poor ineffective partitioning of assimilates towards the grains development process (Jafar et al., 2012). The positive increasing trend between grains and biological wheat yield by bed-furrow-PM under TDS after well-watered condition might be due to the favourable condition of source-sink relationships. The results of 2 years of study demonstrated the clear supremacy in bed-furrrow-PM in enhancing the yields may be due to early and synchronised emergence (Majid et al., 2007), lowest competition of water and light in the fertile tillers establishment (Sepaskhah and Hosseini, 2008), less evaporation losses through plants canopy (Shahrokhnia and Sepaskhah, 2016), efficient nutrients availability for better dry matter assimilation (Nawaz et al., 2016) during grain formation under well-watered condition as well as TDS conditions. Moreover, bed-furrow-PM compensated the damaging impacts of TDS to some extent in grains production by accomplishing the better LAI and SLAD might be lead to the greater CGR resulted in improving NAR and extra interception of solar radiations for grain development (Nawaz et al., 2017).

Terminal drought created an oxidative damaging stress at cellular level (proteins, DNA) by splitting the ratio between reactive oxygen species (ROS) and antioxidant defense activities. The dominant behaviour of ROS at excessive concentration made the plants sensitive which lead to the poor morphological, physiological, and biochemical activities during the entire growing season of crop under water scarcity condition (Apel and Hirt, 2004). The potential of antioxidant defense system (enzymatic as TSP, SOD, POD, CAT and non-enzymatic as AsA, TPC) in plants by ROS scavenging mechanisms has been evidenced as a best protective approach against terminal drought stress (TDS). In this project study, the generation of antioxidants contents (enzymatic and non-enzymatic) under applied sever-TDS and mild-TDS was increased maximum might be maintaining the ionic homeostasis level and help in motivating the plants drought tolerance which having bed-furrow-PM during both the years of trials (Nawaz et al., 2015). The highest production of enzymatic antioxidants SOD, POD, CAT in the plants of bed-furrow-PM may be diminished the stresses impacts during severe-TDS and mild-TDS as compared to well-watered condition (Yasmeen et al., 2012). Similarly, the scavenging ROS mechanism was dominantly activated with the release of better non-enzymatic AsA and TPC contents under sever-TDS and mild-TDS produced tolerance in plants planted in bed-furrow-PM by enhancing photosynthetic activities. Bed-furrow-PM facilitated in the activation of antioxidants contents to protect the plants against ROS cellular oxidative damaging effect under induced severe-TDS and mild-TDS conditions during the both years of study (Nawaz et al., 2013). The production of K^+ contents plays an important role for mineral availability in the leaves of wheat crops and acts as best plant growth regulator during the physiological processes. The significant importance of K^+ contents in bed-fuurow-PM under severe-TDS and mild-TDS revealed the uptake of K^+ may helpful during the physiological attributes especially in stomatal conductance during the both years of trials (Jia et al., 2014).

Crop yield is the collector features of various inputs as chlorophyll contents "*a*" and "*b*" which increased the photosynthetic rate in the well-watered environmental condition under various planting methods. The present study proved that maximum chlorophyll "*a*" and "*b*" contents in the plants with bed-furrow-PM under mild-TDS followed by severe-TDS after well-watered condition might be due to better leaf area index for photosynthesis mechanisms during the both years of exploration (Mehrabi and Sepaskhah, 2018).

Agricultural farmers acknowledged any new agronomic innovations which are commercially feasible and cost effective for crop production. Economic analysis emphasised more BCR values in bed-furrow-PM under well-watered condition as well as severe-TDS and mild-TDS conditions for achieving better grains production of wheat crop (Hussain et al., 2013).

CONCLUSION

Terminal drought stress (TDS) reduced the wheat grains production, but bed-furrow planting method (PM) helped to mitigate the induced drought stress yield losses by modulating the antioxidant defense behaviour.

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