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AGRO-MANAGEMENT PRACTICES FOR SUSTAINABLE WHEAT PRODUCTION UNDER SCARCE WATER CONDITION OF ARID CLIMATE

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ABSTRACT

Irrigation water is vital and most limiting input in arid agriculture. This study evaluates the late sown wheat crop under various agro-management practices for enhancing the crop productivity in water scarce area. Results exhibited that better leaf water relations expressed in terms of an improvement in the leaf water potential, leaf osmotic potential, stomatal conductance and relative water content of flag leaf as well as higher rates of transpiration and net CO_2 assimilation were recorded with the planting technique of seed spreading augmented with furrows. This planting technique also expressed higher number of productive tillers, 1000-grain weight and grain yield whereas lower soil penetration resistance as compared to other planting treatments. The highest water use efficiency (WUE) was achieved with the irrigation regime of 80% (evapotranspiration) ETo while in case of planting techniques, seed spreading augmented with furrows expressed the maximum values of WUE. The highest grain yield was recorded with flat sowing subjected to the irrigation equivalent to 100% reference evapotranspiration (100% ETo) which was almost similar with seed spreading augmented with furrows at 80% ETo. Under deficit irrigation regimes (80 and 60% ETo), seed spreading augmented with furrows performed better than the other two planting techniques.

Key words: Planting techniques, grain yield, irrigation, water use efficiency and wheat

INTRODUCTION

In Pakistan, wheat is used as a staple food and is considered the largest grain crop of the country that contributes 12.5% to the value added in agriculture and 2.6% of gross domestic product (GDP). It was cultivated on an area of 8.7million hectares with total production of 23.5 million tons, during 2011-12 (Anonymous, 2012). Yield potential of wheat crop is not being explored to its full extent and thus the average yield in Pakistan is even lower than its neighboring countries that may attributed to the sub-optimal management practices. In the cotton zone of Punjab province under cotton-wheat-cotton cropping pattern, due to late vacation of cotton fields only 20% of wheatis sown at the optimum sowing time, i.e. the first fortnightof November, while the remaining sowing is done from lateNovember (30%) to December (50%) (Khan et al. 2002).The late sowing of wheat crop is one of the major reasons of its low yield as it negatively effects the germination and emergence thus giving a weaker crop stand. It causes poor tillering due to winter injury in low temperature and also affects grain development (Haq and Khan, 2002) that lowers grain yield, consequently resulting in a yield loss of 39 kg ha^{-1} day^{-1} with delay of each day in sowing from the optimum planting time (Singh and Uttam, 1999). Seed priming can be employed to enhance the performance of late sown wheat (Farooq et al., 2008) as it improves speed and uniformity of germination, promotes synchronized emergence, eventually giving a better crop stand and final yield (Khanet al., 2011; Arif et al., 2008).

One of the most crucial factors restricting plant growth and consequently crop production in the world is water shortage as it constrains plant growth and production (Umar, 2006). This challenge of water scarcity has shifted crop production function from the land productivity concept to water productivity (Sarwar et al., 2013; Fereres and Soriano, 2007; Sarwar and Perry, 2002). Full irrigation to obtain better crop yield to cope with increasing food and fiber demands is no more a viable option for water scarce regions (Geerts et al., 2008a). Thus, a possible solution to this dilemma is deficit irrigation (Geerts et al., 2008b). The practice of applying irrigation water less than crop evapotranspiration demand with intent of imposing a managed level of water stress to the crop is considered as deficit or limited irrigation (Grant, 2008).

Pakistan's agriculture is exclusively based on irrigation water but unluckily per capita water availability has dropped dreadfully from 5260 m^3 in 1951 to 1066 m^3 in 2010 and is projected to be merely 870 m^3 per capita by the year 2025 (Shaukat, 2011; Ahmad et al., 2009). In 2050, Pakistan's population is predicted to be 200 million that will demand 48% additional water thus, due to water shortage a reduction of ten million tons of food grains is being perceived (Javed, 2010). To address these challenges effectively we have to minimize the application losses of irrigation water to ensure availability of more water for crop production as well as to improve the crop water use efficiency that translates into "more crop per drop" of applied water. The sowing of wheat on raised beds and ridges is being adopted rapidly by the farmers in Mexico and many other countries. This method enhances the germination count, improves yield by 10% giving water saving of 30-50%, along with the benefits of reduced lodging, increase in the efficiency of applied fertilizer and water, more water productivity, better utilization of solar radiation, and efficient drainage under high rainfall conditions (Ahmad et al., 2010; Sayre and Moreno-Ramos, 1997). In this study, performance of three planting techniques was compared under various irrigation regimes and an effort was made to develop environment and farmer friendly agro-technology package for sustainable wheat production under scarce water supplies in arid region of Punjab.

MATERIALS AND METHODS

Crop husbandry

The study was conducted for two consecutive crop growth seasons during 2007/08 and 2008/09 under field conditions at Research and Demonstration Farm, Regional Agricultural Economic Development Centre (RAEDC), Vehari, Pakistan (30°1'0 N and 71° 21'0 E with altitude 135 m) that falls under the arid region of southern Punjab (Arnon, 1992). The climate of the experimental site is characterized by hot dry summer and severe cold winter seasons (Fig.1).Water quality analysis was done before irrigation (Table-2).The experimental soil was clay loam having pH 8.4, EC 256 µS cm^{-1} and organic matter 0.61% (Table-1). The analysis was done as per protocols mentioned in Hand Book No. 60 (US Salinity Lab. Staff, 1954) except available P and soil texture, which were determined by the methods demonstrated by Watanabe and Olsen (1965) and Moodie et al. (1959), respectively.The experiment was laid out in randomized complete block design, replicated thrice and comprised of three planting techniques: PT_1 (flat-drill planting in 11 cm apart rows), PT_2 (bed-drill planting in 11 cm apart rows), PT_3 (seed spreading augmented with furrows i.e. ridge planting) and three irrigation regimes namely I_1 (Irrigation equal to 100% ETo), I_2 (Irrigation equal to 80% ETo) and I_3 (Irrigation equal to 60% ETo). The experimental field having precision leveling was irrigated to the field capacity by applying heavy irrigation (locally called "rauni"). When the field reached the proper moisture condition (locally called "wattar"), seed bed was prepared by applying two ploughings followed by planking then beds were formed manually in case of PT_2. A locally recommended wheat variety "Inqlab-91" was planted on December 19 during 2007/08 and on the same date during 2008/09. Seed hydroprimed for 12 hours was used at the rate of 150 kg ha^{-1} in all the treatments.In case of PT_1 crop was sown in flat field with the help of single row hand drill in rows 11 cm apart whereas, in case of PT_2 the sowing was done on 33 cm wide raised beds. On the other hand in PT_3,ridges were formed with help of a ridger after spreading seed uniformly in the field.Irrigation water was applied as in Ali et al., 2013 on the base of evapotranspiration method. Total applied water was recorded in all treatments for both years (Table-8). All other cultural practices were kept standard and uniform for all the treatments throughout the crop growth.

Table 1. Soil characteristics of the experimental site

Characteristics		**Depth (cm)**		
		0-15	**15-30**	**30-45**
Organic matter (%)		0.84	0.68	0.32
pH		8.4	8.4	8.5
EC (µS cm^{-1})		261	230	278
T.S.S. (%)		0.87	0.14	0.14
Available-P (ppm)		8.2	6.5	5.8
Available-K (ppm)		235	180	125
Saturation % age		38	36	35
	Sand (%)	29	30	29
Soil separates	Silt (%)	39	35	35
	Clay (%)	32	35	36
Textural class		Clay loam	Clay loam	Clay loam

PARAMETERS STUDIED

Relative water content (RWC %): Five flag leaves were taken from each sub plot and fresh weight was recoded. Leaves were dipped in distilled water for 14-16 hours and saturated weight was noted after blotting off the excess water. Then after drying in an over at 80 ˚C for 48 hours, the dry weight of the same leaves was recorded and the relative water contents were calculated.

Leaf water potential (Ψ_w): For recoding leaf water potential (Ψ_w), randomly selected, fully expanded, three flag leaves were excised from each treatment and measurements were made from 8.00 am to 9.00 am with a water potential apparatus (Chas W. Cook Div., England).

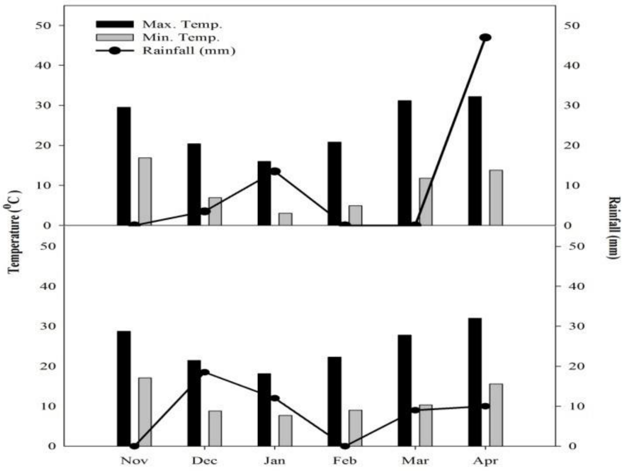

Fig.1. Climate data of growing seasons

Leaf osmotic potential (Ψ_s): The same leaves used for water potential were frozen at -20 ˚C and were kept in Eppendoff tubes for a period of seven days then the cell sap was extracted and centrifuged @ 8000 rpm for 4 minutes. The sap was used for osmotic potential determination in a Vapor Pressure Osmometer (Wescor 5520, Logan, USA).

Table 2. Quality of irrigation water used during the entire course of studies

Characteristics	Unit	Tube well water
Electrical conductivity	µS cm^{-1}	1165
pH		7.55
$Ca^{2+} + Mg^{+2}$	me L^{-1}	7.82
Na^{+}	me L^{-1}	3.08
CO_3^{-2}	me L^{-1}	Nil
HCO_3^{-}	me L^{-1}	5.3
Cl^{-}	me L^{-1}	3.14
SO_4^{-2}	me L^{-1}	1.12
Sodium adsorption ratio	(m mol $L^{-1})^{0.05}$	1.61
Residual sodium carbonate	me L^{-1}	Nil

Gas exchange parameters: The instantaneous measurements of net photosynthetic rate (P_N), transpiration rate (E) and leaf stomatal conductance (g_s) were made on flag leaves of three plants, randomly selected from each experimental unit. Measurements were made from 9.00 am to 11.00 am using an open system portable infrared gas analyzer LCA 4 ADC (Analytical Development Company, Huddleston, England).

Soil penetration resistance

To measure the soil penetration resistance in the field cone penetrometer model CP20 (Agridry RIMIK Pty. Ltd., Toowoomba, Australia) was used. Detailed procedure is described as in Ali et al., 2013.

Agronomic parameters

Germination count (m^2) was recorded after seedlingemergence but before the start of tillering. At harvest a unit area of 1 m^2 in each treatment at four differentlocations was selected and the total number of productivetillers was counted and then averaged. The crop was harvested at maturity, tied into bundles that were tagged, sun dried for a week and then threshedmanually. The grain yield per plot was recorded and then converted into kg ha^{-1}.A sample of one thousand grains was taken from each plot and weighed on an electrical balance (Model No. MJ500 Chyo, Japan) after drying at 70ºC for 24 hours in an oven.

Water use efficiency

Water use efficiency was calculated by using the formula $WUE(kg\ ha^{-1}\ mm^{-1}) = \frac{GY}{TWA}$Where, WUE is water use efficiency (kg ha^{-1} mm^{-1}), GY is grain yield (kg ha^{-1}) and TWA is total water applied (mm).

Statistical analysis

The data was computed and analyzed by using MSTAT-C program (Russel and Eisensmith, 1983). Difference in means was computed by applying LSD at $P<0.05$ (Steel et al.,1997).

RESULTS

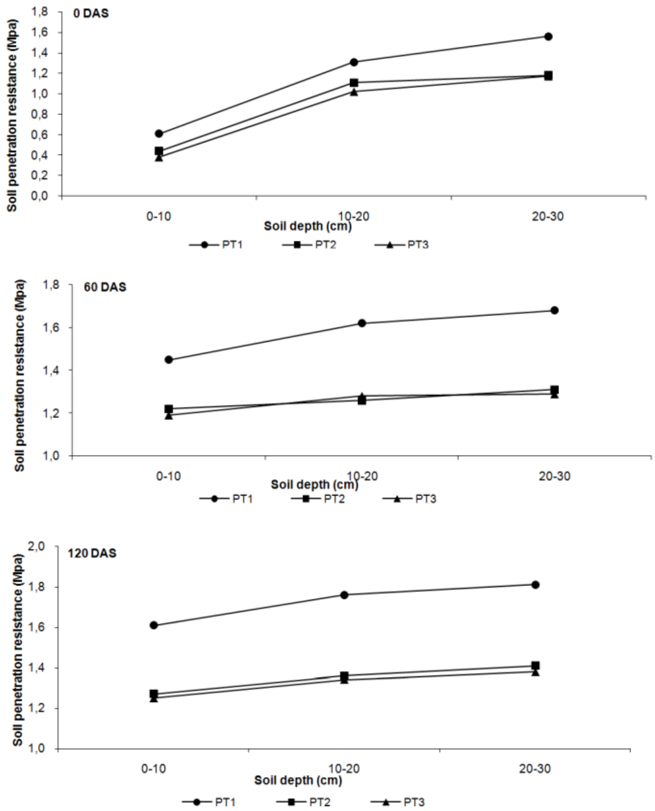

Fig.2. Soil penetration resistance (average of 2007-08 and 2008-09) measured at various soil depths under three planting techniques at different growth stages

Soil penetration resistance

The influence of irrigation regimes on soil penetration resistance was found to be non-significant during both the crop growth seasons. The effect of planting techniques on this attribute averaged for 2007/08 and 2008/09 is presented in Fig.2. Significant differences ($P<0.01$) among different planting techniques showed that the highest values of soil penetration resistance were recorded with the treatment of flat planting while the minimum soil penetration resistance was offered by the treatment of seed spreading augmented with furrows. However, the treatments of bed planting and seed spreading augmented with furrows remained statistically at par with each other.

Data showed that at 0 days after sowing (DAS) soil penetration resistance measured at various soil depths differed significantly ($P<0.01$) from each other. Thus, the maximum soil penetration resistance of 1.30MPa was recorded at the soil depth of 20-30 cm that was followed by the soil penetration resistance measured at 10-20 cm soil depth. Whereas, significantly ($P<0.01$) the lowest value of 0.48 MPa for soil penetration resistance was noted at the soil depth of 0-10 cm. Data recorded at 60 DAS and 120 DAS showed that the various soil depths non-significantly influenced the soil penetration resistance (Fig.2).

Leaf relative water content (%)

The highest leaf relative water content (RWC) of 85.94 and 92.77% during 2007/08 and 2008/09, respectively was estimated with the treatment of Irrigation = 100% ETo that was followed by the treatment of Irrigation = 80% ETo however, these two treatments were found to be statistically at par with each other. The data deciphered that during 2007/08, the maximum leaf RWCvalue of 87.51% was expressed by the crop plants subjected to the planting technique of seed spreading augmented with furrows that was followed by bed planting technique having leaf RWCvalue of 82.50% and the differences between them were found to be non-significant statistically. On the other hand, the lowest leaf relative water content of 74.30% was measured in the flag leaf of crop plants sown with flat planting treatment (Table-3).

Leaf water potential (-MPa)

Significantly ($P<0.01$) the lowest (more negative values) water potential of -1.14 MPa during 2007/08 was measured with the irrigation regime of 60% ETo that increased significantly ($P<0.01$) giving a value of -0.94 MPa when the irrigation level was raised from 60% ETo to 80% ETo but a further increment in the irrigation level showed no significant improvement in the leaf water potential. As regards planting techniques, the lowest value (more negative) of -1.06 MPa was noted with flat planting technique during 2007/08 that was followed by the leaf water potential value of-0.97 MPa recorded in case of bed planting treatment. Whereas, the maximum (less negative values) leaf water potential of -0.93 MPa was expressed by the flag leaves of crop planted under seed spreading augmented with furrows treatment (Table-3).

Table 3. Effect of planting techniques and irrigation regimes on RWC, leaf water potential and osmotic potential of wheat crop

	Relative water content (%)		**leaf water potential (-MPa)**		**Leaf osmotic potential (-MPa)**	
Planting techniques	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
PT_1	74.30b	81.00b	1.06a	1.03a	1.72a	1.68a
PT_2	82.50a	89.04a	0.97ab	0.93b	1.54b	1.47b
PT_3	87.51a	93.98a	0.93b	0.89b	1.48b	1.42b
LSD at 5%	6.203	6.294	0.089	0.070	0.122	0.152
Irrigation (% of ETo)						
I_1	85.94a	92.77a	0.88b	0.85b	1.38b	1.33b
I_2	83.59a	90.30a	0.94b	0.90b	1.47b	1.40b
I_3	74.79b	80.94b	1.14a	1.11a	1.88a	1.82a
LSD at 5%	6.203	6.294	0.089	0.070	0.122	0.152

Leaf osmotic potential (-MPa)

The highest values (less negative) of -1.38 and -1.33 MPa for leaf osmotic potential during 2007/08 and 2008/09, respectively were achieved with the treatment of Irrigation = 100% ETo that was followed by the treatment of Irrigation = 80% ETo. The data revealed that during the crop growth season of 2007/08, the maximum (less negative) osmotic potential of -1.48 MPa was recorded with the treatment of seed spreading augmented with furrows that was followed by bedplanting treatment having the value of -1.54 MPa however, these two treatments remained statistically at par with each other. Whilst the lowest (more negative) value of osmotic potential (-1.72 MPa) was expressed by the crop plants subjected to the flat planting technique (Table-3).

Leaf stomatal conductance (mol m^{-2} s^{-1})

The highest stomatal conductance of 0.40 mol m^{-2} s^{-1} was expressed by the crop plants subjected to the irrigation regime of 100% ETo during 2007/08 whilst, the lowest value of 0.22 mol m^{-2} s^{-1} for stomatal conductance was noted with the treatment of Irrigation = 60% ETo. Seed spreading augmented with furrows showed the maximum stomatal conductance of 0.37 mol m^{-2} s^{-1} that was followed by the bed planting treatment having stomatal conductance of 0.34 mol m^{-2} s^{-1},however, the differences between these treatments were found to be non-significant statistically. Whereas, the minimum stomatal conductance of 0.27 mol m^{-2} s^{-1} was recorded from the flag leaf of crop plants subjected to the flat planting technique. A similar picture emerged during the second crop growth season (Table-4).

Table 4. Effect of planting techniques and irrigation regimes on gas exchange parameters and root dry weight of wheat crop

	Leaf stomatal conductance (mol m^{-2} s^{-1})		**Transpiration rate (mmol m^{-2} s^{-1})**		**Net CO_2 assimilation rate (mmol m^{-2} s^{-1})**		**Root dry weight (g cm^{-3})**	
Planting techniques	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
PT_1	0.27b	0.29b	1.68c	1.79b	9.32c	9.84c	1.37c	1.30b
PT_2	0.34a	0.36b	1.88b	1.99a	12.01b	12.46b	1.90b	1.75a
PT_3	0.37a	0.39a	2.02a	2.12a	13.34a	13.77a	2.06a	1.87a
LSD at 5%	0.031	0.032	0.099	0.152	0.766	0.672	0.145	0.167
Irrigation (% of ETo)								
I_1	0.40a	0.43a	2.04a	2.15a	13.19a	13.66a	1.71	1.58
I_2	0.37b	0.39b	1.98a	2.10a	12.43a	13.01a	1.80	1.66
I_3	0.22c	0.24c	1.56b	1.65b	9.05b	9.40b	1.82	1.68
LSD at 5%	0.031	0.032	0.099	0.152	0.766	0.672	ns	ns

Transpiration rate (μmol m^{-2} s^{-1})

The maximum transpiration rate of 2.04 and 2.15 μmol m^{-2} s^{-1} during 2007/08 and 2008/09, respectively was achieved by the crop plants to which irrigation was applied equivalent to 100% ETo and it was followed by the treatment of Irrigation = 80% ETo and these treatments remained statistically at par with each other. Whilst, significantly ($P<0.01$) the lowest transpiration rate of 1.56 and 1.65 μmol m^{-2} s^{-1} during 2007/08 and 2008/09 was noted from the crop plants subjected to the irrigation regime of 60% ETo. Seed spreading augmented with furrows exhibited significantly ($P<0.01$) the highest value of 2.02 μmol m^{-2} s^{-1} for transpiration rate whilst the lowest transpiration rate of 1.68 μmol m^{-2} s^{-1} was recorded from the crop plants subjected to the flat planting treatment. Later on, during 2008/09, the maximum transpiration rate of 2.12 μmol m^{-2} s^{-1} was achieved with the treatment of seed spreading augmented with furrows that was followed by bed planting treatment, however, the differences between them were found to be non-significant statistically. Again the minimum transpiration rate was noted with the flat planting treatment (Table-4).

Net CO_2 assimilation rate (μmol m^{-2} s^{-1})

The highest values of 13.19 and 13.66 μmol m^{-2} s^{-1} for net CO_2 assimilation rate during 2007/08 and 2008/09, respectively were recorded with the treatment of Irrigation = 100% ETo that was followed by the treatment of Irrigation = 80% ETo however, these treatments remained statistically at par with each other. Whereas, significantly ($P<0.01$) the minimum net CO_2 assimilation rate of 9.05 and 9.40 μmol m^{-2} s^{-1} during 2007/08 and 2008/09, respectively was measured from the crop plants to which irrigation was applied equivalent to 60% ETo. While considering the planting techniques, seed spreading augmented with furrows treatment expressed significantly ($P<0.01$) the maximum net CO_2 assimilation rate of 13.34 μmol m^{-2} s^{-1} during 2007/08 that was followed by bed planting technique having net CO_2 assimilation rate of 12.01 μmol m^{-2} s^{-1}. While the lowest value of 9.32 μmol m^{-2} s^{-1} for net CO_2 assimilation rate was recorded with the treatment of flat planting (Table-4).

Germination count and tillers(m^{-2})

The highest number of seedlings was counted in flat planting treatment that was followed by bed planting during 2007/08 and 2008/09 however;the differences between these two treatments were found to be non-significant statistically while the lowest germination count m^{-2} was recorded with the treatment of seed spreading augmented with furrows. The treatment of seed spreading augmented with furrowsduring both the years produced significantly ($P<0.01$) the maximum number tillers $plant^{-1}$ that was followed by flat planting treatment whereas, as the minimum number oftillers $plant^{-1}$was counted with the treatment of bed planting. As regards the tillers m^{-2}, the highest number of tillers m^{-2} was produced by the treatment of flat planting that was followed by seed spreading augmented with furrows while the minimum number of tillers $m^{-2}$was counted in case of bed planting treatment. However, the differences between the treatments of bed planting and seed spreading augmented with furrows were found to be non-significant statistically.A significant ($P<0.01$) impact of planting techniques on number of unproductive tillers m^{-2} was noted during the both crop growth seasons. Thus, significantly ($P<0.01$) the highest number of 30.9 unproductive tillers during 2007/08 was recorded with the flat planting treatment that was followed by bed planting technique which produced 21.4 unproductive tillers m^{-2}. Whilst, the lowest number of 19.54 unproductive tillers was noted in case of seed spreading augmented with furrows, however, it remained statistically at par with the treatment of bed planting. Almost a similar trend was observed during the second crop growth season(Table-6).

Number of productive tillers m^{-2}

The highest number of 278.5productive tillers (m^{-2}) was achieved with the treatment Irrigation = 100% ETo that was followed by the tiller number of 270.6 m^{-2} recorded with the treatment of Irrigation = 80% ETo and the differences between these two treatments were found to be non-significant statistically. While significantly ($P<0.01$) the lowest number of productive tillers 237.7 m^{-2} was counted with the treatment where irrigation was applied equivalent to 60% ETo. Effect of planting techniques showed that the maximum number of 276.7 and 318.3 m^{-2} productive tillers m^{-2} during 2007/08 and 2008/09, respectively were recorded with the flat planting treatment that was followed by the treatment of seed spreading augmented with furrows but the differences between these treatments were not significant statistically. Whereas, the bed planting treatment produced significantly ($P<0.01$) the lowest number of 244.1 and 277.8 productive tillers during 2007/08 and 2008/09, respectively (Table-5).The interactions between irrigation regimes and planting techniques were found to be significant ($P<0.05$) during both the crop growth seasons. Thus, the highest number of productive tillers (305.33) was producedby the crop plants subjected to the irrigation regime of 100% ETo along with flat planting technique (Table-7).

Table 5. Effect of planting techniques and irrigation regimes on productive tillers, 1000-grain weight and of wheat crop

	Productive tillers (m^{-2})		**1000-Grains weight (g)**		**Grain yield (kg ha^{-1})**		**Water use efficiency (kg ha^{-1} mm^{-1})**	
Planting techniques	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
PT_1	277a	318a	35.29b	37.2b	3609b	4007ab	20.11b	19.95b
PT_2	244b	278b	37.00ab	39.9ab	3535b	3815b	20.12b	19.45b
PT_3	266a	301a	38.18a	41.0a	4035a	4333a	23.22a	22.33a
LSD at 5%	16.08	18.49	2.161	2.78	311.21	348.70	1.727	1.622
Irrigation (% of ETo)								
I_1	278a	317a	38.47a	41.0a	4262a	4676a	19.48b	19.29b
I_2	271a	309a	37.37a	40.0a	3923b	4239b	22.07a	21.39a
I_3	238b	271b	34.63b	37.1b	2994c	3239c	21.90a	21.05a
LSD at 5%	16.08	18.89	2.161	2.78	311.21	348.70	1.727	1.622

Table 6. Efect of planting techniques on germination count m-2, tillers plant-1,tillers m-2 and un-productive tillers m-2of wheat crop

	Germination count m^{-2}		**Tillers $plant^{-1}$**		**Tillers m^{-2}**		**Un-productive tillers m^{-2}**	
Planting techniques	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
PT_1	143.15	155.87	2.15	2.34	307.60	364.74	30.86	46.48
PT_2	141.19	147.91	1.88	2.06	265.44	304.68	21.39	26.86
PT_3	112.87	120.11	2.53	2.61	285.56	313.49	19.54	12.14
LSD at 5%	19.242	25.060	0.238	0.372	ns	47.933	4.488	7.510

1000-grain weight (g)

Significantly ($P<0.01$) the heaviest grains of 38.47 g were produced during 2007/08 with the irrigation regime of 100% ETo that was followed by the treatment of Irrigation = 80% ETo having 1000-grain weight of 37.37 g but the difference between these two treatments was found to be non-significant statistically. Whereas, the minimum 1000-grain weight of 34.63 g was measured from the crop plants subjected to the irrigation equivalent to 60% ETo. In case of planting techniques, seed spreading augmented with furrows showed the best performance during both the crop growth seasons by producing the heaviest grains of 38.18 and 41.00 g during 2007/08 and 2008/09, respectively however, it remained statistically at par with bed planting treatment which presented 37.00 and 39.94 g weight of 1000-grains during 2007/08 and 2008/09, respectively. While significantly ($P<0.01$) the lowest 1000-grain weight of 35.29 and 37.17 g during 2007/08 and 2008/09, respectively was produced with the flat planting technique (Table-5).

Table 7. Interactive effect of planting techniques and irrigation regimes on productive tillers and grain yield of wheat crop

	Productive tillers (m^{-2})		**Grain yield (kg ha^{-1})**	
Interactions	2007-08	2008-09	2007-08	2008-09
PT_1x I_1	305a	351a	4481a	5098a
PT_2 x I_1	257cd	293cd	3996a~d	4308bc
PT_3 x I_1	273bc	308bc	4310ab	4624ab
PT_1x I_2	294ab	338ab	3888bcd	4239bc
PT_2 x I_2	250cde	285cde	3702cd	3994c
PT_3 x I_2	267bc	303c	4179ac	4486bc
PT_1x I_3	231de	266de	2459e	2685d
PT_2 x I_3	224e	256e	2910e	3146d
PT_3 x I_3	258cd	293cd	3616d	3889c
LSD at 5%	27.85	32.02	539.03	602.22

Grain yield (kg ha^{-1})

Improved grain yield of 4262.2 kg ha^{-1} was achieved with the treatment of Irrigation = 100% ETo that was followed by the treatment of Irrigation = 80% ETo which produced 3922.6 kg ha^{-1} of grains during year of 2007/08. As regards planting techniques, significantly ($P<0.01$) the highest grain yield of 4034.9 kg ha^{-1} was recorded with the treatment of seed spreading augmented with furrows. Whilst, the bed planting treatment secured the bottom rank by producing the minimum grain yield of 3534.94 kg ha^{-1} (Table-5). The interactions between irrigation regimes and planting techniques were found to be significant ($P<0.01$ and $P<0.05$) during both the crop growth seasons. These significant effects might be associated to the better performance of flat planting treatment during both the crop growth seasons at the highest irrigation level of 100% ETo than other planting techniques but under the lower irrigation regime i.e 60% ETo its response was significantly reduced than the treatments of bed planting and that of seed spreading augmented with furrows. It was also noted that reducing the irrigation level from 80% EToto 60% ETo resulted in a significant decline in the grain yield of flat planting treatment (Table-7).

Table8. Amount of water applied and rainfall during crop seasons

	Irrigation (mm)	Rainfall (mm)	Total (mm)
2007-08			
I_1	205.31	13.50	218.81
I_2	164.25	13.50	177.75
I_3	123.19	13.50	136.69
2008-09			
	Irrigation (mm)	**Rainfall (mm)**	**Total (mm)**
I_1	221.45	21.00	242.45
I_2	177.16	21.00	198.16
I_3	132.87	21.00	153.87

There was a strong and linear relationship of grain yield with the number of productive tillers m^{-2} and 1000-grain weight. The regression accounted for 68.9 and 81.9%, respectively variance in grain yield for the above mentioned yield components, respectively during 2007/08 while the corresponding figures for the year 2008/09 were 66.2 and 58.5%, respectively (Fig.3, 4).

Water use efficiency

The highest water use efficiency of 22.07 kg ha^{-1} mm^{-1} was achieved by the crop plants irrigated at the rate of 80% ETo that was followed by the treatment of Irrigation = 60% ETohowever, these treatments remained statistically at par with each other. Whereas, significantly ($P<0.01$) the lowest water use efficiency of 19.48 kg ha^{-1} mm^{-1} was recorded with the irrigation treatment of 100% ETo. The highest water use efficiency of 23.22 kg ha^{-1} mm^{-1} during 2007/08 was measured with the treatment of seed spreading augmented with furrows and it was followed by bed planting technique having the WUE value of 20.12 kg ha^{-1} mm^{-1}. While the minimum water use efficiency of 20.11 kg ha^{-1} mm^{-1} was noted from the crop plants subjected to the flat planting treatmentand the differences between the treatments of bed planting and flat planting were found to be non-significant statistically. A similar trend was noted during the second crop growth season (Table-5).

DISCUSSION

In this study comparatively lower germination count was recorded with seed spreading augmented with furrows planting technique as compared to flat planting that might have taken place due to possible deep placement of few seeds in seed spreading augmented with furrows planting treatment which affected the germination count. However, this treatment exhibited an excellent compensation for lower plant population by expressing a better tillering potential and producing a lesser number of parasite tillers (i.e. unfertile tillers) that was probably associated to the increased soil surface area of the parabolaof the ridge and the seeds got spread uniformly all over the parabola resulting in more space available to each plant. While, bed-drill planting showed better germination count but gave poor tillering against the seed spreading augmented with furrows treatment that might be related to a higher in-row inter-plant competition, as the more seeds were placed in each row due to reduced number of rows per unit area (Waraich, 2006).

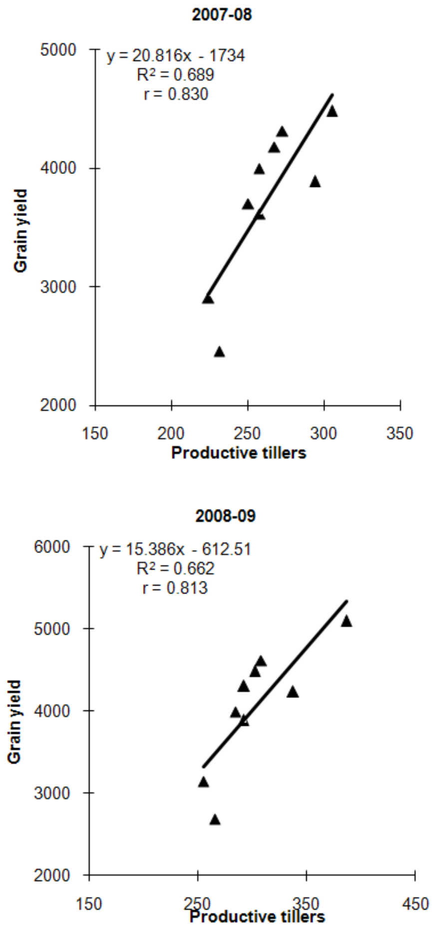

Fig.3. Relationship between grain yield and productive tillers

Moreover, the enhanced crop growth and higher grain yield might be linked to the improved soil physical conditions in case of seed spreading augmented with furrows planting technique resulting in lower soil compaction, reduced root penetration resistance, enhanced soil porosity, aeration and water holding capacity that encouraged better root proliferation thus giving rise to vigorous plants which were less prone to lodging. Consequently, higher water use efficiency was recorded with the planting techniques of seed spreading augmented with furrows and that of bed planting as compared to the flat planting technique (Amin et al. 2006; Waraich, 2006; Tripathi et al., 2005; Aggarwal and Goswami, 2003). In addition to the above mentioned factors, this improvement in water use efficiency might also be endorsed to the better availability of plant nutrients in ridges, the lower weed density and weed biomass, and ultimately an enhanced final crop yield (Nasrullah et al., 2009).

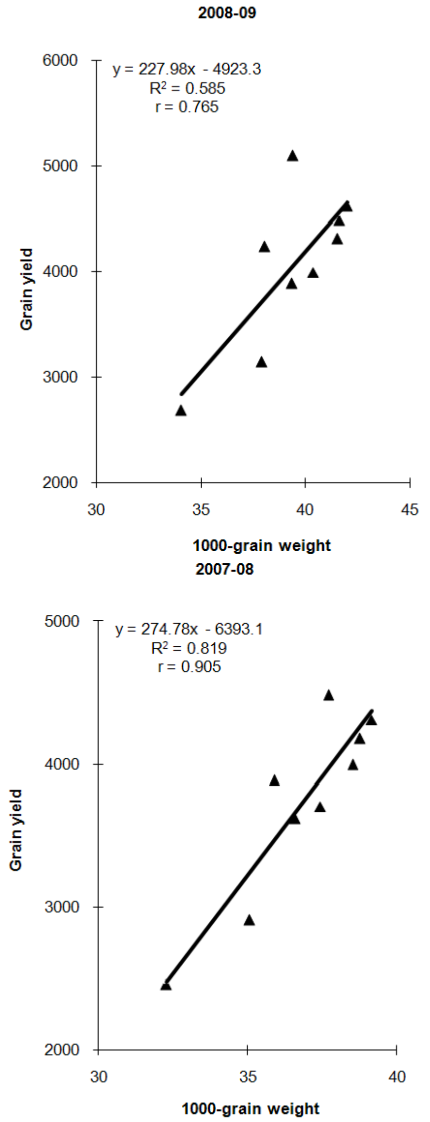

Fig.4. Relationship between grain yield and 1000-grain weight

Leaf water potential has a vital significance for its association to the cell turgor pressure and osmotic potential. It was observed that during both crop growth seasons, the leaf water potential, osmotic potential and relative water content dropped linearly with decreasing irrigation levels from 100% ETo to 60% ETo. This reduction in these attributes might have caused partial closure of stomata that resulted in a significant decrease in stomatal conductance which limited the access of photosynthetic apparatus to CO_2 thus having pronounced effect on net CO_2 assimilation rate. Heaton and Tallman (1987) also reported a decrease in stomatal conductance due to water deficit. Moisture stress due to limited irrigation possibly caused a decline in water absorption by the roots subsequently decreasing the rate of transpiration. In this study the treatments of seed spreading augmented with furrows and that of bed planting provided more favorable soil conditions for root growth including lower penetration resistance thus enhanced root biomass that might have promoted the absorption of soil moisture hence increasing the leaf water potential and relative water content which boosted stomatal conductance that consequently promoted transpiration rate which encouraged net CO_2 assimilation rate and finally a higher biomass production as well as crop yield.

In the study, it was observed that each incremental irrigation from 60 to 100% ETo improved the yield and yield components as well as physiological attributes of wheat crop sown under flat planting technique. While, under the planting technique of seed spreading augmented with furrows the aforementioned parameters increased significantly by increasing the irrigation level from 60% ETo to 80% ETo but an additional increment in irrigation beyond this point (from 80 to 100% ETo) showed no significant enhancement in majority of the said attributes. This indicates that wheat crop can be grown more successfully with a lesser quantity of irrigation water (irrigation equal to 80% ETo) under seed spreading augmented with furrows planting method as compared to the flat planting. Erekul et al. (2012) recorded highest wheat yield and quality with 80mm irrigation regime. Pierre et al.(2008) also observed non-significant differences in wheat total dry matter accumulation, kernel weight and diameter, and grain yield by decreasing the irrigation level from 100% ETo to 80% ETo whereas, a further decrease in irrigation caused a decline in grain yield. Our results are in line with the findings of other scientists Zhang et al. (2002)who also reported a decrease in WUE with increasing amount of irrigation but yield increased. Our findings are also endorsed by the results of Xue et al. (2006) and Mehmood et al. (1999).

CONCLUSION

Keen perusal of the results revealed that seed spreading augmented with furrows along with application of water equivalent to 80% ETo proved to be better strategy for efficient utilization of water input under arid climate for sustainable wheat crop production.

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