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RESEARCH ARTICLE

Simulating the Impact of Sowing Methods and Water Deficit Levels on Wheat Yield Under Semi-Arid Environment

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ABSTRACT

The present study was undertaken to investigate the effect of deficit irrigation (DI) on wheat grain yield under different sowing methods. The field experiment was layout using randomized complete block design (RCBD) with split plot arrangements by keeping four DI regimes (I1, I2, I3, I4 as 0%, 20%, 35% and 50% deficit respectively) and two sowing methods (bed sowing and drill sowing) in sub plots and main plots respectively with three repeats. Research also evaluated the ability of AquaCrop model to simulate wheat gain yield and biological yield under full and deficit water conditions in a semi-arid environment. The model was calibrated for the full irrigation treatments under both sowing method and remaining six treatments were used for validation purpose. The results showed that the maximum grain yield was recorded 5.724 tons/ha for 0% DI treatment under drill sowing method. The DI (I1, I2, I3, and I4) levels under drill sowing method gave 13.12%, 14.28%, 16.38%, and 19.59% more grain yield than the corresponding DI levels (I1, I2, I3, and I4) under bed sowing method respectively, whereas the average crop water use efficiency for I1, I2, I3, and I4 treatments under bed sowing was found higher than the corresponding treatments under drill sowing method by 17.94%, 14.34%, 9.96%, and 5.36% respectively. AquaCrop model simulated gain yields and biological yield showed a good agreement with measured values of both gain yield (RMSE=0.25ton ha^{-1}, NRMSE= 5.41, d=0.96 and NSE=0.79) and biological yield (RMSE=0.59 ton ha^{-1}, NRMSE= 5.36, d=0.94 and NSE=0.74). The high values of the statistical indicators confirmed that the AquaCrop model (v3.0) can simulate wheat yield under no to mild water stress conditions which makes it very useful for evaluating the deficit irrigation strategies under different cultural and management practices with minimal input data requirements and ease of use.

INTRODUCTION

The water resources management and its allocation to agriculture sector is challenging issue due to climate change and demographic growth. In such scenarios, irrigated agriculture requires intensive management of limited water supplies, and irrigation management shifted from emphasizing production per unit area towards maximizing the production per drop of water to provide food for the growing population. Hence, finding reliable ways of planting and management of existence water resources is key priority of each country (Smith, 2000). Wheat is most important agricultural product in Pakistan which represents 9.6% of the total value added of the agricultural sector and 1.9% of the gross domestic product (Anonymous, 2018). The crops are sown by conventional broadcasting on level soil surface with shallow tillage followed by planking and flood irrigation. A resource conservation planting technique, raised bed plantation is gaining popularity after the successful experimentation in Mexico (Sayre and Hobbs, 2004), as it allows 30 to 50 % water saving for wheat, cotton, maize and 20 to 30% for rice crop (Majeed et al., 2015; Bakhsh et al., 2013).

Deficit Irrigation (DI) is one of the promising irrigation strategies whereby crop is subjected to water stress by applying less amount of water than the crop requirement at critical growth stages without significant yield reduction (Geerts et al., 2009; Kirda et al., 2005). The utilization of these techniques effectively demands better understanding of crops behavior against water stress following by different cultural and environmental factors. The application of crop simulation models allows researchers to analyze the yield response to various fertilizer and water application rates thus reducing time consuming and costly field tests. (Whisler et al., 1986). The results of these models would enable government organizations and other stake holder agencies to decide which management system is reliable for particular field and crop by estimating the optimum yield and crop water productivity (Pawar et al., 2017). Models allow an amalgamate assessment of different elements affecting yield in order to derive optimum irrigation strategies for different scenarios (Liu et al., 2007). Nowadays, different complex models such as WOFOST (Diepen et al., 1989), EPIC (Sharpley and Williams, 1990), CropSyst (Stockle et al., 2003), DSSAT (Jones et al., 2003), APSIM (Keating et al., 2003), WAVES (Kang et al., 2003) and AquaCrop (Steduto et al., 2009) have been used for crop simulations and integrate multiple factors that influence the crop. The FAO-AquaCrop model has a considerable balance between accuracy, simplicity, and robustness. This model was selected for the present irrigation water management study due to its some specific features that distinguishes it from other crop models such as: i) its focus on water; ii) less data requirement iii) use of canopy cover instead of leaf area index; iv) use of normalized water productivity (WP) values for the calculation of atmospheric evaporative demand and CO_2 concentration that deliberate the model an extended extrapolation capacity to diverse locations, seasons, and climate, including future climate scenarios. One of the limitations of the Aquacrop model (v3.0) is the inability to simulate effect of soil salinity stress on crop growth and yield that limits its application on saline areas. It has been successfully used all around the world for simulation of the crop development and yields of many crops such as: maize (Stricevic et al., 2011; Heng et al., 2009), wheat (Toumi et al., 2016; Jin et al., 2014), cotton (Tan et al., 2018), rice (Maniruzzaman et al., 2015), sunflowers (Stricevic et al., 2011), barley (Araya et al., 2010), soybean (Silva et al., 2018) and others . Although numerous studies used Aquacrop model for irrigation strategies management, however studies that consider deficit irrigation levels and crop plantation method simultaneously are scarce. Keeping in view, this study was aimed to examine the integrated effect of DI levels and sowing methods on wheat grain yield, biological yield and water use efficiency.

MATERIALS AND METHODS

Experimental site

The reported study was conducted to examine the effect of various treatments of DI and sowing methods on wheat grain yield during winter season 2014-15 at Water Management Research Centre, University of Agriculture Faisalabad-Pakistan located at 31º38.74 North and 73º01.29 East having altitude of 184 m above mean sea level. Climatic conditions of Faisalabad are semi-arid with mean annual rainfall of 350 mm, most of which occurs during monsoon season (July – September) and face extreme summer with maximum ambient temperature of 50ºC and minimum temperature sometimes reaches up to freezing point during winter. Figure 1(a,b) represents daily weather record (max/min temperature, sunshine hours and relative humidity) and (rainfall, wind speed and pan evaporation) during the growing period. The topography of the study area is flat. For the assessment of initial soil conditions, various physio-chemical measurements such as soil texture, bulk density, moisture contents at field capacity and permanent wilting point, pH, EC, Organic Matter, Potassium (ppm) and Phosphorous (ppm) were made for explaining the responses of experimental treatments on wheat growth parameters, soil health and their substitutions into AquaCrop model. Three bulk soil samples were made from nine sub samples taken from three depths (0-15 cm, 16-30 cm, and 31-45 cm) at three different locations within the field. The soil physio-chemical properties were analyzed according to procedure described in Estefan et al. (2013) and are given in Table 1. The results show a non-significant variation throughout the study area and vertical profile up to 45 cm.

Field layout and experimental details

The experiment was performed using randomized complete block design (RCBD) with split plot arrangements by keeping four DI regimes (I1, I2, I3, I4) and two sowing methods (S1 and S2) in sub plots and main plots respectively with three repeats. The layout of the experimental units is shown in Fig. 2. Whole field was divided into 6 main plots. Each main plot was divided into 4 subplots.

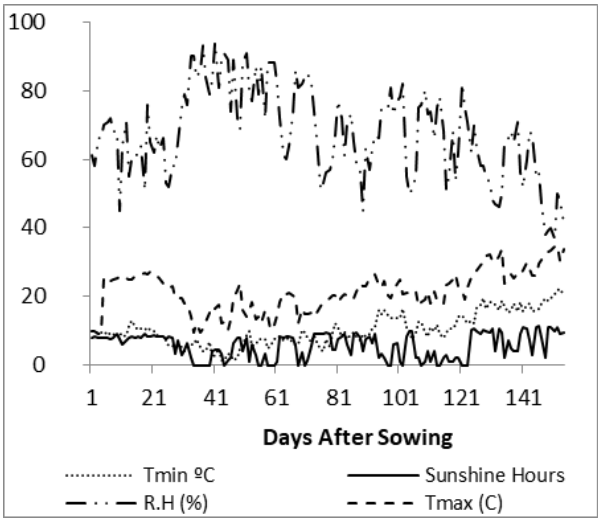

Fig. 1(a): Daily weather record of the study area during whole growing season.

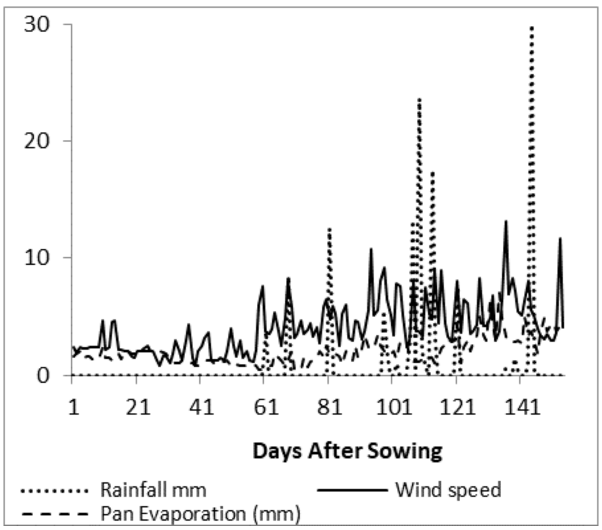

Fig. 1(b): Daily weather record of the study area during whole growing season.

Table 1: Physical and Chemical Properties of soil

Properties	Parameters	Soil Depth Layers (cm)		
		0-15	16-30	31-45
Physical properties	Sand (%)	63	67	66
	Silt (%)	23	19	18
	Clay (%)	14	14	16
	Soil Type	Sandy loam	Sandy loam	Sandy loam
	Bulk Density (g/cc)	1.54	1.56	1.55
	Field Capacity (%)	21.7	21.3	21.8
	Wilting Point (%)	8.42	8.00	8.45
Chemical properties	pH	8.40	8.27	8.25
	EC (dS/m)	1.32	1.30	1.33
	Organic Matter (%)	0.45	0.43	0.46
	Potassium (ppm)	1.8	1.7	1.5
	Phosphorous (ppm)	100	87	73

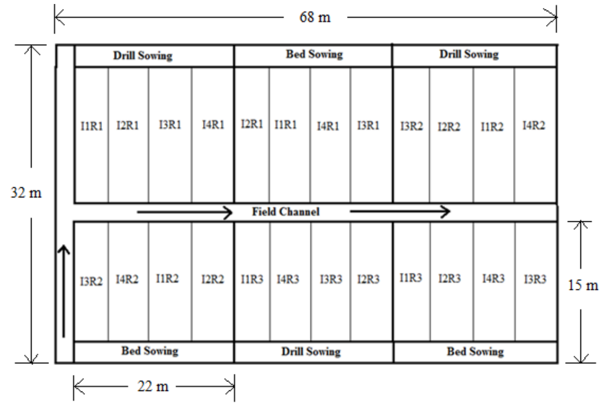

Fig. 2: Field layout of experimental units

Whole field area: 68 m × 32m Main plots in whole field: 6
Main plot area: 22 m × 15 m Subplots in each main plot: 4
Subplot area: 5 m × 15 m No. of Beds in a subplot: 6
No. of drill lines in a subplot: 21

Irrigation treatments	**Sowing methods**
I1 = 0% deficit irrigation	S1=Bed sowing
I2 = 20% deficit irrigation	S2=Drill sowing
I3 = 35% deficit irrigation	
I4 = 50% deficit irrigation	

Crop management

The wheat cultivar (Galaxy) was sown at mid-November 2014 using seed drill and bed-furrow wheat planter. The seeding was done at the rate of 125 kg/ha. Three types of fertilizers were applied; i) Urea as a source of nitrogen at the rate of 48 Kg-N/ha, ii) Di-Ammonium Phosphate (DAP) as a source of phosphorus at the rate of 52 Kg-P/ha and iii) Muriate of Potash (MOP) as a source of potassium at the rate of 64 Kg-K/ha. Plant protection measures including insecticides, pesticides and all other cultural practices were also carried out during its growth period whenever required for all the treatments. All the treatments were irrigated three times in the whole growing season with flood irrigation method and discharge was calculated using cutthroat flume. Available soil moisture was measured with time domain reflectometer (TDR) before irrigation. Irrigation was applied based on the quantity of water required to reach field capacity. The 1st irrigation was applied on December 6, 2014, the 2nd irrigation on January 16, 2015 and the 3rd irrigation on February 12, 2015. Later the crop water requirement was fulfilled by rainfall only (67.90 mm in March and 32.80 mm in April). The required depth of water for a plot in each irrigation was calculated by using the formula: $d_r = [(FC-MC)/100] \times BD \times RD$

Where, d_r is the required depth, FC is field capacity, MC is moisture content, BD is bulk density (g/cm^3) and RD is rooting depth (cm). The 50% less water was applied to the bed planted treatments than the required depth, as it allows 30-50% water saving for wheat crop (Bakhsh et al., 2013).

Harvesting

The ten plant from each plot were selected randomly for the measurement of plant height and spike length at harvest with measuring scale. A small area (1m x 1m) of the crop was manually harvested from each plot on April 21, 2015. All samples were threshed manually for the estimation of grain yield and biological yield in tons/ha. The ratio of grain yield to total water applied to crop was measured to estimate crop water use efficiency (CWU).

AquaCrop model

The AquaCrop model (v3.0) is a water-driven crop growth model that simulates achievable yields of major herbaceous crops as a function of water use under rainfed, full, supplemental and deficit irrigation supply situations. The model was sub divided into four modules: climate (minimum and maximum air temperature, ETo, rainfall and CO2), crop (time to emergence, maximum canopy cover, start of senescence, and maturity), soil (water balance) and management practices (major agronomic practices such as planting dates, fertilizer application and irrigation etc). The model uses canopy ground cover (CGC) instead of leaf area index (LAI) as the basis to calculate transpiration which is proportional to the extent of soil cover whereas evaporation is proportional to the area of soil uncovered (1-CGC) (Araya et al., 2010). Transpiration calculated from canopy ground cover was converted into biomass using a conservative (that do not change with location) and non-conservative (user-specific) parameters (Geerts et al., 2009). The conservative ones are crop-specific but do not change with time, management practice and local climate. In this study, the conservative parameters for wheat were adopted from the AquaCrop manual for wheat (Raes et al., 2009). The same values of these conservative parameters were used for the validation purpose to evaluate the performance and strength of AquaCrop model. The non-conservative or user specific are not universal and dependent on management decisions and environmental conditions and need to be adjusted to local conditions and specific cultivars. For this study, field experiments were used to define the non-conservative wheat parameters for the study area. (See Table 2). Raes et al. (2009) illustrated the detailed operating Mechanism and internet applications of the model. Detailed description of the model was given by Steduto et al. (2009).

Model was calibrated against observed final grain yield and biomass production with full irrigation treatments (I1S1 and I2S2) and remaining six treatments were used for validation purpose. Adjustment in non-conservative parameters were done manually using trial and error approach until a better match between the model-simulated and the measured values were achieved.

Table 2: Crop and soil parameters used in AquaCrop model for wheat yield simulation

Crop parameters	Value	Units	Determination
Base temperature	5	°C	L
Upper Temperature	35	°C	L
Plant density	1,700,000	(Plants/ha)	M
Time for Plant to emergence	7	Days	M
Planting to flowering	87	Days	M
Planting to maximum rooting depth	100	Days	M
Planting to start senescence	120	Days	M
Planting to maturity	154	Days	M
Maximum rooting depth	0.5	m	M
Reference harvest index, HIo	45	(%)	C
Maximum canopy cover	0.91	fraction soil cover	C
Water productivity normalized for ET0 and CO2	15	(g m^{-2})	C
Min. and max. air temperature below and above which pollination starts to fail	10, 40	(°C)	C
Canopy growth coefficient (CGC)	0.02833	(fraction per day)	C
Canopy decline coefficient (CDC)	0.06680	(fraction per day)	C
Maximum root water extraction in top quarter of root zone	0.036	m^3 water/m^3 soil/day	C
Maximum root water extraction in bottom quarter of root zone	0.009	m^3 water/m^3 soil/day	C
Soil water depletion factor for pollination (upper threshold)	0.80	(-)	D
Soil water depletion fraction for stomatal control (upper threshold)	0.65	(-)	D
Shape factor for water stress coefficient for canopy expansion	4	(-)	L
Crop coefficient when canopy is complete but prior to senescence (Kcb,x)	1.10	(-)	D
Shape factor describing root zone expansion	15	(-)	D
Effect of canopy cover in reducing soil evaporation in late season stage	50	(-)	D
Saturated hydraulic conductivity	180	mm/day	M
Initial soil water content		(%)	M

C: Calibrated, D: default, M: measured, L: literature.

AquaCrop performance was evaluated by means of qualitative (graphical) and quantitative (statistical) manners. In the graphical method, regression analyses were performed to generate equations to relate measured and simulated values of grain yield and biological yield. In the statistical method, goodness of fit between the measured and simulated values were assessed by using root mean square error (RMSE), normalized root means square error (NRMSE), index of agreement (or equivalently, the d-index) and Nash–Sutcliffe efficiency (NSE) given below:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2} \quad \ldots\ldots (1)$$

$$NRMSE = \left[\sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2}\right] \times \frac{100}{\bar{M}} \quad \ldots (2)$$

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - M_i)^2}{\sum_{i=1}^{n}(|S_i - \bar{M}| + |M_i - \bar{M}|)^2} \quad \ldots\ldots (3)$$

$$E = 1 - \frac{\sum_{i=1}^{n}(M_i - S_i)^2}{\sum_{i=1}^{n}(M_i - \bar{M})^2} \quad \ldots\ldots (4)$$

Where Si and Mi are the simulated and measured values respectively, $\bar{M}$ is the average of the measured values and n is the number of observations.

The zero value of RMSE depicts reliable agreement between simulated and observed values.

According to NRMSE scale, the simulation results is excellent if values fall below 10%, 10-20% good, 20-30% fair and greater than 30% marked as poor. The scaling index of d-statistic is considered too good between observed and model value when d-statistic is closer to one. Similarly, Nash Scuffle Efficiency (NSE) closer to one is excellent, greater than 0.7 good, 0.35-0.7 fair and less than 0.35 is poor (Jamieson et al., 1991).

Statistical analysis

The grain yield data and other crop parameters were statistically analyzed using Analysis of variance (ANOVA) with comparison of means using Least Square Difference (LSD) test at $P \leq 0.05$.

RESULTS

Effect of DI levels and sowing method on development and grain yield

The growth parameters considered in the current study includes plant height at harvest, spike length at harvest, 1000 grain weight, grain yield, biological yield and crop water use efficiency. The significant statistical difference was obtained for bed and drill sowing for all growth parameters (Table 3). Spike length and crop water use efficiency were higher in bed sowing than drill sowing plots by 10.8% and 13.5% respectively, while all other parameters were found to be high in drill sowing plots. The deficit irrigation levels have significant effect on wheat yield and growth components. The grain yield and growth parameters decreased drastically with increase in DI level. The highest grain yield (4.97 tons/ha and 5.72 tons/ha) was obtained in full irrigation treatments and lowest (3.75 tons/ha and 4.67 tons/ha) with the most water stressed treatments (I4-50% deficit) under Bed sowing and Drill sowing respectively. The wheat yield and component except crop water use efficiency of the DI levels discussed in the research were followed the trend I1>I2>I3>I4. The crop water use efficiency was found to be higher in most water stressed treatment (I4). The average crop water use efficiency for I1, I2, I3, and I4 treatment under bed sowing was found higher than the corresponding treatments (I1, I2, I3, and I4) under drill sowing method by 17.94%, 14.34%, 9.96%, and 5.36% respectively as bed sowing allows 50% water saving compared to drill sowing. The analysis of variance (ANOVA) of crop water use efficiency shows a significant difference for all four irrigation deficit levels, further the LSD pair-wise comparison test between means reveals that the only I1 irrigation level has a significant difference with other three irrigation levels (I2, I3 & I4). The variations in grain yield with applied water in terms of irrigation and rainfall to the crop is shown in Fig. 3.

AquaCrop model

The comparison between measured and simulated values of grain yield and biological yield calibrated and validated treatments were made as a percentage of the measured value and presented in Table 4. The results showed the deviations between the measured and simulated values were in the range of -9.74 to 3.82 and -8.53 to 1.59 for grain yield and biological yield respectively. The grain yield was over-estimated in full supply irrigation treatment under both sowing method, with deviation of 2.43 and 3.82 in bed and drill sowing, respectively. All other water deficit treatments showed under-estimation of 1.75 to 7.53 and 0.68 to 9.74% in bed and drill sowing, respectively.

Regarding biological yield, it was again over-estimated in no stressed treatment (I1) to as high as 1.59 and 0.89% in bed and drill sowing, respectively. The other water stressed treatments showed variability in the range of 0.55 to 7.72% and 1.42 to 8.53% in bed and drill sowing, respectively.

Regarding the relationship between simulated and measured grain yield and biological yield shown in Fig. 4 and 5, respectively, the model underestimates the grain yield and biological yield for more deficit level, however simulation was good under full irrigation treatment. Measured and simulated values of both parameters correlated well giving a R^2 of 0.96 and 0.94 respectively. The results of different statistical indices are also shown in Table 4 and showed good performance between the measured and simulated values for grain yield (RMSE=0.25 $tonha^{-1}$, NRMSE= 5.41, d=0.96 and NSE=0.79) and biological yield (RMSE=0.59 $tonha^{-1}$, NRMSE= 5.36, d=0.94 and NSE=0.74).

Table 3: Analysis of variance (ANOVA) and comparison of means (LSD) for DI levels and sowing methods on wheat grain yield and its growth component

Treatments		Plant Height at Harvest (cm)	Spike Length at Harvest (cm)	1000 Grain weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	Crop water use efficiency (kg/ha/mm)
Sowing method	S1	95.89[b]	10.35[a]	33.43[b]	4.39[b]	10.52[b]	20.26[a]
	S2	102.14[a]	9.34[b]	37.05[a]	5.21[a]	12.32[a]	17.85[b]
Significance at 5%		*	*	*	*	*	*
SE_m		1.007	0.68	0.636	0.049	0.259	0.810
LSD		4.634	2.926	2.730	0.210	1.26	3.75
Irrigation Levels	I1	105.8[a]	10.99[a]	39.94[a]	5.34[a]	12.65[a]	18.16[b]
	I2	101.64[b]	10.00[b]	36.86[b]	5.06[b]	11.77[b]	19.16[a]
	I3	96.36[c]	9.46[c]	34.23[c]	4.58[c]	11.06[b]	19.16[a]
	I4	92.26[d]	9.11[c]	29.92[d]	4.21[d]	10.21[c]	19.75[a]
Significance at 5%		*	*	*	*	*	*
SE_m		0.886	0.25	0.302	0.064	0.336	0.446
LSD		1.930	0.54	0.658	0.014	0.73	0.97
Interaction	I1S1	102.29	11.31	37.15	4.97	11.94	19.95
	I1S2	109.31	10.67	42.73	5.72	13.36	16.37
	I2S1	98.79	10.59	34.92	4.67	10.90	20.64
	I2S2	104.49	9.42	38.81	5.45	12.64	17.68
	I3S1	92.62	10.01	33.16	4.17	10.09	20.17
	I3S2	100.1	8.92	35.30	4.99	12.03	18.16
	I4S1	89.87	9.50	28.49	3.75	9.19	20.30
	I4S2	94.66	8.72	31.36	4.67	11.25	19.21
Significance at 5%		ns	ns	ns	ns	ns	ns

* = Significant; ns = Non-significant; Means followed by the same letter(s) do not differ significantly from one another at 5% probability level, using LSD test.

Table 4: Measured vs. simulated results and statistical assessment of AquaCrop model

Treatments	Grain Yield (t/ha)			Biological Yield (t/ha)		
	Measured	Simulated	Deviation (%)	Measured	Simulated	Deviation (%)
Calibrated dataset						
I1S1	4.97	5.09	2.43	11.94	12.13	1.59
I1S2	5.72	5.94	3.82	13.36	13.48	0.89
Validated dataset						
I2S1	4.67	4.59	-1.75	10.90	10.84	-0.55
I2S2	5.45	5.41	-0.68	12.64	12.46	-1.42
I3S1	4.17	3.97	-4.86	10.09	9.68	-4.06
I3S2	4.99	4.80	-3.84	12.03	11.35	-5.65
I4S1	3.75	3.47	-7.53	9.19	8.48	-7.72
I4S2	4.67	4.21	-9.74	11.25	10.29	-8.53
Statistical Indices						
RMSE		0.25			0.59	
NRMSE		5.41			5.36	
R^2		0.96			0.94	
d		0.96			0.94	
NSE		0.79			0.74	

DISCUSSION

Water-saving irrigation methods such as temporal deficit irrigation is one of the approaches used (limited water availability areas) that reduce water use without significant yield reduction thus maximizing farmers profit (Kirda et al., 2005). In this experiment, the deficit irrigation levels have significant effect on wheat yield and growth components. The grain yield and growth parameters decreased drastically with increase in DI level. The highest grain yield was obtained in full irrigation treatment and lowest with the most water stressed treatment (I4-50% deficit). The grain yield reduced as the water supply reduced. The primary reason of yield reduction may attribute to the water stress at emergence which increases with further reduction in irrigation water at all stages. Mohyuddin and Tarique (2008) reported highest grain yield for wheat crop with 100% irrigation whereas highest water use efficiency was achieved with 25% DI during all growth stages in medium textured soil. The I1, I2, I3, and I4 treatments under drill sowing method gave 13.12%, 14.28%, 16.38% and 19.59% more grain yield than the corresponding treatments under bed sowing method

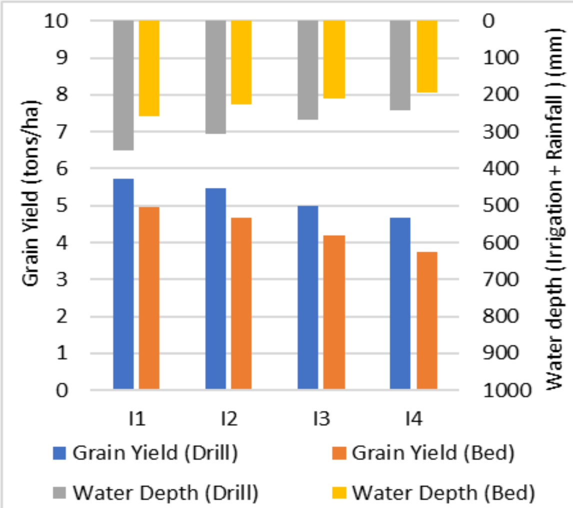

Fig. 3: Variation in grain yield (tons/ha) and water depth (mm).

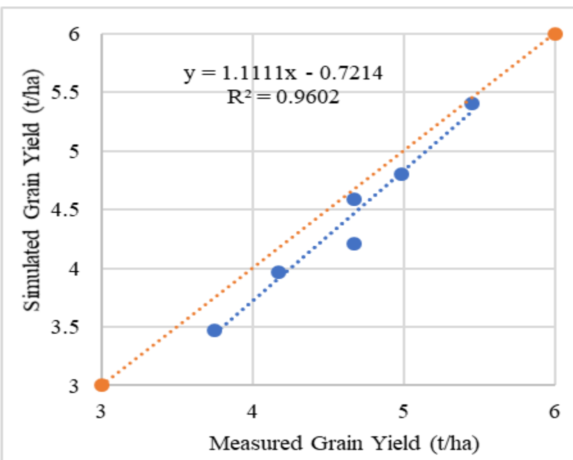

Fig. 4: Comparison of simulated and measured grain yield.

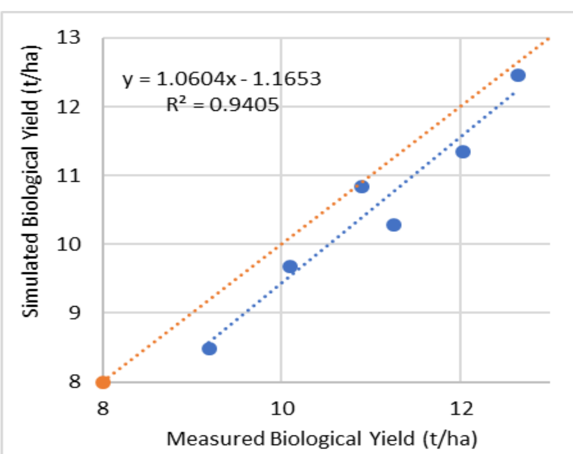

Fig. 5: Comparison of simulated and measured biological yield.

respectively, whereas crop water use efficiency was observed high in bed sowing than drill sowing method. The possible reason behind this is that the water stress created passive adaptation of plants towards water scarcity conditions, which can be used as an active means for the improvement of crop yield and water use efficiency through a regulated deficit irrigation treatment (Du et al., 2015). Greenwood et al. (2010) discussed the sensitivity of crops to reduce water supply and stated that the growth of many crops were slightly affected by considerable lowering of soil moisture. The average crop water use efficiency for I1, I2, I3, and I4 treatment under bed sowing was found higher than the corresponding treatments under drill sowing method by 17.94%, 14.34%, 9.96%, and 5.36% respectively as bed sowing allows 50% water saving compared to drill sowing. The possible reason of lower water use efficiency in drill sowing treatments was the significant loss of water through stomatal opening in CO_2 uptake and carbon gain process as well irrigated plants have wide stomatal opening in their leaves. A small thinning of the stomatal opening can decrease water loss considerably with slight effect on photosynthesis rate. Majeed et al. (2015) reported 29% higher economic return from raised bed plantation than flat sowing and save about 30% water and reduced water logging.

AquaCrop

Many scientists used AquaCrop model to evaluate deficit irrigation strategies for many crops for future use all around the world (Silva et al., 2018; Tan et al., 2018; Toumi et al., 2016; Maniruzzaman et al., 2015; Jin et al., 2014; Stricevic et al., 2011; Stricevic et al., 2011; Araya et al., 2010; Heng et al., 2009). There was a dire need to evaluate this model for quantification of cultural and management practices.

Model was calibrated by using the full irrigation treatments for both sowing methods and remaining six treatments were used for validation purpose. Results showed over-estimation for full irrigation treatment while all deficit irrigation treatments under-estimated for both sowing methods. The treatment with I4−50% deficit level under both sowing methods showed more deviation for grain yield and biological yield (under-estimated). This may be due to the fact that under acute water stress conditions plant canopy accelerates to senescence, and it becomes difficult for root system to extract soil water from a greater depth, thus limiting its water uptake. Moreover, Aquacrop use canopy ground cover to calculate transpiration and convert it into biomass. Several authors (Heng et al., 2009; Araya et al., 2010; Zeleke et al., 2011; Abedinpour et al., 2012) stated more variation in measured and simulated values under acute water stress or rainfed conditions, as compared to no water stress condition simulated by AquaCrop model. Heng et al. (2009) results showed that the AquaCrop model simulate yield good under no water stress to mild water stress conditions, but not for acute water stress condition. Katerji et al. (2013) stated that under acute water stress conditions, AquaCrop model was unable to simulate canopy cover accurately, especially during the senescence period.

The model underestimates the grain yield and biological yield for more deficit level; however, simulation was good under full irrigation treatment. Measured and simulated values of both parameters correlated well giving a R^2 of 0.96 and 0.94 respectively. Jin et al. (2014) reported R^2 values greater than 0.90 for both grain and biological yield for wheat crop simulated by AquaCrop. Similarly, Silva et al. (2018) reported higher R^2>0.92 when simulating yield of soybean in Brazil. The high values of the statistical indices confirm that the AquaCrop model can be used to simulate wheat grain yield and biological yield accurately. Recent research conducted all around the world (Toumi et al., 2016; Iqbal et al., 2014; Jin et al., 2014; Mkhabela and Bullock, 2012; Andarzian et al., 2011) confirm the ability of AquaCrop model to accurately simulate wheat yields and, hence, can be used for management of scarce water resources for wheat crop.

On the whole, it was concluded that maximum grain yield was found 5.724 tons/ha for 0% DI treatment under drill sowing method which was 13.12% more than the corresponding (0% DI) bed sowing method. Similarly, grain yield under drill sowing was higher than the bed sowing for all DI levels. As bed sowing allows 50% water saving compared to drill sowing, therefore, bed sowing is better option for wheat crop production under DI conditions. The higher values of the statistical indices indicate that the AquaCrop can simulate wheat yields under no to mild water stress conditions which makes it very useful for evaluating the deficit irrigation strategies under different cultural and management practices with minimal input data requirements and ease of use.

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Authors' contribution

All authors contributed equally in this study and all authors read and approved the final manuscript before publication.

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