INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
18–1460/2019/21–5–1004–1012
DOI: 10.17957/IJAB/15.0986
http://www.fspublishers.org

Full Length Article

Response of Wheat Cultivars to Deficit Irrigation under Semiarid Conditions of Faisalabad, Pakistan

Muhammad Fahad[1*], Syed Aftab Wajid[1], Ashfaq Ahmad[1] and Muhammad Jehanzeb Masud Cheema[2]
[1]*Departrment of Agronomy, University of Agriculture, Faisalabad, Pakistan*
[2]*Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan*
[*]For correspondence: fahadagr@outlook.com

Abstract

Decreasing availability of water resources for crop production can be handled with rational and wise management of irrigation. Deficit irrigation could be a potential tool for irrigation management, but it requires a clear understanding of water movement in soil profile and crop response to water stress throughout the growing season. A field experiment was conducted to evaluate the response of wheat (*Triticum aestivum* L.) crop to deficit irrigation with analysis of soil water balance, soil moisture content and relationship between evapotranspiration and grain yield. Five different levels of deficit irrigation along with farmers' irrigation practice [*i.e*., irrigation was applied at tillering, stem elongation, booting and grain formation stage I_1(farmers' practice at all growth stages), I_2(farmers' practice at all growth stages but no irrigation at stem elongation), I_3(farmers' practice at tillering and grain formation, while no irrigation at other growth stages), I_4(farmers' practice at tillering only and no irrigation at other growth stages), I_5(50% of farmers' practice at all growth stages) and I_6(75% of farmers' practice at all growth stages)] were applied to three wheat cultivars, *i.e*., Aas-2011, Galaxy-2013 and Punjab-2011. Experiment was conducted in winter seasons of 2014–2015 and 2015–2016 with three replications with strip plot arrangement under semi-arid conditions of Faisalabad. Grain yield was reduced by 35 to 44% when irrigation was skipped at booting and grain formation stage. Linear relationship was found between cumulative evapotranspiration and grain yield. The application of 75% of farmers' irrigation practice (I_6) saved 13 to 17% water and produced similar grain yield as acquired by farmers' irrigation practice (I_1). Therefore, it could be a potential strategy to cope with the drought period of crop from sowing to maturity under changing water scenarios of Faisalabad, Pakistan.

Keywords: Water scarcity; Deficit irrigation; Soil water balance; Water dynamics in soil profile

Introduction

Diminishing water resources and expansion in global drought have become serious issues for sustainable crop production under changing climate, throughout the world (Cai *et al.*, 2011; Hussain *et al*., 2018; Zhang *et al.*, 2018). Continuous and rapid increase in population, urbanization and industrialization have triggered the competition for fresh water with agriculture industry (Godfray *et al.,* 2010; Tilman *et al.,* 2011). It is also a known fact that the world requirement for food crops would be twice in 2050 (Tilman *et al.,* 2011) and irrigation is also inevitable for sustainable crop production and food security (Yazar *et al.,* 1999). Thus, current situation emphasizes that the production of more food with less water is future demand of agriculture to fulfill the food requirement of the masses (Godfray *et al.,* 2010), which can be dealt by efficient planning and management of available fresh water resources in agriculture (Smith, 2000).

For saving maximum agriculture water, irrigation application to a crop should be in a way that drainage and soil evaporation losses are minimized, and least sensitive crop growth stage should face irrigation deficiency (Arora and Gajri, 1998). Application of less water than full crop water requirement is defined as deficit irrigation (Fereres and Soriano, 2006). This irrigation approach has been widely accepted and adopted in many countries because less quantity of water is applied than required quantity of irrigation during crop growing season without compromising the yield (Fereres and Soriano, 2006; Ali and Talukder, 2008; Behera and Panda, 2009; Blum, 2009; Farré and Faci, 2009; Tari, 2016).

Wheat (*Triticum aestivum* L.) is the most important cereal crop which provides 20% of the calories required by world's population (Braun *et al.,* 2010). It is cultivated on 220 m ha which is 32% of global cultivated area under cereals (FAO, 2016). It is staple food in Pakistan and majority of the cultivated land of Punjab, Pakistan is occupied by wheat crop in winter season. Numerous studies showed that deficit irrigation in wheat crop is more promising strategy than other irrigation strategies (Behera and Panda, 2009; Pradhan *et al.*, 2014; Hussain *et al.*, 2016; Peake *et al.,* 2016; Tari, 2016; Saeed *et al.,* 2017). However, results of all these studies are variable among different wheat cultivars under different climatic conditions. Further, deficit irrigation has different water productivity in different areas because of crop water requirement is directly affected by pedo-climatic factors and management practices (Zhang, 2003). Geerts and Raes (2009) reported that deficit irrigation implementation requires the quantification of crop yield response to deficit irrigation under micro climatic conditions of a specific area due to difference in environmental conditions and agronomic practices. It is also important to understand the mechanism among crop yield, soil water deficit and water use efficiency to devise better water management practices in semi-arid environments (Wiedenfeld, 2000; Halitligil *et al.,* 2000). To experimental date, there was no study reported about the response of latest and widely grown wheat cultivars to deficit irrigation with soil moisture dynamics under semi-arid conditions of Faisalabad district.

This experiment was conducted to analyze the effects of optimum and deficit irrigation strategies on wheat grain yield, water use efficiency and soil moisture deficit under semi-arid conditions of Faisalabad district, Pakistan. Therefore, this two-year field experiment was conducted to evaluate the effect of deficit irrigation on soil water balance, soil moisture content, and grain yield and water use efficiency of different wheat cultivars under semi-arid conditions of Faisalabad, Pakistan.

Materials and Methods

Experimental Site

Experiment was conducted at Water Management Research Centre, Post Graduate Agricultural Research Station, University of Agriculture, Faisalabad (31°23'17.36"N, 73° 0'36.28"E) at 184 m above sea level during winter seasons of 2014–2015 and 2015–2016. Annual precipitation in the region is around 300 mm, while 70% of the precipitation is received in July and August. Average wheat season receives less than 100 mm and overall climatic condition is semi-arid. Daily meteorological data (maximum and minimum temperature, sunshine hours and rainfall) of experiment seasons are presented in Fig. 1. Weather data was obtained from automatic weather station located 5 km away from the experimental site. Different soil samples were collected from experimental site in zig zag way prior to experiment. Each sample was collected up to 105 cm soil depth with constant increment of 15 cm depth. Composite samples were prepared to analyze the soil by mixing the samples having same depth. Field capacity and permanent wilting point of each soil layer were determined by pressure plate apparatus at pressures of 33 and 1500 kPa, respectively (Richards and Weaver, 1943). Proportion of soil particles (sand, silt and clay) were estimated by Bouyoucos hydrometer method (Bouyoucos, 1936). Soil chemical properties were determined following standard procedures (Table 1). Physiochemical properties of soil are described in Table 2.

Experimental Design and Crop Husbandry

Experiment was conducted under strip plot arrangement with five replications. Wheat cultivars were sown on 20th November of both years in vertical strips using tractor drawn seed cum fertilizer wheat drill and irrigation was applied in horizontal strips as per requirement of experimental design. Vertical and horizontal strips were randomized separately for each replication. Seed rate 125 kg ha^{-1} was used for each cultivar and 20 cm row to row distance was maintained during sowing. Net area of each experimental plot was 7 m × 3.6 m and 1 m buffer area was maintained between irrigation strips to avoid the effects of percolated water from one plot to other. Nitrogen, phosphorus and potassium were applied at the rate of 65:114:62 kg ha^{-1} during sowing time. Nitrogen was applied in two equal splits: first split was applied at sowing time and second split (65 kg ha^{-1}) was top dressed before application of first irrigation. The sources of N, P_2O_5 and K_2O were urea, diammonium phosphate and sulphate of potash, respectively. Mixture of two herbicides (Bromoxynil+MCPA and sulfosulfuron+adjuvent) was applied in a single spray to control weeds within a week after first irrigation. Major infested weeds were *Avena fatua, Phalaris minor, Chenopodium album, Chenopodium murale, Rumex dentatus, Convolvulus arvensis, Anagallis arvensis, and Melilotus indica.*

Treatments

Five different levels of deficit irrigation along with farmers' irrigation practice were applied in latest and widely grown three wheat cultivars (Punjab-2011, Aas-2011 and Galaxy-2013) to evaluate the response of wheat crop for different irrigation strategies. Almost all farmers in Pakistan do not plan their irrigation schedule based on soil moisture content but apply irrigation by counting the days after sowing or on onset of specific crop growth stages as recommended by agriculture department. Therefore, irrigation treatments were designed based on farmers' irrigation practice following the crop growth stages. Different applicable combinations of deficit irrigation were proposed by decreasing the number or quantity of irrigation in farmers' irrigation practice to optimize the best irrigation schedule under changing climate and water scarcity (Table 3 and 4). Uniform irrigation was applied at tillering stage in all irrigation treatments because tillering is the most critical growth stage and farmers do not compromise on this stage for irrigation. Irrigation was skipped at stem elongation stage in I_2 but next irrigation was applied at booting stage with more quantity (80 mm) to ensure the soil moisture up to field capacity in both years. Similar case was happened with I_3

Table 1: Chemical properties of soil and their standard procedures for analysis

Parameter	Method	Depth (0–15 cm)		Depth (15–30 cm)	
		2014–2015	2015–2016	2014–2015	2015–2016
Soil pH	Nelson and Sommers, 1982	7.6	7.2	7.5	7.4
Available Phosphorus	Olsen method (Chapman and Pratt, 1962)	7.1 ppm	8.3 ppm	6.2 ppm	6.6 ppm
Available K	Mehlich, 1953	120 ppm	128 ppm	120 ppm	122 ppm
Soil OM	Walkley-Black method (Walkley and Black, 1934)	1.6%	1.8%	1.15%	1.12%
Nitrogen	Kjeldahl method (Bremner, 1960)	0.04%	0.03%	0.02%	0.02%

Table 2: Physical properties of soil

Depth	Sand%	Silt%	Clay%	†FC (cm^3/cm^3)	※PWP (cm^3/cm^3)	Bulk density (g/cm^3)
15	56	23.8	18.8	0.232	0.114	1.51
30	66.5	17.5	15	0.206	0.109	1.55
45	72	15	12.5	0.191	0.099	1.55
60	67.5	17.5	15	0.206	0.109	1.55
75	67.5	15	17.5	0.214	0.12	1.56
90	67.5	20	12.5	0.199	0.099	1.52
105	70	15	15	0.203	0.109	1.56

† Field capacity; ※ Permanent wilting point

Table 3: Details of irrigation treatments

Treatments	Growth stages			
	Tillering	Stem elongation	Booting	Grain formation
I_1	✓	✓	✓	✓
I_2	✓	×	✓	✓
I_3	✓	×	×	✓
I_4	✓	×	×	×
I_5	✓	½✓	½✓	½✓
I_6	✓	¾✓	¾✓	¾✓

Here I_1: Irrigation was applied at tillering, stem elongation, booting and grain formation stage (farmers' practice at all growth stages); I_2: farmers' practice at all growth stages but no irrigation at stem elongation; I_3: farmers' practice at tillering and grain formation, while no irrigation at other growth stages; I_4: farmers' practice at tillering only and no irrigation at other growth stages ; I_5: 50% of farmers' practice at all growth stages; I_6: 75% of farmers' practice at all growth stages

Table 4: Irrigation (mm) and rainfall (mm) received during rabi (winter) season of 2014–2015 and 2015–2016

Year	Irrigation	Date	I_1	I_2	I_3	I_4	I_5	I_6
2014-15	1st	09-Dec	30	30	30	30	30	30
	2nd	10-Jan	50	0	0	0	25	37
	3rd	16-Feb	50	80	0	0	25	37
	4th	11-Mar	40	40	100	0	20	30
	Rain fall		135	135	135	135	135	135
	Irrigation		305 (4)	285 (3)	265 (2)	165 (1)	235 (4)	269 (4)
2015-16	1st	10-Dec	30	30	30	30	30	30
	2nd	12-Jan	50	0	0	0	25	36
	3rd	10-Feb	60	80	0	0	30	45
	4th	07-Mar	60	60	100	0	30	45
	Rain fall		96	96	96	96	96	96
	Irrigation		296 (4)	266 (3)	226 (2)	126 (1)	211 (4)	252 (4)

Here I_1: Irrigation was applied at tillering, stem elongation, booting and grain formation stage (farmers' practice at all growth stages); I_2: farmers' practice at all growth stages but no irrigation at stem elongation; I_3: farmers' practice at tillering and grain formation, while no irrigation at other growth stages; I_4: farmers' practice at tillering only and no irrigation at other growth stages ; I_5: 50% of farmers' practice at all growth stages; I_6: 75% of farmers' practice at all growth stages

in both years which reduced the difference in total applied irrigation volume in I_1, I_2 and I_3 as compared to the total irrigations applied in each treatment (Fig. 4).

Soil Sampling and Irrigation Scheduling

Before sowing, 50% of total available water (TAW) (half of the field capacity) was maintained during sowing in upper 30 cm soil layer for proper germination and emergence of crop. First irrigation (30 mm) was applied uniformly at initiation of tillering stage to all experimental plots. After that, each irrigation was applied up to field capacity or less than field capacity as per treatments (Table 3). Time domain reflectometer (TDR) was used to determine the soil moisture. The length of TDR probes was 30 cm; therefore, soil auger was used to dig the soil for placement of TDR probes more than 30 cm soil depth. Soil moisture was measured in each irrigation treatment of all wheat cultivars prior to sowing and irrigation applications, and after harvesting. However, in

Table 5: Effect of deficit irrigation on grain and biological yields, harvest index, evapotranspiration and water use efficiency of wheat cultivars

Parameters	Grain yield (kg/ha)		Biological yield (kg/ha)		Harvest index (%)		Evapotranspiration (mm)		Grain water use efficiency ($g/mm/m_2$)	
Treatment	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016
Punjab-2011	2833.7a	3126.0a	7629.7	8026.0	37.0a	39.0a	206.1	202.0	1.37a	1.54
Aas-2011	2481.9b	2728.0b	7978.7	8367.2	30.9b	32.5c	207.2	201.6	1.19b	1.35
Galaxy-2013	2791.8a	3148.5a	8050.4	8427.7	34.6ab	37.5b	204.4	204.1	1.36a	1.54
HSD	161.8	369.8	NS	NS	3.8	1.3	NS	NS	0.087	NS
I_1	3129.9a	3549.3a	9251.5a	9920.4a	33.9bc	35.8ab	225.0a	227.0a	1.40a	1.58a
I_2	2901.3ab	3301.0ab	8209.0b	8926.9b	35.3abc	37.2a	209.6ab	212.9ab	1.39a	1.55a
I_3	2321.1c	2694.3c	7093.2c	7157.1d	32.6cd	38.2a	193.5bc	190.8b	1.20ab	1.42ab
I_4	2033.4d	1966.3d	6912.3c	6361.1e	29.5d	31.0b	177.5c	158.4c	1.15b	1.25b
I_5	2750.6b	2986.7bc	7330.4c	8053.6c	37.7a	37.6a	208.7ab	205.6ab	1.32ab	1.47ab
I_6	3078.5a	3507.3a	8521.3ab	9222.9b	36.1ab	38.1a	221.1a	220.7a	1.39a	1.60a
HSD	280.4	391.0	840.3	678.7	3.4	5.3	24.7	23.5	0.22	0.24
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Here I_1: Irrigation was applied at tillering, stem elongation, booting and grain formation stage (farmers' practice at all growth stages); I_2: farmers' practice at all growth stages but no irrigation at stem elongation; I_3: farmers' practice at tillering and grain formation, while no irrigation at other growth stages; I_4: farmers' practice at tillering only and no irrigation at other growth stages ; I_5: 50% of farmers' practice at all growth stages; I_6: 75% of farmers' practice at all growth stages

wheat cultivar Punjab-2011, it was measured after every 10 days interval to analyze the temporal soil moisture content and deficit. Different wheat cultivars have similar evapotranspiration under same climatic conditions and management practices (Djaman *et al.,* 2018). Therefore, analysis of temporal soil moisture content of one wheat cultivar could be representative of other wheat cultivars.

Calculation of Irrigation Volume

Soil profile was divided into three soil layers to analyze the soil moisture deficit at different depths; first soil layer 0–30 cm, second soil layer 30–60 cm and third soil layer 60–105 cm. At the time of sowing, upper soil layer (0–30 cm) retained 50% of available water, while lower two layers (30–60 cm and 60–105 cm) were at permanent wilting point which accumulated 130 mm total soil moisture in soil profile up to 105 cm. First irrigation was applied up to 30 cm soil depth, second irrigation was applied up to 60 cm, third and fourth irrigation was applied up to 105 cm soil depth after measuring rooting depth (Bohm, 1979). A rain gun connected with portable water pump was used to apply the irrigation with fixed discharge. Portable water pump was hinged with tractor and driven by power takeoff (PTO) shaft of tractor. Constant discharge of rain gun was ensured by fixing the number rotations per minute (rpm) of PTO shaft using tachometer. All plots were made accessible and irrigated by changing the rain gun position and direction. Specific quantity of irrigation was applied to each experimental plot using this equation:

$$T = AD_i / Q$$

Where T = time in seconds for predetermined quantity of irrigation, A = area to be irrigated (m^2), D_i = depth of irrigation (m) and Q = discharge of hose pipe (cumec).
Depth of irrigation (D_i) was determined by this formula:

$$D_i = (FC\text{-}SMC)/100 \times BD \times D_r$$

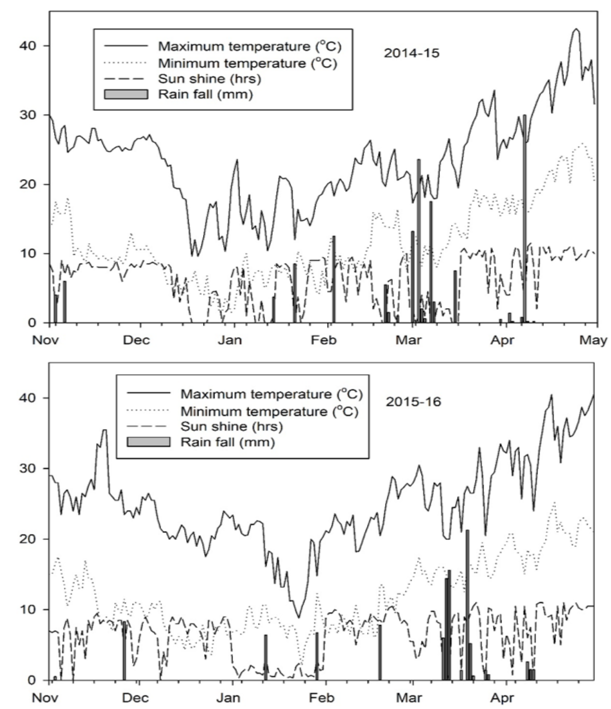

Fig. 1: Weather data obtained from Faisalabad Airport Meteorological Observatory located 5 km away from Experimental site

Where D_i = Depth of irrigation (cm) or Crop Water Requirement in depth (cm), FC = field capacity (% on volume basis), SMC = soil moisture content (% on volume basis), BD = bulk density (g/cm^3) and D_r = depth of root zone (cm).

Calculation of Soil Water Balance

Soil water balance equation was used to analyze the different components of water present in the root zone depth of 105 cm (James, 1988):

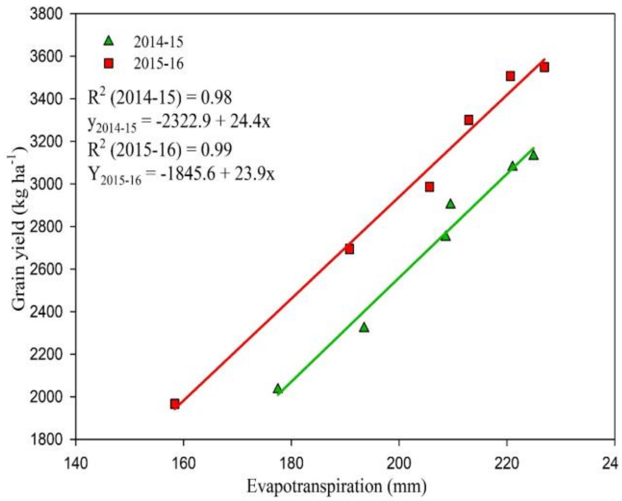

Fig. 2: Relationship between cumulative evapotranspiration and grain yield

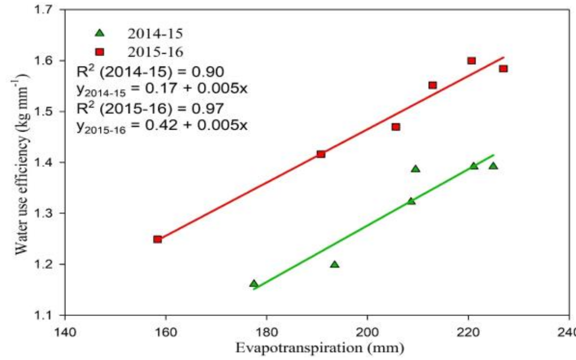

Fig. 3: Relationship between evapotranspiration and water use efficiency

$$P + I = ET_c + D + R \pm \Delta SW$$

Where P = precipitation, I = applied amount of irrigation, D = percolated water beyond the root zone, R = runoff and ΔSW = change in stored soil water, with all variables in units of equivalent mm water.

P and I were measured directly, ΔSW was measured by the difference of soil moisture content between sowing and harvesting in root zone (105 cm), R was zero due to bounding of each plot by 30 cm high bunds, D was calculated as drained water beyond the root zone (>105 cm) and ET_c was calculated as left-over component of water balance equation. Water table depth was more than 30m and no water was added by capillary rise in root zone.

Plant Sampling and Measurement

Standard procedures were adopted for recording biomass and grain yield. Half area of each plot was harvested at maturity from ground level to record the final biomass and grain yield (<12% moisture content). Water use efficiency (WUE in kg mm^{-1} ha^{-1}), defined as the ratio of grain yield per hectare to seasonal water consumption and calculated by following Howell (1990).

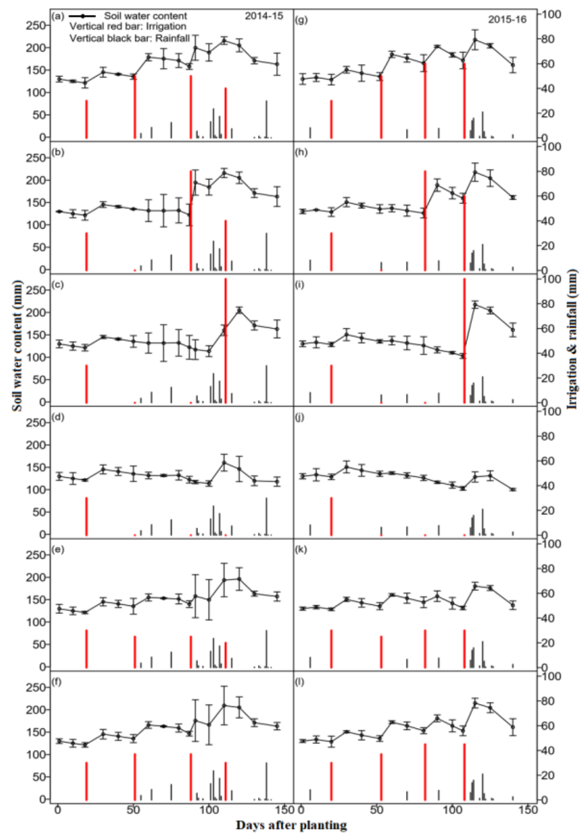

Fig. 4: Effect of irrigation and rainfall water on moisture dynamics of soil profile. Graph (**a**) to (**f**) and (**g**) to (**l**) showing the data of 2014-2015 and 2015-2016, respectively with irrigation treatments sequencly (Error bar represent the standard deviation of three replications)

Statistical Analysis

Data of three replications were used instead of five to remove the outliers and normalize the data. Analysis of variance (ANOVA) technique was used to analyze the recorded data of different parameters under strip plot design using Agricolae package (Mendiburu, 2014) in R (Team, 2014). Year effect was significant; therefore, experimental data of both years were analyzed separately. F-test was applied to determine the significant effect of treatments in ANOVA and treatment's means were compared using Tukey's test at 5% level of significance. Linear regression analysis was performed to investigate the empirical and site-specific relationship between cumulative evapotranspiration and, grain yield and water use efficiency. Linear regression analysis was performed using R (Team, 2014).

Results

Biomass, Grain Yield, Harvest Index, Evapotranspiration and Water Use Efficiency

The effect of different irrigation levels was significant on grain yield during both years of field trial. Wheat cultivars Punjab-2011 and Galaxy-2013 produced higher grain yield than Aas-2011. However, overall grain yield was higher in second year due to favorable climatic conditions. Irrigation treatments I_3 and I_4 produced 35–44% less grain yield than I_1. Deficit irrigation I_5 produced higher grain yield than I_3 and I_4.

Irrigation treatments significantly altered the harvest indices of wheat cultivars during both years of experiment (Table 5). In first year, wheat cultivars Punjab-2011 and Galaxy-2013 have higher harvest indices than Aas-2011. But in second year, all three wheat cultivars have different harvest indices. The highest harvest index (37.71%) was recorded in I_5 and it was statistically at par with I_2 and I_6 during 2014–2015. The lowest harvest index was recorded in I_4 during both years. There was no significant difference among evapotranspiration of different wheat cultivars (Table 5). The highest evapotranspiration was recorded for I_1 which was statistically at par with I_2, I_5 and I_6, while the lowest evapotranspiration was recorded in I_4. Different wheat cultivars and irrigation strategies had significant effect on water use efficiency. Punjab-2011 had the highest water use efficiency and it was statistically at par with Galaxy-2013. The lowest water use efficiency (1.15 and 1.25 g/mm/m^2 in 2014–2015 and 2015–2016, respectively) was recorded under severe water deficit, *i.e.*, I_4.

Response of Grain Yield and Water Use Efficiency to Evapotranspiration

The evapotranspiration of wheat crop varied from 177 mm to 225 mm in 2014–2015 and 158 mm to 227 mm in 2015–2016 from optimum to deficit irrigation levels. A linear response was found for grain yield and water use efficiency with evapotranspiration in both years. A strong relation (R^2= 0.98 to 0.99) was found between evapotranspiration and grain yield in both years (Fig. 2). Similarly, evapotranspiration relation with water use efficiency was also very good (R^2 = 0.90 to 0.97) (Fig. 3). Upper limit of evapotranspiration was similar for both years, but lower limit of evapotranspiration was different. For first year, lower limit of evapotranspiration was higher and narrower than second year. However, wider range from lowest to highest grain yield and water use efficiency were observed in second year against evapotranspiration under full and deficit irrigation. Maximum evapotranspiration (225 and 227 mm) in I_1 produced highest grain yield (3130 and 3549 kg ha^{-1}) and water use efficiency (1.4 kg ha^{-1} mm^{-1} and 1.58 kg ha^{-1} mm^{-1}) in both years, and vice versa due to linear relationship.

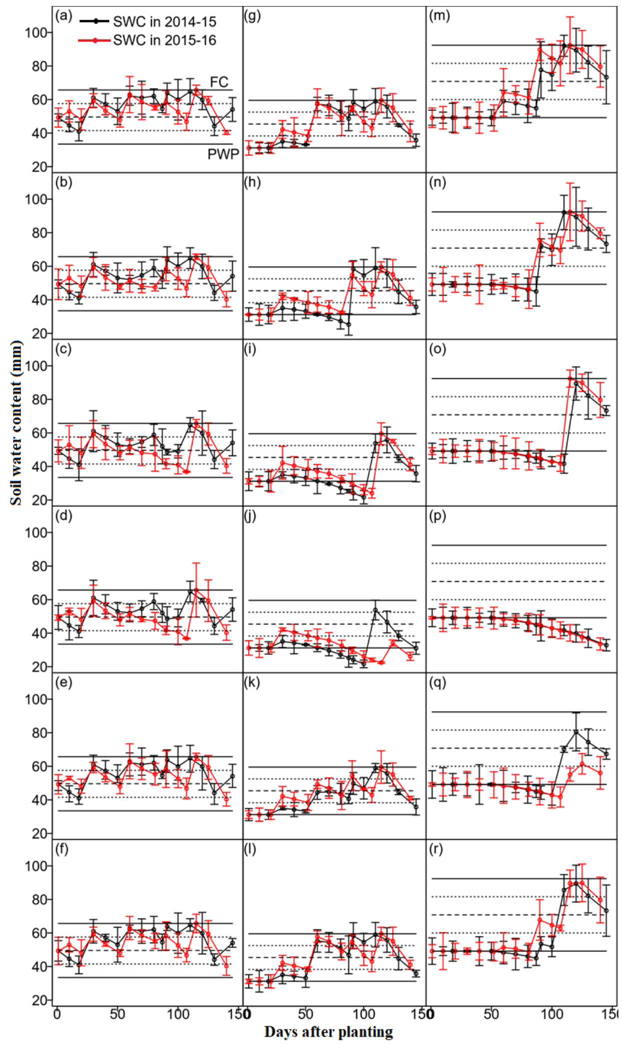

Fig. 5: Graph (**a**) to (**f**), (**g**) to (**l**) and (**m**) to (**r**) are representing the soil water content (mm) of all irrigation treatments at different depths; 0-30 cm, 30-60 cm and 60-105 cm, respectively (Error bar represent the standard deviation of three replications)

Total Soil Water Balance of Punjab-2011 Wheat Cultivar

More rainfall was received in first year (135 mm) than second year (96 mm), therefore, overall less quantity of total irrigation was applied in first year (2014–2015). However, more drainage losses were observed in irrigation treatments in first year. The irrigation treatments where higher amount of water was applied had more evapotranspiration and vice versa (Table 6).

Highest soil moisture variation was recorded in upper soil layer as compared to lower layers of I_4(1000) irrigation treatment due to rainfall (Fig. 5). Variation in moisture content of second soil layer (30–60 cm) was observed after fulfilling the field capacity level of upper soil layer

Table 6: Total soil water balance and its components of all irrigation treatments

Treatments	I_1		I_2		I_3		I_4		I_5		I_6	
Year	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016	2014–2015	2015–2016
Initial soil moisture	130	130	130	130	130	130	130	130	130	130	130	130
Irrigation	170	200	150	170	130	130	30	30	100	115	134	156
Rainfall	135	96	135	96	135	96	135	96	135	96	135	96
Total infiltrated water	435	426	415	396	395	356	295	256	365	341	399	382
Drained	51	40	46	25	40	9	2	1	2	0	18	3
Soil moisture at harvesting	163	161	163	161	163	161	118	100	157	138	163	161
Evapotranspiration	221	225	206	210	192	186	175	155	206	203	218	218
Total removed and offseason water	435	426	415	396	395	356	295	256	365	341	399	382

Here I_1: Irrigation was applied at tillering, stem elongation, booting and grain formation stage (farmers' practice at all growth stages); I_2: farmers' practice at all growth stages but no irrigation at stem elongation; I_3: farmers' practice at tillering and grain formation, while no irrigation at other growth stages; I_4: farmers' practice at tillering only and no irrigation at other growth stages ; I_5: 50% of farmers' practice at all growth stages; I_6: 75% of farmers' practice at all growth stages

(almost 100 days after sowing). Both years soil moisture content in second layer (30–60 cm) of I_4(1000) could not cross the field capacity and did not affect the moisture content of third soil layer (60–105 cm). Lowest soil layer (60–105 cm) of I_4(1000) has same moisture content in both years. Thus, upper soil layers play buffering role for lower soil layers to variation in soil moisture content at different depth. Therefore, lesser quantity of rainfall is more effective for upper soil layer than lower layers. Upper soil layer (0–30 cm) of both irrigation treatments I_6 and I_5 have more moisture contents (75 to 100% of TAW) as compared to I_2 (50 to 75% of TAW) during 50 to 100 days after sowing (Fig. 5). Second soil layer (30–60 cm) showed moisture content of irrigation treatment I_6 and I_5 varied from 50 to 100% and 25 to 75% of TAW, respectively as compared to irrigation treatment I_2 (25% of TAW to PWP) during 50 to 100 days after sowing. Moisture dynamics of third soil layer (60–105 cm) of all irrigation treatments is different from each other during later crop growth stages and it contributes minimum in total water uptake. Further, maximum drainage (46 and 25 mm) was observed in irrigation treatment I_2 as compared to irrigation treatments I_6 (18 and 3 mm) and I_5 (2 and 0 mm) during both years.

Discussion

During both years, results showed that reducing the amount of irrigation water by 25% did not affect grain yield and this could be a good management practice to save irrigation water without compromising grain yield. The results also indicated that skipping irrigation at any critical growth stage or reducing the irrigation water by 50% reduced the grain yield significantly. Some earlier studies also showed that skipping irrigation at any critical growth stage caused significant reduction in grain yield (Maqsood *et al.,* 2002; Waraich *et al.,* 2007; Farooq *et al*., 2015). The important outcome of research is applying of 75% of farmer's irrigation practice can produce statistically same grain yield produced by farmer practice I_1 and I_2. Considering equitable use of water, this management strategy has potential to save irrigation water under water shortage conditions. Saeed *et al.* (2017) reported same results and observed no significant reduction in grain yield with 80% of full irrigation at all critical growth stages of wheat cultivar Millat-2011. Irrigation applied at stem elongation only increased the plant biomass and did not contribute in grain yield.

Irrigation treatments showed different trend in first year as compared to second year for biomass production. Rainfall during grain formation stage minimized the effects of water deficiency in irrigation treatments I_4 and I_5 in first year. Therefore, I_3, I_4 and I_5 produced statistically same biomass. But, in second year, I_4 produced the lowest biomass due to less water applied and low moisture availability inhibited cell division and cell elongation (Schuppler *et al.,* 1998). The biomass accumulation results are in line with Onyibe (2005), as he reported no significant effect of increased water from 60 to 90% available soil moisture on biomass accumulation in wheat crop. Sarwar *et al.* (2010) also reported similar results for different levels of irrigation. Zhan-Jiang *et al.* (2010) reported that application of less water reduced the biomass accumulation and well-watered conditions improved the biomass accumulation. Irrigation skipped at stem elongation stage in I_2 improved the harvest index because stem elongation was not a critical growth stage for grain yield and only increased the plant height (biomass). Higher harvest index in I_2, I_5 and I_6 evident that irrigation with lesser quantity of water at all critical growth stages of wheat improved the grain yield proportion to biomass production. Harvest index is a cultivar dependent character and all irrigation treatments did not affect the harvest index except I_4 where severe drought was applied and minimum harvest index (31.0%) was recorded.

Linear relationship was found between grain yield and water use efficiency to evapotranspiration which showed gradual increase of evapotranspiration from deficit to optimum irrigation also improved the grain yield and water use efficiency. Lowest water use efficiency under severe drought in I_4 proved that proportion of grain yield production per unit of cumulative evapotranspiration was reduced. Trend of relationship is similar in both years but upper and lower limits of evapotranspiration, grain yield and water use efficiency are different. Climate of second year was more favorable for wheat productivity due to plenty of sunshine hours as compared to first year; therefore, overall second year produced more grain yield in all treatments.

Linear relationship between evapotranspiration, grain yield and water use efficiency provide the information about potential grain yield and water productivity of any area in context of climatic conditions. However, it does not explain intensity and frequency of soil moisture deficit period in different irrigation strategies having same cumulative evapotranspiration. For example, similar quantities of cumulative evapotranspiration were observed in irrigation treatments I_1 and I_6, and I_2 and I_5. All these irrigation treatments are statistically same for evapotranspiration (Table 5) but analysis of soil moisture deficit showed that intensity and frequency of moisture deficit is different in each irrigation treatment from sowing to maturity. Frequent irrigation continuously improves the soil moisture content in upper soil layer because each irrigation first irrigates the upper soil layer up to field capacity then subsurface is irrigated and plant roots uptake maximum water from upper soil layer. Irrigation scheduling having less number of irrigation retains more moisture content in lower soil surface as compared to upper soil surface during drought period. Therefore, frequent irrigation is more efficient, and crop faces minimum moisture deficit period as compared to irrigation scheduling having less number of irrigations even total evapotranspiration is same in both cases. Application of 75% of full irrigation (farmer practice) is equally effective to produce the maximum grain yield as produced in full irrigation.

Conclusion

Wheat cultivars Punjab-2011 and Galaxy-2013 produced the higher grain yield as compared to Aas-2011. Application of 75% of full irrigation at tillering, stem elongation, booting and grain formation produce the maximum grain yield and it saved 13 to 17% water. Frequent irrigation with less volume of water is more effective strategy because it reduced the drought period of crop from sowing to maturity.

Acknowledgement

The first author would like to thank Higher Education Commission, (HEC) Pakistan for funding this research during his PhD study.

References

Ali, M.H. and M.S.U. Talukder, 2008. Increasing water productivity in crop production—a synthesis. *Agric. Water Manage*., 95: 1201–1213

Arora, V.K. and P.R. Gajri, 1998. Evaluation of a crop growth-water balance model for analysing wheat responses to climate- and water-limited environments. *Field Crops Res.*, 59: 213–224

Behera, S.K. and R.K. Panda, 2009. Integrated management of irrigation water and fertilizers for wheat crop using field experiments and simulation modeling. *Agric. Water Manage.*, 96: 1532–1540

Blum, A., 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field Crops Res.*, 112: 119–123

Bohm, W., 1979. *Methods of Studying Root Systems*, Vol. 33, p: 188. Springer Verlag, Berlin Heidelberg, New York, USA

Bouyoucos, G.J., 1936. Directions for making mechanical analysis of soils by the hydrometer method. *Soil Sci*., 42: 225–230

Braun, H.J., G. Atlin and T. Payne, 2010. Multi-location testing as a tool to identify plant response to global climate change. *Clim. Change Crop Prod.*, 1: 115–138

Bremner, J.M., 1960. Determination of nitrogen in soil by the Kjeldahl method. *J. Agric. Sci.*, 55: 11–33

Cai, X., D. Molden, M. Mainuddin, B. Sharma, M.U.D. Ahmad and P. Karimi, 2011. Producing more food with less water in a changing world: assessment of water productivity in 10 major river basins. *Water Intl.*, 36: 42–62

Chapman, H.D. and P.F. Pratt, 1962. Methods of analysis for soils, plants and waters. *Soil Sci.*, 93: 68

Djaman, K., M. O'Neill, C. Owen, D. Smeal, M. West, D. Begay, S. Allen, K. Koudahe, S. Irmak and K. Lombard, 2018. Long term winter wheat (*Triticum aestivum* L.) seasonal irrigation amount, evapotranspiration, yield and water productivity under semiarid climate. *Agronomy*, 8: 96

FAO, 2016. Food and agriculture organization of the United Nations. FAO, http://www.fao.org/faostat/en/#data (accessed 06.12.18)

Farooq, S., M. Shahid, M.B. Khan, M. Hussain and M. Farooq, 2015. Improving the productivity of bread wheat by good management practices under terminal drought. *J. Agron. Crop Sci.*, 201: 173–188

Farré, I. and J.M. Faci, 2009. Deficit irrigation in maize for reducing agricultural water use in a Mediterranean environment. *Agric. Water Manage.*, 96: 383–394

Fereres, E. and M.A. Soriano, 2006. Deficit irrigation for reducing agricultural water use. *J. Exp. Bot.*, 58: 147–159

Geerts, S. and D. Raes, 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agric. Water Manage.*, 96: 1275–1284

Godfray, H.C.J., J.R. Beddington, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, J. Pretty, S. Robinson, S.M. Thomas and C. Toulmin, 2010. Food security: the challenge of feeding 9 billion people. *Science*, 327: 812–818

Halitligil, M.B., A. Akın, N. Bilgin, Y. Deniz, K. Öğretir, B. Altınel and Y. Işık, 2000. Effect of nitrogen fertilization on yield and nitrogen and water use efficiencies of winter wheat (durum and bread) varieties grown under conditions found in Central Anatolia. *Biol. Fertil. Soils*, 31: 175–182

Howell, T.A., 1990. Relationships between crop production and transpiration, evapotranspiration, and irrigation. *Agronomy*, 30: 391–434

Hussain, M., S. Farooq, W. Hasan, S. Ul-Allah, M. Tanveer, M. Farooq and A. Nawaz, 2018. Drought stress in sunflower: Physiological effects and its management through breeding and agronomic alternatives. *Agric. Water Manage.*, 201: 152–167

Hussain, M., M. Waqas-ul-Haq, S. Farooq, K. Jabran and M. Farooq, 2016a. The impact of seed priming and row spacing on the productivity of different cultivars of irrigated wheat under early season drought. *Exp. Agric*., 52: 477–490

James, L.G., 1988. *Principles of Farm Irrigation Systems Design*, 1st Edition, pp: 543. John Wiley and Sons Limited, New York, USA

Maqsood, M., A. Ali, Z. Aslam, M. Saeed and S. Ahmad, 2002. Effect of irrigation and nitrogen levels on grain yield and quality of wheat (*Triticum aestivum* L.). *Intl. J. Agric. Biol.*, 4: 164–165

Mehlich, A., 1953. Determination of P, Ca, Mg, K, Na and NH_4. *In: Short Test Methods Used in Soil Testing Division, Department of Agriculture, Raleigh, North Caroline*, pp: 23-89. Mendiburu, F.D., 2014. *Agricolae: statistical procedures for agricultural research*. R Package version

Nelson, D.W. and L.E. Sommers, 1982. Total carbon, organic carbon and organic matter. *In: Methods soil Analsis*, Part 3, Vol. 9, pp: 539–579. Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin, USA

Onyibe, J.E., 2005. Effect of irrigation regime on growth and development of two wheat cultivars (*Triticum aestivum* L.) in the Nigerian savanna. *J. Agric. Rural Dev. Trop. Subtrop*., 106: 177–192

Peake, A.S., P.S. Carberry, S.R. Raine, V. Gett and R.J. Smith, 2016. An alternative approach to whole-farm deficit irrigation analysis: Evaluating the risk-efficiency of wheat irrigation strategies in sub-tropical Australia. *Agric. Water Manage.,* 169: 61–76

Pradhan, S., U.K. Chopra, K.K. Bandyopadhayay, R. Singh, A.K. Jain and I. Chand, 2014. Effect of deficit irrigation and nitrogen levels on water productivity and nitrogen use efficiency of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Ind. J. Agric. Sci.,* 84: 1–9

Richards, L.A. and L.R. Weaver, 1943. Fifteen-atmosphere percentage as related to the permanent wilting percentage. *Soil Sci.,* 56: 331–340

Saeed, U., S.A. Wajid, T. Khaliq and Z.A. Zahir, 2017. Optimizing irrigation and nitrogen for wheat through empirical modeling under semi-arid environment. *Environ. Sci. Pollut. Res.,* 24: 11663–11676

Sarwar, N., M. Maqsood, K. Mubeen, M. Shehzad, M.S. Bhullar, R. Qamar and N. Akbar, 2010. Effect of different levels of irrigation on yield and yield components of wheat cultivars. *Pak. J. Agric. Sci.,* 47: 371–374

Schuppler, U., P.H. He, P.C.L. John and R. Munns, 1998. Effect of water stress on cell division and Cdc2-like cell cycle kinase activity in wheat leaves. *Plant Physiol.,* 117: 667–678

Smith, M., 2000. The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. *Agric. For. Meteorol.,* 103: 99–108

Tari, A.F., 2016. The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions. *Agric. Water Manage.,* 167: 1–10

Team, R.C., 2014. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria

Tilman, D., C. Balzer, J. Hill and B.L. Befort, 2011. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA*, 108: 20260–20264

Walkley, A. and I.A. Black, 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.*, 37: 29–38

Waraich, E.A., R. Ahmad, A. Ali and S. Ullah, 2007. Irrigation and nitrogen effects on grain development and yield in wheat (*Triticum aestivum* L.). *Pak. J. Bot.,* 39: 1663–1672

Wiedenfeld, R.P., 2000. Water stress during different sugarcane growth periods on yield and response to N fertilization. *Agric. Water Manage.,* 43: 173–182

Yazar, A., T.A. Howell, D.A. Dusek and K.S. Copeland, 1999. Evaluation of crop water stress index for LEPA irrigated corn. *Irrig. Sci.,* 18: 171–180

Zhan-Jiang, H.A.N., Y.U. Zhen-Wen, W. Dong and Y.L. Zhang, 2010. Effects of supplemental irrigation based on testing soil moisture on dry matter accumulation and distribution and water use efficiency in winter wheat. *Acta Agron. Sin.,* 36: 457–465

Zhang, H., 2003. Improving water productivity through deficit irrigation: examples from Syria, the North China Plain and Oregon, USA. *Water Product. Agric. Limits Oppor. Improv. Wallingford CABI*: 301–309

Zhang, H.H., N. Xu, X. Sui, H.X. Zhong, Z.P. Yin, X. Li and G.Y. Sun, 2018. Photosystem II function response to drought stress in leaves of two alfalfa (*Medicago sativa*) varieties. *Int. J. Agric. Biol*., 20: 1012–1020

(Received 16 October 2018; Accepted 22 December 2018)