



Response of drip-irrigated maize to different soil moisture depletion levels in autumn and spring season in loam soil

Asrar Mahboob¹, Muhammad Shoaib^{1*}, Muhammad Manzoor², Ijaz Mahboob³, Naveed Akhtar⁴, Javed Iqbal¹,
Muhammad Arif⁴, Sadia Sultana⁵ and Muhammad Saeed Ashraf⁴

¹Maize and Millets Research Institute, Yusafwala Sahiwal, Punjab Pakistan

²Water Management Research Farm, Renala Khurd-Okara, Punjab Pakistan

³Soil and Water Testing Laboratory for Research, Kasur, Punjab Pakistan

⁴Agronomic Research Institute, AARI, Faisalabad, Punjab Pakistan

⁵Institute of Soil Chemistry and Environmental Sciences, AARI, Faisalabad, Punjab Pakistan

[Received: January 20, 2022 Accepted: November 10, 2022 Published Online: December 03, 2022]

Abstract

Depleting irrigation resources necessitate the introduction of more efficient irrigation approaches to sustain maize production in Pakistan. Therefore, this field study was conducted to evaluate maize response to different irrigation strategies under drip irrigation system in autumn and spring seasons. Treatments comprised of management allowable depletion (MAD) of soil moisture viz. 15%, 30%, 45% and 60% of field capacity. Results showed that, across the depletion levels, ear length and grains row⁻¹ were 8.6% and 28% greater in autumn compared to spring season while 9%, 25%, 7.55% and 6.3% more grain rows ear⁻¹ and fresh ears ha⁻¹, fresh ear weight and grain yield, respectively, were recorded in spring. Higher grain starch% and protein% were recorded in autumn. In both the seasons, studied parameters decreased with increase in soil moisture depletion level from 15% to 60%, however difference among means were marginal among 15%, 30% and 45% but decreased significantly ($p < 0.05$) thereafter in autumn season. While in spring, yield and other parameters were affected significantly when soil moisture decreased beyond 30%. More sensitive parameters to the increasing soil moisture depletion in both the seasons were grain yield > fresh ear weight > grain rows ear⁻¹. Irrigation water use efficiency (IWUE) and water use efficiency (WUE) decreased with increased soil moisture depletion level. Across the years, IWUE and WUE ranged from 22.1-18.0 kg ha⁻¹ mm⁻¹ and 23.3-17.7 kg ha⁻¹ mm⁻¹, respectively, in autumn while in spring IWUE and WUE ranged from 19.8-10.5 kg ha⁻¹ mm⁻¹ and 20.3-11.3 kg ha⁻¹ mm⁻¹, respectively. Based on the results, it may be concluded that under local climatic and soil conditions, maize could sustain its yield at irrigating the maize crop at 45% and 30% soil moisture depletion in autumn and spring, respectively.

Keywords: Water stress; ear characteristics; grain quality; growing season; CROPWAT model

Introduction

Pakistan's agricultural system gets benefits from a range of water resources including precipitation, river flow that stems from snow, glacier melt and runoff from rains and underground water reserves. However, Pakistan, gradually has become a water stressed country with <1000 m³ per capita water availability and fresh water storage capacity for mere 30 days (Shahid, 2016). Erratic rainfall, greater evapo-transpiration demand, high conveyance and field application losses (up to 45.52 and 26.63 million acre feet per annum, respectively) and inappropriate fusty crop production practices are some of the

reasons of this growing problem (Maqbool, 2017). During the last decade, average actual surface water availability for agricultural system is declining with average of was 9.15% than its average usage (GoP, 2020). Agriculture has a lion's share (about 90%) in usage of both fresh and underground water in Pakistan. Most of the crops are irrigated through flood irrigation (basin, border and furrow) in which whole or chunk of the soil surface is flooded without taking into account the consumptive use of water (Tagar *et al.*, 2012). Therefore adoption of the modern and more efficient irrigation system is inevitable to sustain the agricultural production system. Drip irrigation system refers to a system of watering the crops that deliver the water directly to individual plants on gradual and

*Email: drmsshoaibshah@gmail.com

Cite This Paper: Mahboob, A., M. Shoaib, M. Manzoor, I. Mahboob, N. Akhtar, J. Iqbal, M. Arif, S. Sultana and M.S.Ashraf. 2022. Response of drip-irrigated maize to different soil moisture depletion levels in autumn and spring season in loam soil. *Soil Environ.* 41(2): 121-134.

continuous bases (Singandhupe *et al.*, 2003). Surface drip irrigation system is widely used in agricultural systems for perennial crops and annual row crops (Schwankl and Hanson, 2007). High efficiency of the drip irrigation system arises from reduced surface evaporation and surface runoff in addition of least deep-percolation (Li *et al.* 2003). The advocated benefits of the drip irrigation are yield increase, reduced water and fertilizer application rates, saving in tillage cost and labor charges and better weed and pest control (Michael, 2009; Levidow *et al.*, 2014). While comparing border, furrow and drip irrigation systems in China, Zhang *et al.* (2021) reported that furrow and drip irrigation system saved 31% and 57% irrigation water compared to flood irrigation with comparable yield with 10% irrigation water lost through deep percolation in border irrigation. They also reported that water consumption coefficient was greater under drip irrigation compared to furrow and border irrigation system.

Maize is a standout cereal crop in Punjab province where it is grown in two distinct seasons i.e. spring (January-June) and autumn (July-December). During 2019-20 area under maize cultivation was 1413000 hectares with total production of 7.236 million tons (GoP, 2020). Punjab province shares nearly 60% maize acreage while its share in total production is 90%. In Punjab, maize is grown in irrigated areas where it is irrigated 10-12 times in spring season and 8-10 times in autumn season. Generally, farmers in Punjab do not consider stage of the crop, environmental conditions and water sensitive crop stages, soil type and its physical characteristics while irrigating, rather every irrigation consists of a theoretical depth of 7.5 cm. This uncontrolled and un-managed irrigation strategy also results in indiscriminate pumping of underground water in addition to very low water use efficiency. Irrigation management is one of the most critical factors to optimizing maize yield (Zamora-Re *et al.*, 2020). Maize is sensitive to drought stress at all growth stages and different researchers have reported substantial negative impacts on dry matter (DM) accumulation and partitioning, plant growth, grain yield and nutrition of the produce when crop was exposed to moisture stress at different stages of crop (Panda *et al.*, 2004; Payero *et al.*, 2008; Wang and Frei 2011; Mi *et al.*, 2018; Yue *et al.*, 2018). Maize is not only sensitive to the severity of the drought but stage of the crop at stress is also critical (Ge *et al.*, 2012). Irrigation scheduling that is based on evapotranspiration demand of the crop for a specific area is more efficient irrigation strategy to align with crop water requirements and gives higher water use efficiency (WUE) and crop yield (Ko and Piccinni, 2009; Zamora-Re *et al.*, 2020). Two distinct maize growing areas in upper Indus plains (autumn and spring) are characterized by altogether different climatic conditions

with different evapotranspiration demands. Therefore, irrigation management strategy might differ for autumn and spring season.

To optimize crop yield and quality, a locally adaptable and efficient irrigation strategy, must also be developed and adopted by local farmers (Gheysari *et al.*, 2017). Limited moisture availability to maize during the growing season reduced yield (Patel *et al.*, 2006; Greaves and Wang, 2017) though high corn yield could be maintained under certain level of soil moisture stress using different irrigation strategies (Vories *et al.*, 2009). Zhang *et al.* (2021) have reported the treatment that received water 80% of ET at V1-V7 stage and 60% of ET from tasseling to maturity gave similar yield to the control (full 100% irrigation) and they also reported that maize yield was reduced only when maize received 40% less irrigation of total ET requirement. Similarly, Aguilar *et al.* (2007) found 29% larger productivity of applied water for limited irrigation treatments in comparison to full irrigation in a semi-arid environment. However, no study in Punjab conditions has hitherto been conducted to gauge the impact of different soil moisture depletion levels on maize under drip irrigation. This study was planned to

1. Evaluate the impact of different irrigation strategies based on soil moisture depletion percentage on ear characteristics, grain yield, and water use efficiency under surface drip irrigation system in semi-arid conditions of maize growing areas of Punjab.
2. Assess seasonal differences in crop response to moisture depletion levels in autumn and spring and needs to adjust irrigation scheduling thereof.

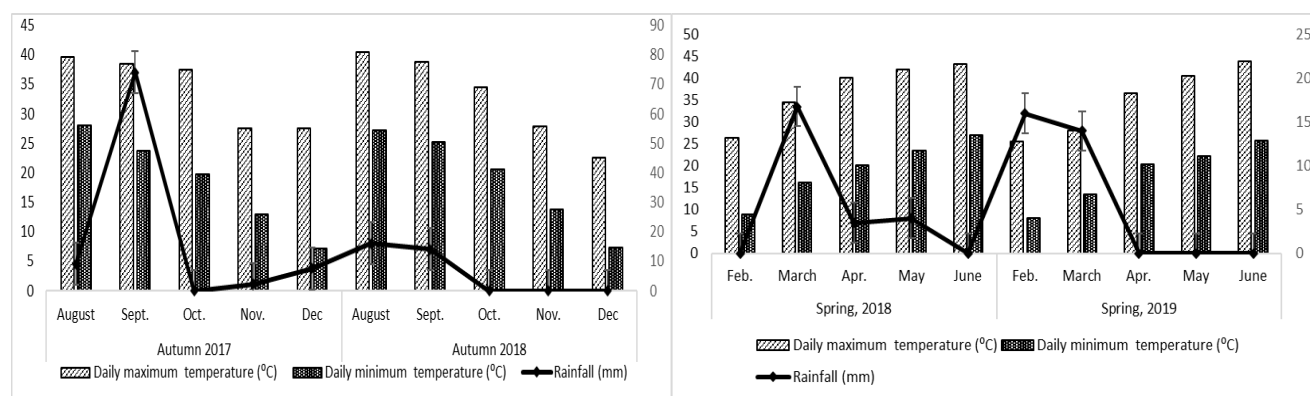
Materials and Methods

This study was conducted with an objective to find out the appropriate irrigation management plan based on soil moisture depletion levels for hybrid maize under drip irrigation to obtain maximum grain yield in autumn and spring season. Maize growing areas of Punjab are situated in upper Indus basin with subtropical continental lowland type climate (250-300 mm average annual rainfall, classified as semi-arid) that mainly comprises of districts of Pakpattan, Sahiwal, Okara, Vehari and Kasur. Experiment was conducted at Water Management Research Farm, Renala Khurd, Okara (30.53°N, 73.36°E, 170 m above sea level) during autumn season 2017 and 2018 and spring season 2018 and 2019. Physico-chemical analysis of the soil at experimental area conducted prior to sowing is given in Table-1 while climatic conditions during the study period are depicted in Figure-1.



Table 1: Physico-chemical analysis of soil at experimental site

Soil depth	EC (mS/cm)	pH	OM (%)	Avail. P (mg kg ⁻¹)	Avail. K (mg kg ⁻¹)	Saturation (%)	Texture
Autumn							
0-15cm	1.1	8.2	0.62	12	210	41	Loam
5-30cm	1.4	8.4	0.48	9	196	38	Loam
Spring							
0-15cm	1.3	8.2	0.71	14	212	40	Loam
5-30cm	1.5	8.3	0.53	9	197	39	Loam

**Figure 1: Daily average maximum and minimum temperature and monthly rainfall during the study period**

Four irrigation treatments were studied based on predetermined MAD levels. The MAD levels were 15% (D₁), 30% (D₂), 45% (D₃) and 60% (D₄) of available soil moisture (ASM). Allowed depletion is based on ASM which was the difference between soil moisture at field capacity and permanent wilting point. The soil at experimental site is loamy with average 31% total soil moisture contents at field capacity and permanent wilting point at 14% therefore foregoing soil moisture depletion levels correspond to 28.45, 25.9, 23.35 and 20.8% soil moisture contents, respectively. Soil moisture contents at active rooting depth (30 cm up to 30 days after sowing, 60 cm for 30 days after sowing to maturity) were measured by soil moisture meter on alternative day and plots were irrigated with measured amount of water on reaching the predetermined depletion. Total amount of irrigation water and some other related details of irrigation strategies are given in Table-2.

Initially (before first season) land was prepared by deep plough with sub-soiler. Finally (before both seasons) soil was tilled with 3 plough succeeded by planking. Raised beds (1.05 m wide ridge + furrow) were prepared by tractor mounted adjustable bed shaper. Each experimental unit measured 12.6 m × 5 m which was repeated four times under randomized complete block design. Maize was planted on both sides of 105 cm wide raised beds (57 cm furrow and 48 cm bed top).

Hence each experimental unit comprised of 12 raised beds with 24 rows of maize. Area with dimension of 3.15 m × 4 m was allocated for data collection.

Sowing was done on both sides of the bed with almost 15 cm apart from the drip tube resulting in theoretical row spacing of about 30 cm on the same bed while about 70 cm trans-bed rows. Plant to plant spacing was maintained at 28.75 cm during autumn while 21.25 cm in spring season to attain the recommended plant population for each season. The experiment was planted on first fortnight of the August and February in autumn and spring, respectively, in both years. Dibblers were used to create hills of specified spacing and later on one seed was planted in each hill at 5-6 cm depth. Monsanto maize hybrids DK6103 and DK6789 were used in spring and autumn season, respectively. Each experimental unit was kept at field capacity up to completion of germination to facilitate germination process by avoiding moisture stress during germination; afterwards irrigation treatments were implemented. Nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) at the rates of 205, 82 and 205 kg ha⁻¹ were applied to the crop, respectively. Detail of fertigation is given in Table-3.

Within 24 hours of the planting Primextra Gold (S-metolachlor + atrazine) 720 SC (400 mL acre⁻¹) was sprayed

to control the weeds. At V₆-V₇ crop growth stage, Furadan 3G (Carbofuran) was applied in the whorls against borers.

discharge rate of 4 liters hour⁻¹ while pressure at the end of each lateral was measured as 1.0 bar.

Table 2: Detail of irrigation schedule under different soil moisture depletion

	15% MAD	30% MAD	45% MAD	60% MAD
Autumn season				
No. of irrigation events	20	10	7	5
Days after planting at treatment implementation	5	8	12	16
Days after planting at last irrigation event	107	96	105	96
Total irrigation applied (mm)	541	521	538	521
Total operational time (minutes)	1259	1199	1257	1224
Average time between irrigation events during vegetative period (days)	4.3	7.85	12	15.7
Average time between irrigations during reproductive period (days)	8.4	13.66	22.5	24.5
Spring season				
No. of irrigation events	30	16	11	09
Days after planting at treatment implementation	8	14	20	26
Days after planting at last irrigation event	109	104	102	108
Total irrigation applied (mm)	720	688	675	714
Total operational time (minutes)	1667	1593	1563	1653
Average time between irrigation events during vegetative period (days)	4.41	7.66	8.8	14.5
Average time between irrigations during reproductive period (days)	3	5.5	7.6	10.6

Table 3: Detail of fertigation schedule during the growth of crop

Growth Stage	Nutrients kg acre ⁻¹ day ⁻¹			Fertilizer kg acre ⁻¹ season ⁻¹		
	N	P ₂ O ₅	K ₂ O	Urea	MAP	SoP
Vegetative Phase	0.717	0.550	0.317	52.973	36.066	25.385
Flowering Phase	1.076	0.550	0.635	42.082	18.033	25.385
Ear Development Phase	0.717	0.000	1.269	46.786	0.000	76.154
Grain Development Phase	0.359	0.000	0.635	23.393	0.000	38.077

MAP= mono-ammonium phosphate, SoP= sulphate of potash

Drip irrigation system consisted of a cemented ditch (4 m × 2 m with 2 m depth) from where water was supplied by a pump to the main line (59.8 mm diameter). Sub-main line was of 37 mm diameter with which laterals (16 mm diameter with 40 cm dripper spacing) were attached. Each drip lateral was connected to subsurface (45cm deep) sub-main line with an above ground valve. This joint was also fitted with backflow preventer, pressure regulator, filter and tubing adapter. Distal end of the tube was crimped over and tied. One drip lateral was placed on the center of 1.05 cm spaced bed-top in a 3-5 cm deep groove carved by a man driven device to minimize tube displacement and facilitate water absorption in the soil by avoiding possible water overflow. Water was supplied with 2.5 to 3.0 bar pressure with a

Time of the harvest was determined by appearance of black layer at the kernel tip. At harvest 3.15 m × 4 m area was hand harvested then ears were separated from stovers. Number of ears was counted to calculate ears m⁻². Later on ears were shelled and weighed. Grain moisture was determined by Agratonic™ MT-16 grain moisture tester; subsequently grain yield was expressed at 15% grain moisture. Ten random ears were selected from each experimental unit to determine the ear length with the help of scale, number of rows per ear, number of grains per row and 1000-grain weight (grain weight hereafter). Grain starch%, oil% and protein% were determined by 'Inframatic 9200', a whole grain near infra-red (NIR) analyzer.



CROPWAT model is being extensively used in agriculture for irrigation scheduling all over the world and has been proved a reliable tool (George, 2000; Zheng *et al.*, 2012). It was developed by United Nation's Food and Agriculture Organization (FAO) and it calculates evapotranspiration and water requirements of crops (FAO, 2009). CROPWAT calculates crop water and irrigation requirements with inputs of climatic, crop and soil data. CROPWAT model uses Penmann-Monteith formula to estimate ET_0 which provides relatively better calculations under arid and semiarid conditions (Allen *et al.*, 1998). The ET_0 was calculated for every 10-day time step (denoted as 'decade' by FAO). To calculate actual crop evapotranspiration model uses the following equation:

$$ET_c = K_c \times ET_0$$

Where ET_c is the actual crop evapotranspiration, ET_0 is the reference evapotranspiration while K_c is the crop coefficient.

Effective rainfall during was calculated by the formula below as suggested by soil conservation method of USDA;

$$P_{eff} = \left(P \times \frac{125 - 0.2 \times P}{125} \right); P \leq 250 \text{ mm}$$

$$P_{eff} = 125 + 0.1 \times P; P \geq 250 \text{ mm}$$

Where P_{eff} is the effective rainfall and P is the total rainfall.

The net irrigation requirement (IR_n) of the crop was based on the difference between the crop evapotranspiration requirements and the effective rainfall.

$$IR_n = ET_c - P_{eff}$$

Gross irrigation requirement (IR_g) was calculated by encompassing the irrigation system efficiency 'E' (90% for drip irrigation system) (FAO, 2002).

$$IR_g = \frac{IR_n}{E}$$

Irrigation frequency (IF) corresponding to each predefined MAD was determined by the following method (Savva and Frenken, 2002);

$$IF = \frac{SM_a \times MAD \times D}{ET_c}$$

Where SM_a is the available soil moisture in mm (field capacity-permanent wilting point), MAD is maximum allowable depletion of soil moisture (decimal), D is the

effective root zone depth (m) and ET_c is daily evapotranspiration (mm day^{-1})

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) was calculated to assess the yield response to irrigation treatments through entire growing season and yield produced per unit of water consumed, respectively:

$$IWUE = \frac{\text{Economic Yield}}{IW}$$

$$WUE = \frac{\text{Economic Yield}}{ET_c}$$

Loss and gain of phenotypic expression was assessed to estimate the effect of progressive soil moisture depletion on ear characteristics, yield parameters and grain quality.

Data recorded was subject to analysis of variance performed through SAS software (Version 9.1; SAS Institute, Cary, NC). Means with significant F-test were separated by least significant different (LSD) test at probability $p < 0.05$. Correlation analysis was performed to evaluate the relation between different parameters. Boxplots were constructed to assess variation in parameters in autumn and spring season.

Results and Discussion

In this experiment total water applied across the MAD levels was 501mm, 557 mm, 751 mm and 695 mm in autumn 2017, autumn 2018, spring 2018 and spring 2019, respectively. Spring season has higher evaporation demands owing to characteristic temperature regime in the season (Figure 1). In spring, crop is sown during low temperature months that gradually increases up to >40 towards maturity while in autumn sowing is done during hot months and temperature gradually decreases towards maturity (Figure 1). In spring, crop took on an average 12 days more to reach physiological maturity. A lower temperature during early plant growth stages (seedling and knee-height) causes late maturing of the maize crop that increases total water requirement (Sah *et al.*, 2020). Total numbers of irrigation events were 20, 10, 7 and 5 in autumn season while 30, 16, 11 and 9 in spring season for 15, 30, 45 and 60% MAD, respectively (Table 2).

Season impact on ear length was significant ($p < 0.05$) (Table 4). Ears were 8.6% shorter in spring season than autumn. Mokhtarpour *et al.* (2011) have also reported significant variation in ear length in two different seasons and attributed largely to difference in temperature that is also true for this study. In both seasons, ear length decreased significantly ($p < 0.05$) as the MAD increased from D_{15} to D_{60}



with average variation ranged from 6% and 9.5% among treatments in autumn and spring, respectively. Generally decrease in ear length was not significant among D₁₅ and D₃₀. Shortest ears were obtained at D₆₀. Mi *et al.* (2018) have reported significant reduction in ear length under moisture stress progressively applied at different growth stages of maize. Panda *et al.* (2004) have also previously reported that

spring compared to autumn that may be attributed to different growing conditions in both seasons. In autumn season, crop went through early growth phase in high temperature and according to Strachan (2016) any environmental around V₇ growth stage reduces the grain rows ear⁻¹.

Effect of season and MAD level on average number of grains per row was significant in all study years (Table 5).

Table 4: Effect of different soil moisture depletion levels on ear length and number of grain rows per ear of maize under drip irrigation in autumn and spring season

Treatment (MAD %)	Ear length (cm)				Grain Rows per Ear			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
15	17.4 a	17.2 a	16.7 a	15.8 a	17.4	16.4	18.9 a	18.7
30	17.4 a	17.0 ab	16.45 a	15.5 a	17.1	17.0	18.3ab	19.0
45	17.2 ab	16.7 b	15.5 b	15.1 ab	17.1	16.8	17.9 bc	19.2
60	16.9 b	15.9 c	14.6 c	14.3 b	17.0	16.3	17.5 c	18
<i>p</i> -Value _{0.05}	0.0139	0.0006	0.005	0.042	0.447	0.371	0.0082	0.7301
LSD _{0.05}	0.3249	0.47	0.7379	1.232	ns	Ns	0.6953	Ns
Season mean	17.0 A		15.5 B		16.9 B		18.4 A	
LSD _{0.05} for Season	0.44				0.33			

Means not followed by the same letter within a column are significantly different

Table 5: Effect of different soil moisture depletion levels on number of grains per row and 1000-grain weight ear length and number of grain rows per ear of maize under drip irrigation in autumn and spring season

Treatment (MAD %)	Grains per Row				1000-Grain Weight (g)			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2017	2018	2018	2019	2018	2019
15	33.5 a	37.1 a	29.3 a	30.2 a	251 a	284 a	282 ab	275 a
30	33.3 a	37.4a	27.1 b	30.0 a	250 a	280 a	288 a	282 a
45	33.1 a	37.7a	27.2 b	30.8 a	244 ab	275 a	278 b	281 a
60	31.1 b	34.5 b	24.8 c	26.4b	241 b	257 b	265 c	248 b
<i>p</i> -Value _{0.05}	0.0179	0.0187	0.0002	0.0262	0.0450	0.0012	0.0031	<.0001
LSD _{0.05}	1.481	1.98	1.298	2.85	7.29	10.373	13.35	8.7
Season mean	34.7 A		28.3 B		260.31 B		274.66 A	
LSD _{0.05} Season	2.04				3.23			

Means not followed by the same letter within a column are significantly different

soil moisture depletion beyond 45% significantly limited the water extraction by roots in maize that affected yield and yield parameters.

Number of grain rows per ear generally decreased with increase in soil moisture deficit but the effect was significant only once in four study instances (Table 4). According to Yue *et al.* (2018) number of grain rows per ear is more drought tolerant trait compared to other ear characters i.e., grain weight and number of grains. Moser *et al.* (2006) has also reported decreased number of grain rows in maize under pre-anthesis drought stress. However, season effect was significant ($p < 0.05$) with 9% more grain rows per ear in

Statistically, 28% higher number of grains were recorded in autumn than in spring ($p < 0.05$). Results are in-consistent with Mokhtarpour *et al.* (2011) who reported lower number of grains per ear under higher temperature. In 3 out of 4 study instances, number of grains remained stable up to D₄₅ moisture depletion and decreased significantly at D₆₀. On an average, number of grains decreased by 8% in autumn and 15% in spring from D₁₅ to D₆₀. Similarly, Moser *et al.* (2006) recorded decrease in number of grains per unit area in maize when crop was subjected to pre-anthesis drought stress. In spring 15 g heavier grains were obtained compared to autumn and difference was significant ($p < 0.05$) (Table 5). In both years of autumn and spring-2019 grain weight remained



consistent among D₁₅, D₃₀ and D₄₅ moisture depletion and decreased thereafter. Similar trends have previously been stated by Nabizadeh *et al.* (2012) while studying the effect of 20% and 40% moisture deficit on number of grains and grain weight of maize. Moser *et al.* (2006) also described adverse effect of drought stress on grain weight and argued that under stress conditions plants were unable to meet the demand of

row⁻¹ may be obtained under certain level of soil moisture stress in both seasons.

Number of ears ha⁻¹ varied among growing seasons ($p < 0.05$) that were 25% higher in spring compared to autumn and may largely be attributed to higher seeding density in spring that was 86,000 plants ha⁻¹ compared to 74,000 plant

Table 6: Effect of different soil moisture depletion levels on number of ears ha⁻¹ and fresh ear weight of maize under drip irrigation in autumn and spring season

Treatment (MAD %)	Ears per ha				Fresh Ear Weight (kg ha ⁻¹)			
	Autumn		Spring		Autumn		Spring	
	2017	2018	2018	2019	2017	2018	2018	2019
15	68690 a	72421 a	93750 a	96000 a	14600 a	16961 a	18182 a	19465 a
30	67250 a	71230 ab	92250 a	94750 a	14446 a	16965 a	16257 b	19167 a
45	66548 a	70833 ab	91750 a	90000 b	13976 a	16405 a	14689 c	16885 b
60	62024 b	67064 b	86250 b	84250 c	12906 b	13891 b	11999 d	12599 c
<i>p</i> -Value _{0.05}	0.0008	0.0866	0.0003	0.0003	0.0007	<.0001	<.0001	<.0001
LSD _{0.05}	2396	4264.8	2355	3845	629	744	986	1322
Season mean	68257 B		91125 A		15019 B		16155 A	
LSD _{0.05} Season	2105				528			

Means not followed by the same letter within a column are significantly different

Table 7: Effect of different soil moisture depletion levels on grain yield of drip-irrigated maize in autumn and spring

Treatment (MAD %)	Grain Yield (kg ha ⁻¹)			
	Autumn		Spring	
	2017	2018	2018	2019
15	10323 a	12111 a	12200 a	14203 a
30	10316 a	11996 a	11002 ab	13987 a
45	9987 a	11724 a	9822 b	12462 b
60	9189 b	9855 b	8054 c	9165 c
<i>p</i> -Value _{0.05}	0.0093	<.0001	<.0001	<.0001
LSD _{0.05}	636.90	633	1230	1013.6
Season mean	10688 B		11362 A	
LSD _{0.05} for Season	201			

Means not followed by the same letter within a column are significantly

the growing grains. According to Moser *et al.* (2006), lower number of grains due to pre-anthesis moisture stress was compensated for by heavier grains but in our study this was not the case and the contradiction might have been the result of the fact that in our study plants remained under constant pre-irrigation stress throughout the growing season. In maize phenotypic expressions like ear length, grain weight, number of grains, grain rows etc. are significantly altered after a certain level of water deficit stress (Sah *et al.*, 2020). Therefore irrigation management strategy that maximizes the number of grains is the key to optimize yield in maize (Mi *et al.*, 2018). This study shows that optimum number of grains

ha⁻¹ in autumn. Increase in moisture depletion from D₁₅ to D₆₀ decreased ($p < 0.05$) the number of fresh ear ha⁻¹ in all the growing instances (Table 6). Moser *et al.* (2006) has also reported lower number of ears in maize when moisture stress was imposed on plants at certain growth stage.

Seasonal effect on fresh ear weight (kg ha⁻¹) and grain yield (kg ha⁻¹) was significant with 7.5% and 6.3% more fresh ear weight and grain yield in spring than in autumn, respectively (Table 6 and 7). Variation in fresh ear weight among the treatments in autumn was 4059 kg ha⁻¹ and 2922 kg ha⁻¹ compared to 7466 kg ha⁻¹ and 6149 kg ha⁻¹ in spring that depicts more critical role of soil moisture stress in spring



than autumn owing to higher temperature towards pollination and grain filling period. In autumn grain yield remained stable between D₁₅, D₃₀ and D₄₅ soil moisture depletion and

decreased significantly at D₆₀. In spring grain yield significantly decreased when soil moisture was allowed to decrease beyond 30%. This implies that in autumn season

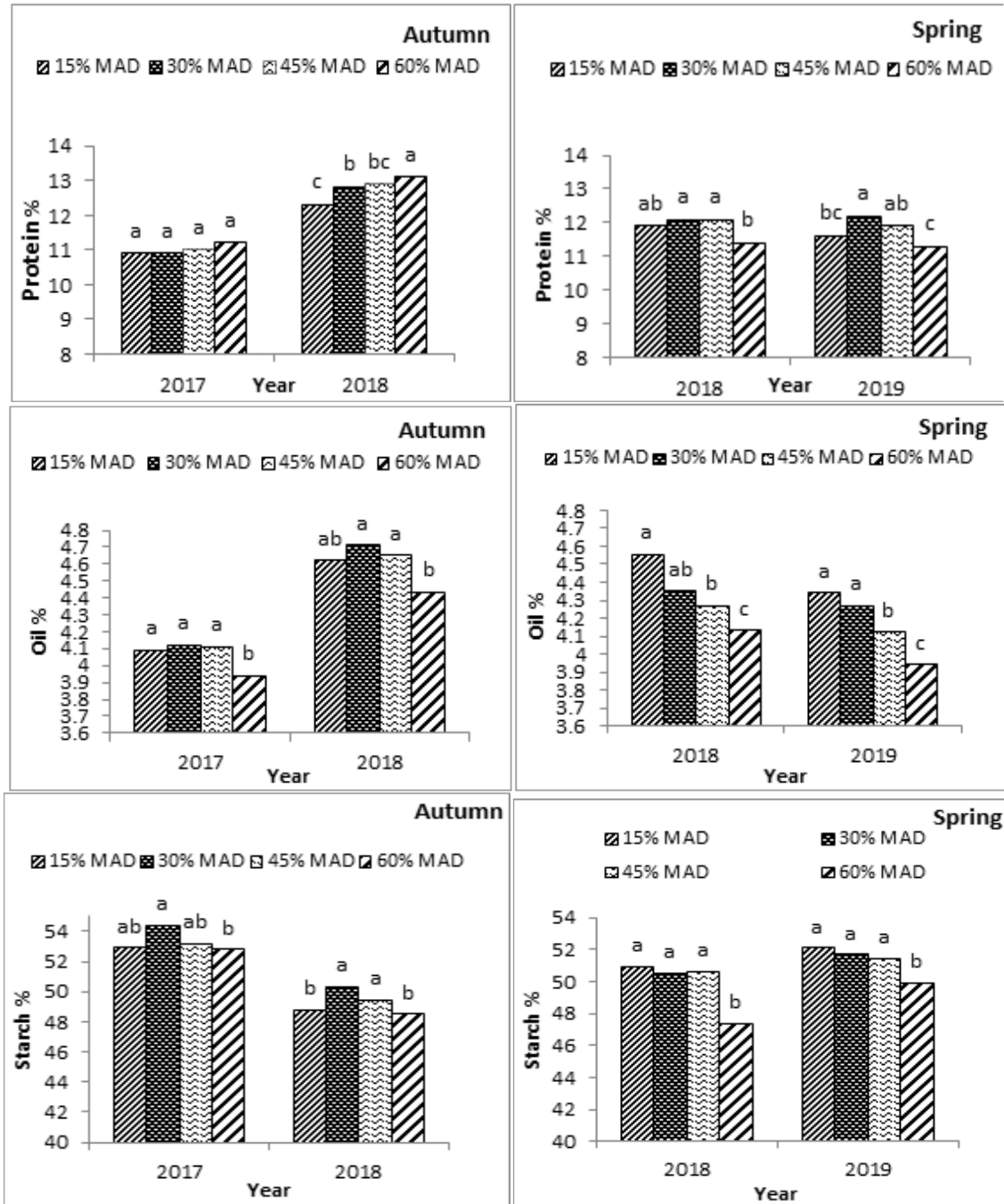


Figure 2: Grain protein %, starch % and oil % of maize in response to different soil moisture depletion levels under drip irrigation in autumn and spring season



plant roots did not face substantial difficulty in extracting soil moisture up to 45% soil moisture depletion to meet crop evapotranspiration demand of the crop under prevailing climatic conditions while in spring season, this critical limit was 30% soil moisture depletion. The seasonal significant variation in crop response to soil moisture depletion in terms of grain yield is attributed to the fact that in spring, grain development occurred in higher temperature compared to autumn season. Panda *et al.* (2004) while studying different irrigation strategies in maize based on different MAD levels stated that grain yield decrease was marginal between 10-45% MAD levels however yield decrease was substantial when soil moisture depleted beyond 45%. Wang *et al.* (2019) reported that soil moisture stress substantially decreased the net photosynthetic rate and supply capacity of ear leaf that largely contributes to the developing ear and grains. Oktem *et al.* (2003) while studying the effect of irrigation schedule based on 4, 6 and 8 days irrigation frequency on sweet corn has also reported decreased yield with increased water stress. They also reported that high temperature caused the closure of stomata under moisture stress resulting in lower CO₂ uptake for assimilation. Several other researchers have reported the significant yield loss of maize due to drought stress ranging from 30% to 90% depending on stage and duration of stress (Moser *et al.*, 2006; Ge *et al.*, 2012; Ertek and Kara, 2013; Wang *et al.*, 2019; Sah *et al.*, 2020).

Effect of the season on grain starch % and protein % was significant ($p < 0.05$) while oil % remained stable ($p > 0.05$)

between seasons (Figure. 3). Higher starch % and protein % and oil% (non-significantly) were obtained in autumn season. In spring season, higher temperature prevailed during grain filling phase that limits the activity of starch synthase resulting in decreased starch concentration in grain (Yang *et al.*, 2018). In contrast to our study, previous studies (Wang and Frei, 2011; Yang *et al.*, 2018) have reported increased maize grain protein contents under high temperature and they mainly attribute this to the concentration effect. This contradiction might have arisen due to different temperature ranges to which plants were exposed and variation in crop management practices like nutrient management, irrigation approaches and planting densities, time of the maize exposure to heat stress etc. that might have diluted the concentration effect.

Treatment effect on studied quality parameters was also significant (Figure 2). In autumn season, starch% was high, during both the years, at D₃₀ that was not different from that recorded at D₄. However minimum was obtained at D₆₀. Ertek and Kara (2013) also recorded higher sugar contents in sweet corn at 30% deficit irrigation that decreased in higher and lower irrigation water treatments. In spring season, starch% was statistically not different among D₁₅, D₃₀ and D₄₅ soil moisture depletion while decreased significantly at D₆₀. Generally, oil contents decreased with decrease in soil moisture depletion however remained stable ($p > 0.05$) up to 45% soil moisture depletion in autumn 2017 and 2018 and spring 2019 while during spring-2019 oil contents decreased significantly at D₄₅ soil moisture depletion. Results are

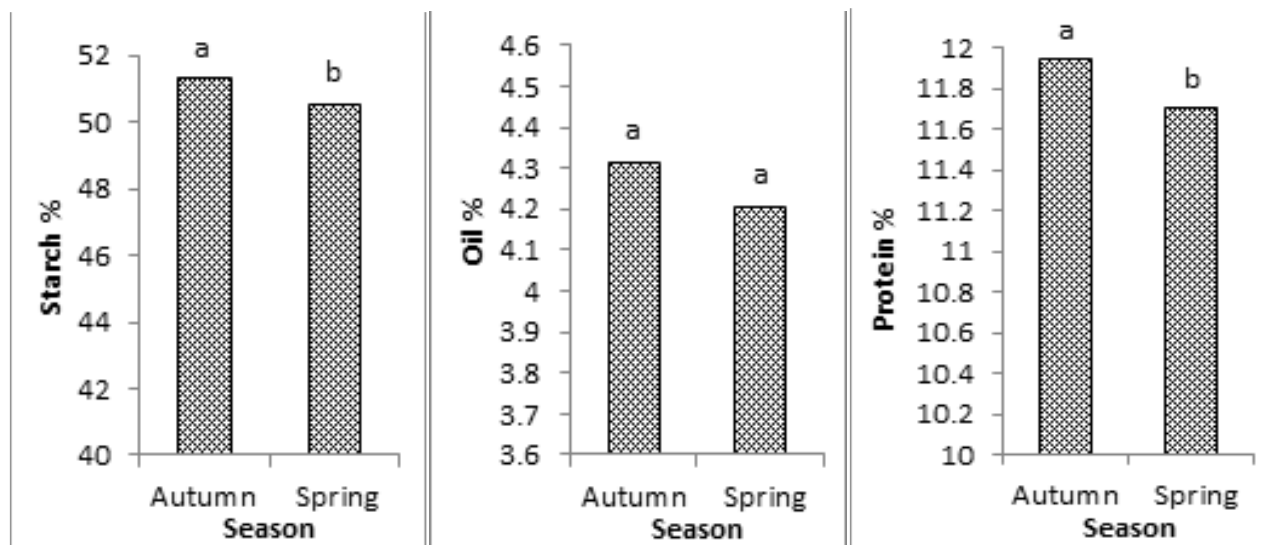


Figure 3: Grain protein %, starch % and oil % of drip-maize in autumn and spring growing season in response to different soil moisture depletion levels

similar to that those recorded by Harrigan *et al.* (2007). In our study, seasonal effect on oil% was not significant however protein contents increased with increase in soil moisture depletion with maximum protein% at D₆₀. Similar results have been reported by Oktem (2008) while studying the effect of water shortage on sweet corn. According to Wang and Frei (2011), effect of abiotic stresses on DM accumulation in grains is greater as compared to that on total N contents resulting in greater protein contents in abiotic stress condition. However in spring season, greatest protein % was obtained at 30% soil moisture depletion level while 60% MAD recorded the lowest grain protein%. Ertek and Kara (2013) have also recorded lower protein contents at treatments with highest and lowest soil moisture levels.

Significant correlation existed between many studied parameters (Table 8). Type of the correlation between parameters was similar in both the seasons but extent varied. Stark variation was also observed in type of correlation between the seasons. For instance, in autumn, protein % and starch % in grain correlated negatively with all other parameters however, in spring they correlated positively to almost all other parameters. This inconsistent response might have been arisen from the fact that autumn crop faced higher temperature stress during vegetative phase while in spring high temperature prevailed during grain formation and maturation phase. Similarly Wang and Frei (2011) have reported that timing of the abiotic stress determines the response of protein concentration in grains. In autumn season, grain yield correlated strongly with ear length, grains

Table 8: Correlation between various parameters under different soil moisture depletion levels under drip irrigation in autumn and spring season

Parameter	Ear length	Rows per ear	Grains per row	Grain weight	Ears ha ⁻¹	Fresh Ear weight	Protein	starch	Oil
Autumn Season									
Rows per ear	0.7540								
Grains per row	0.9044*	0.8838							
Grain Weight	0.9972*	0.7450	0.8766						
Ears ha ⁻¹	0.9896*	0.7508	0.9396 *	0.9761 *					
Fresh Ear Weight	0.9863*	0.8480	0.9541*	0.9785*	0.9836*				
Protein	-0.932*	-0.4664	-0.7434	-0.9305*	-0.9253*	-0.8639			
Starch	-0.6336	-0.0326	-0.4752	-0.6111	-0.6758	-0.5341	0.8485		
Oil	0.8292	0.9360*	0.9834*	0.7999	0.8667	0.9064	-0.6138	-0.3159	
Yield	0.9732*	0.8812	0.9641*	0.9643*	0.9719*	0.9977*	-0.828*	-0.4833	0.9283*
Spring Season									
Rows per ear	0.9486*								
Grains per row	0.8717	0.9733*							
Grain Weight	0.8493	0.9390*	0.8836						
Ears per ha	0.9913*	0.9819*	0.9255*	0.8959					
Fresh Ear Weight	0.9961*	0.9712*	0.9116*	0.8718	0.9985*				
Protein	0.6972	0.8254	0.7672	0.9680*	0.7570	0.7231			
Starch	0.9041*	0.9860*	0.9538*	0.9816*	0.9489*	0.9304*	0.9073		
Oil	0.2544	-0.0528	-0.2515	-0.0899	0.1290	0.1680	-0.1714	-0.116	
Yield	0.9951*	0.9749*	0.9148*	0.8820	0.9994*	0.9998*	0.7376	0.9374*	0.1587



per row, grain weight, ears per ha and oil % in grain. In spring season, grain yield significantly correlated with ear length, grains per row, ears per ha and starch % but grain weight did not correlate significantly.

Seasonal Variation of Parameters

Variation in parameters in response to different soil moisture depletions in autumn and spring (two years average) is depicted. Boxplots highlight the average distribution of data around mean for attributes. On an average, parameters were significantly affected by growing season and distribution of data regarding studied parameters varied differently in both seasons. Two studied seasons differed in temperature during different crop growth period that affected

for ear development and ear characteristics especially ear length and grains row⁻¹ (Yang *et al.*, 2018; Coelho *et al.*, 2022). Mokhtarpour *et al.* (2011) have also reported similar trend and were of the view that temperature was the main difference that caused the variation in yield and yield parameters in two growing seasons in spite of the fact that there was no irrigation and nutrient stress between the seasons.

Variation in studied traits was recorded in response to different soil moisture depletion treatments (Table 8). Though most of the traits did not vary significantly between D₁₅-D₃₀ soil moisture depletion however some traits were statistically similar up to D₄₅. The effect of progressive moisture stress on ear characteristics, yield and quality of

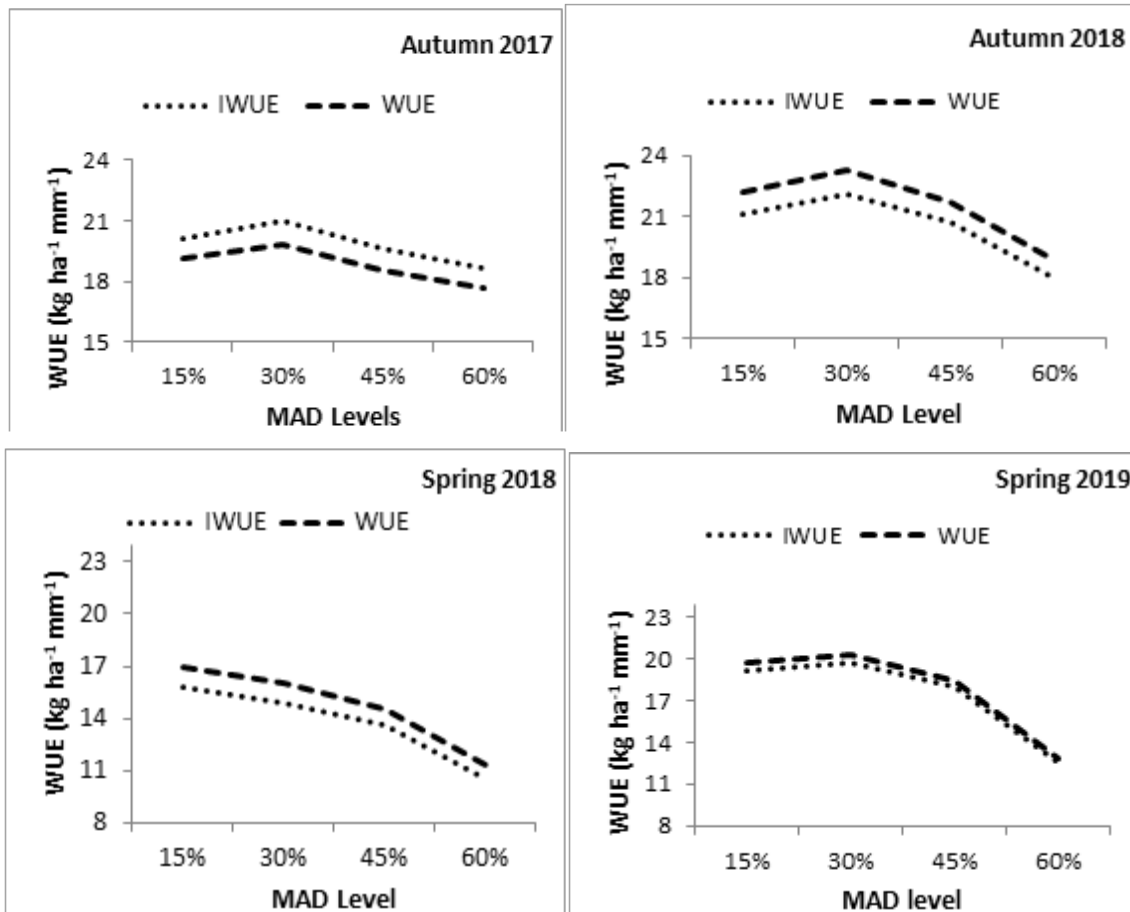


Figure 5: IWUE and WUE of maize under different moisture depletion levels in autumn and spring season under loam soil

the yield and yield parameters differently. Ear development in spring season took place under high temperature that adversely affected the plant ability to uptake and use nutrient

grain was more prominent in spring season compared to autumn season. According to the extent of variation in response to different soil moisture depletion in spring season,



characters are ordered: grain yield (34.8%)>fresh ear weight (34.6%)>grains per row (15.2)>ear length (11.1%)>ears per ha (10.2%)>oil% (10.1%)>grain weight (10%)>rows per ear (6.7%)>protein % (6.6%)>starch% (5.5%). While in autumn the recorded order is: fresh ear weight (16.9%)>grain yield (14.8%)>ear per ha (8.6)>grains per row (8%)>grain weight (6.75%)>oil% (5.6%)>ear length (5.25%)>protein (4.4%)>starch (3.3%)>rows per ear. Yue *et al.* (2018) while evaluating the response of different varieties to the drought stress in Hebei province, China reported that yield parameters were most sensitive to the drought compared to other agronomic traits. They also stated that increased moisture stress decreased the DM production and accumulation that have different effects on different parts of plants in maize. Results are also in line with Mi *et al.* (2018) who concluded that less number of grains per ear is the main reason of lower yield under moisture deficit conditions. Severity of the effect of increasing soil moisture depletion on studied parameters substantially differed among seasons however the expressions that were affected the most in both the season were grains per row and ear length.

IWUE and WUE

Values of IWUE and WUE values on grain yield basis in response to different MAD levels are presented in Figure-5. Crop water requirement was greater for spring maize than autumn maize. On average, K_c values ranged from 521 mm to 541 mm among treatments in autumn season while for spring it varied between 675 mm to 720 mm. This variation was due to different climatic conditions during both seasons. More rain was received in autumn-2017 (79 mm) and spring-2019 (54 mm) that lowered the gross irrigation compared to autumn-2018 (29 mm) and spring-2018 (23 mm). Across the years, in autumn IWUE and WUE ranged from 22.1 to 18.0 $\text{kg ha}^{-1} \text{mm}^{-1}$ and 23.3 to 17.7 $\text{kg ha}^{-1} \text{mm}^{-1}$, respectively, while in spring IWUE and WUE ranged from 19.8 to 10.5 $\text{kg ha}^{-1} \text{mm}^{-1}$ and 20.3 to 11.3 $\text{kg ha}^{-1} \text{mm}^{-1}$, respectively. Steeper decrease in IWUE and WUE were observed when soil moisture was decreased from 45% to 60%. Panda *et al.* (2004) have also reported significant decrease in field water use efficiency in maize after 45% soil moisture depletion and narrated that after 45% soil moisture depletion roots found it difficult to extract water from soil to meet crop demand. Oktem *et al.* (2003) studied 2, 4, 6, and 8 days irrigation frequency effect (100, 90, 80 and 70% of evaporation, respectively) on sweet corn and reported that IWUE and total WUE decreased substantially when crop was irrigated after 8 days interval. Average across the years, variation among treatments (for each incremental decrease from D_{15} to D_{60}) for IWUE and WUE

was 3.2 and 3.3 $\text{kg ha}^{-1} \text{mm}^{-1}$ for autumn-2017 and autumn-2018 while in spring-2018 and spring-2019 it varied by 6.3 and 6.5 $\text{kg ha}^{-1} \text{mm}^{-1}$, respectively. Greater variation in IWUE and WUE in spring may be attributed largely to prevalence of higher temperatures during grain filling stage in spring. Payero *et al.* (2008) also found that relationship between irrigation and yield varies among seasons and locations. WUE and IWUE are general terms having different interpretation with changing objectives. In our study the objective was to assess the impact of different depletion level prior to irrigation while total applied water (K_c) was constant across the treatment so decrease in IWUE and WUE was expected with increased soil moisture depletion. Irrigation management of maize is the function of finding combination of water use efficiencies and maximum profitability. We expect that farmers' decision on the irrigation management of maize in irrigated maize growing areas of Punjab will largely be based on easiness of the management of drip irrigation system (how frequent farmer has to irrigate based on depletion level), maximum grain yield and profitability rather than maximum water use efficiencies. This study provides a valuable guideline for the farmers regarding irrigation strategy as in autumn season farmers may irrigate the maize crop after 12 days (45% soil moisture depletion) while in spring season irrigation interval should not exceed 5-6 days (30% soil moisture depletion) to achieve higher grain yield with improved WUE and IWUE.

Conclusions

Ear characteristic and yield attributes responded significantly to the treatments but their extent of variation was different in autumn and spring season. In both seasons, most of the studied parameter decreased significantly when soil moisture was depleted beyond 30-45%. However, extent of variation in studied parameters was steeper in spring than in autumn suggesting that higher soil moisture contents are needed in spring season to meet the higher evapotranspiration demands of crop. During both the seasons, parameters that were affected the most by increasing moisture deficit were grain yield, fresh ear weight and number of grains per row. IWUE and WUE decreased as MAD level increased from 15% (minimum soil moisture stress) to 60% (maximum soil moisture stress) however with greater rate after 45% depletion. Under local climatic conditions, irrigating the maize crop beyond 45% soil moisture depletion in autumn and 30% soil moisture depletion in spring will significantly decrease the maize yield and quality.

References



- Aguilar, M., F. Borjas and M. Espinosa. 2007. Agronomic response of maize to limited levels of water under furrow irrigation in southern Spain. *Spanish Journal of Agricultural Research* 5: 587-592.
- Allen, R. G., L. S. Pereira, D. Raes and M. Smith. 1998. FAO Irrigation and Drainage Paper No. 56; Food and Agriculture Organization of the United Nations, Rome, Italy.
- Coelho, A.E., L. Sangoi, A.A. Balbinot, H.F. Kuneski and M.C. Martins. 2022. Nitrogen use efficiency and grain yield of corn hybrids as affected by nitrogen rates and sowing dates in subtropical environment. *Revista Brasileira de Ciencia do Solo* 45: e0210087.
- Ertek A. and B. Kara. 2013. Yield and quality of sweet corn under deficit irrigation. *Agricultural Water Management* 129: 138-144.
- FAO. 2009. Land and Water Development Division of Food and Agriculture Organization (LWD-FAO). Available online: <http://www.fao.org/land-water/databases-and-software/cropwat/en/>.
- Ge, T., F. Sui, L. Bai, C. Tong and N. Sun. 2012. Effects of water stress on growth, biomass partitioning, and water-use efficiency in summer maize (*Zea mays* L.) throughout the growth cycle. *Acta Physiologiae Plantarum* 34: 1043-1053.
- George, B., S. Shende and N. Raghuvanshi. 2000. Development and testing of an irrigation scheduling model. *Agricultural Water Management* 46: 121-136.
- Gheysari, M., S.H. Sadeghi, H.W. Loescherc, S. Amiri, M.J. Zareian, M.M. Majidi, P. Asgarinia and J.O. Payero. 2017. Comparison of deficit irrigation management strategies on root, plant growth and biomass productivity of silage maize. *Agricultural Water Management* 182: 126-138.
- GoP. 2020. Economic Survey of Pakistan. Ministry of Finance, Economic Advisor's Wing, Islamabad.
- Greaves, G.E. and Y.M. Wang. 2017. Effect of regulated deficit irrigation scheduling on water use of corn in southern Taiwan tropical environment. *Agricultural Water Management* 188: 115-125.
- Harrigan, G.G., L.G. Stork, S.G. Riordan, W.P. Ridley, S. MacIsaac, S.C. Halls, R. Orth, D. Rau, R.G. Smith, L. Wen, W.E. Brown, R. Riley, D. Sun, S. Modiano, T. Pester, A. Lund and D. Nelson. 2007. Metabolite analyses of grain from maize hybrids grown in the United States under drought and watered conditions during the 2002 field season. *Journal of Agricultural and Food Chemistry* 55:6169-6176.
- Ko, J. and G. Piccinni. 2009. Corn yield responses under crop evapotranspiration-based irrigation management. *Agricultural Water Management* 96: 799-808.
- Levidow, L., D. Zaccariab, R. Maiac, E. Vivasc, M. Todorovicd and A. Scardigno. 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. *Agricultural Water Management* 146: 84-94.
- Li, J., J. Zhang and L. Ren. 2003. Water and nitrogen distribution as affected by fertigation of ammonium nitrate from a point source. *Irrigation Science* 22:19-30.
- Maqbool, N. 2022. Water crisis in Pakistan: Manifestation, causes and the way forward. Knowledge Brief No. 60. Pakistan Institute of Development Economics, Islamabad, Pakistan.
- Mi, N., F. Cai, Y. Zhang, R. Ji, S. Zhang and Y. Wang. 2018. Differential responses of maize yield to drought at vegetative and reproductive stages. *Plant, Soil and Environment* 64:260-267.
- Michael, A.M. 2009. Irrigation Theory and Practice. 2nd Edition. Vikas Publishing House PVT Ltd. New Delhi. India.
- Mokhtarpour, H., C. Teh, G. Saleh, A. Selamat, M.E. Asadi and B. Kamkar. 2011. Corn yield response to crowding stress and cropping season. *Archives of Agronomy and Soil Science* 57: 853-871.
- Moser, S.B., B. Feil, S. Jampatong and P. Stamp. 2006. Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. *Agricultural Water Management* 81: 41-58.
- Nabizadeh, E., M. Banifazel and E. Taherifard. 2012. The effects of plant growth promoting on some of traits in maize (cv. S.C.704) under drought stress condition. *European Journal of Experimental Biology* 2: 875-881.
- Oktem, A., M. Simsek and A.G. Oktem. 2003. Deficit irrigation effects on sweet corn (*Zea mays* saccharata Sturt) with drip irrigation system in a semi-arid region I. Water-yield relationship. *Agricultural Water Management* 61: 63-74.
- Oktem, A. 2008. Effect of water shortage on yield, and protein and mineral compositions of drip-irrigated sweet corn in sustainable agricultural systems. *Agricultural Water Management* 95: 1003-1010.
- Panda, R.K., S.K. Behera and P.S. Kashyap. 2004. Effective management of irrigation water for maize under stressed conditions. *Agricultural Water Management* 3:181-203.
- Patel, J.B., V.J. Patel and J.R. Patel. 2006. Influence of different methods of irrigation and nitrogen levels on crop growth rate and yield of maize (*Zea mays* L.). *Indian Journal of Crop Science* 1: 175-177.
- Payero, J.O., D.D. Tarkalson, S. Irmak, D. Davison and J.L. Petersen. 2009. Effect of timing of a deficit-irrigation allocation on corn evapotranspiration, yield, water use



- efficiency and dry mass. *Agricultural Water Management* 96: 1387-1397.
- Sah, R.P., M. Chakraborty, K. Prasad, M. Pandit, V.K. Tudu, M.K. Chakravarty, S.C. Narayan, M. Rana and D. Moharana. 2020. Impact of water deficit stress in maize: Phenology and yield components. *Scientific Reports* 10: 2944.
- Savva, A.P. and K. Frenken. 2002. Crop water requirements and irrigations scheduling. Irrigation Manual Module 4. Food and Agriculture Organization of United Nations, Sub-Regional Office for East and Southern Africa, Harare, 2002.
- Schwankl, L.J. and L.R. Hanson. Surface drip irrigation. 2007. p. 431-472. In: Micro-irrigation for Crop Production, Design, Operation, and Management. Lamm F.R., J.E. Ayars and F.S. Nakayama (eds). Vol. 13. Elsevier: Amsterdam, Netherlands.
- Shahid, A. 2016. Water Sector of Pakistan: A situational analysis. p. 2-10. In: Water Security in Pakistan, Issues and Challenges. M. Hassan (eds.). Development Advocate Pakistan. UNDP Pakistan, Islamabad.
- Singandhupe, R.B., G.G. S.N. Rao, N.G. Patil and P.S. Brahmanand. 2003. Fertigation studies and irrigation scheduling in drip irrigation system in tomato crop (*Lycopersicon esculentum* L.). *European Journal of Agronomy* 19:327-340.
- Strachan, S.D. 2016. Corn grain yield in relation to stress during ear development. *Crop Insight* Vol. 26(9). DuPont Pioneer, Johnston, IA.
- Tagar, A., F.A. Chandio, I.A. Mari and B. Wagan. 2012. Comparative study of drip and furrow irrigation methods at farmer's field in umarkot. *International Journal of Agricultural and Biosystem Engineering* 6: 788-792.
- Vories, E.D., P.L. Tacker, S.W. Lancaster and R.E. Glover. 2009. Sub surface drip irrigation of corn in the United States Mid-South. *Agricultural Water Management* 96:912-916.
- Wang, B., C. Liu, D. Zhang, C. He, J. Zhang and Z. Li. 2019. Effects of maize organ-specific drought stress response on yields from transcriptome analysis. *BMC Plant Biology* 19:335.
- Wang, Y. and M. Frei. 2011. Stressed food-The impact of abiotic environmental stresses on crop quality. *Agriculture Ecosystem and Environment* 141: 271-286.
- Yang H., X. Gu, M. Ding, W. Lu and D. Lu. 2018. Heat stress during grain filling affects activities of enzymes involved in grain protein and starch synthesis in waxy maize. *Scientific Reports* 8:15665
- Yue, H., S. Chen, J. Bu, J. Wei, H. Peng, Y. Li, C. Li and J. Xie. 2018. Response of main maize varieties to water stress and comprehensive evaluation in Hebei province. IOP Conf. Series: Earth and Environmental Science. 108: 042002.
- Zamora-Re, M.I., M.D. Dukes, D. Hensley, D. Rowland and W. Graham. 2020. The effect of irrigation strategies and nitrogen fertilizer rates on maize growth and grain yield. *Irrigation Science* 38:461-478.
- Zhang T., Y. Zou., I. Kisekka, A. Biswas and H. Cai. 2021. Comparison of different irrigation methods to synergistically improve maize's yield, water productivity and economic benefits in an arid irrigation area. *Agricultural Water Management* 243: 106497.
- Zheng, X., J.J. Zhu, Q.L. Yan and L. N. Song. 2012. Effects of land use changes on the groundwater table and the decline of *Pinus sylvestris* var. mongolica plantations in southern Horqin Sandy Land, Northeast China. *Agricultural Water Management* 109: 94-106.

