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Phenology and Yield of Spring Maize (*Zea mays* L.) under Different Drip Irrigation Regimes and Planting Methods

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ABSTRACT

Maize response to deficit water and planting methods was studied for assessing phenological development and yield under Punjab conditions. Experiment was planned with eleven (9+2) treatments; nine treatments were the combinations of three levels of Cumulative Pan Evaporation (CPE) i.e. Drip Irrigation (DI) to replenish 60, 80, and 100% of base (30 mm) CPE and three planting methods i.e. 1Row/Ridge, 1Row/Bed and 1Row (zigzag)/Bed. The additional two treatments i.e. flat and ridge sown, were kept as control. Each increase from DI_{60} to DI_{100} caused significant earliness in visibility of collar of the 8^{th} leaf, tasselling, and silking and significant delay in dough stage and physiological maturity. Irrigation water applied was linearly related to the duration of the reproductive phase and grain yield. Higher Dry Matter (DM) production and longer reproductive phase led to significantly higher grain yield under DI_{100}. All phenological stages were delayed under flat sown as compared to ridge sown control. Ridge sown was better than flat sown control with respect to DM and grain yield. Drip irrigation treatments showed advancement in tasselling and silking and significantly late physiological maturity with longer reproductive phase that resulted in significantly higher crop DM and grain yield as compared to the mean of the two control treatments. Crop phenology was affected by drip irrigation regimes and increase in drip irrigation regimes was linearly and positively related with length of reproductive phase. Thus, grain yield was also increased significantly. However, crop phenology and yield were not affected much by the planting methods used.

Keywords: Pan evaporation, Reproductive phase, Ridge planting, Silking, Tasselling.

INTRODUCTION

Water is an important natural resource and its increasing scarcity has led to concerns for its efficient use, management, and sustainability. At present, crop water requirements for the Punjab state are estimated to be 45.3 billion cubic meter, against the current availability of only 32.6 billion cubic meter, comprising 15.8 billion cubic meter of surface water and 12.7 billion cubic meter of groundwater resources (Minhas *et al.,* 2010). Thus, a deficit of about 1.27 M ha-m of water is of major concern. The extensive use of traditional irrigation systems has led to overexploitation of groundwater and overuse of surface water (Mohammadzadeh *et al.,* 2014). Average application efficiencies of different systems are: Surface (flood) irrigation, 60 to 90%; sprinkler irrigation, 65 to 90%; drip irrigation, 75 to 90% (Fairweather *et al.,* 2003). Modern methods of water application such as drip irrigation system come as the first choice for efficient utilization of water to sustain production, especially in wide row spaced crops like maize.

Maize is the third most important cereal crop after wheat and rice in terms of area and production and is grown throughout a wide range of climates. In Punjab, spring

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maize is becoming popular among the farmers especially in the fields vacated after early harvesting of potato, toria, peas, and sugarcane. In arid and semi-arid regions, the evapotranspiration rates from the spring maize field often exceed 10 mm day^{-1} for significant time periods (Howell *et al.*, 1995). Furthermore, maize is highly susceptible to water stress compared to other crops, especially at flowering and pollination stages because of its unusual floral structure with separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem. Its response to water stress varies according to different development stages (Cakir, 2004), like stress during the vegetative stage (any stress prior to 2 weeks before silking) can slow down the appearance of new leaves and delay crop maturity (Nielsen, 2002). Stress during reproductive stages causes early maturity and reduces yield (Traore *et al.,* 2000). Wopereis *et al.* (1996) and Winkel *et al.* (1997) also reported that water stress delays flowering (anthesis), accelerates flower/inflorescence growth, development and abortion. Water deficits stress may extend the interval from silking to pollen shed (Herrero and Johnson, 1981) and curtail the grain filling period (Westgate, 1994). Water deficit reduces the duration of grain filling period (Westgate, 1994). For instance, NeSmith and Ritchie (1992) reported that the reduction in maize yield even exceeded 90% due to the water deficit during flowering and pollination stages. Dagdelen *et al.* (2006) reported that water deficiency significantly affected corn yield and the highest corn yield was obtained from the full irrigation treatment. Viswanatha *et al.* (2002) stated that yield decreased with reduced irrigation water. So, there is need to study the frequency and amount of water supply through drip irrigation system to meet the water requirement of maize crop and its timely phenological development and higher grain yield.

Proper planting method can play a key role in soil moisture conservation, judicious use of water, good crop stand, better crop growth and yield as reported by several authors (Sharma, 1991; Ahmed *et al.,* 2002; Bakht *et al.,* 2006; Kumar, 2008; Mehta, 2009) under conventional irrigation methods (flood irrigation, furrow irrigation etc.). But there are comparatively few studies on planting methods under drip irrigation system. Also, the phenological response to planting methods was often ignored by the researchers. Keeping these considerations in view, the present study was planned. The hypothesis was that some particular drip irrigation regime and planting method may produce a higher grain yield without affecting crop phenology. Therefore, the experiment was conducted to determine the effect of drip irrigation regimes and planting methods on crop phenological stages development and its relationship with grain yield in spring maize.

MATERIALS AND METHODS

Experimental Site

Field experiment was conducted during 2011 and 2012 in spring season at Punjab Agricultural University, Ludhiana, (30° 54′ N and 75° 48′ E) with an altitude of 247 m above the mean sea level, located in the central plain region of Punjab under Trans-Gangetic agro-climatic zone of India. The meteorological data for the crop season (February to June) during both years was obtained from meteorological observatory of the Punjab Agricultural University and normal data averaged over the last 30 years (1981-2010) is summarised in Table 1. Soil of the experimental field was loamy sand with average bulk density of 1.59 g cm^{-3} and soil moisture storage of 41.27 and 10.99 cm at Field Capacity (FC) and Permanent Wilting Point (PWP), respectively, in 0-180 cm soil profile. The soil reaction and Electrical Conductivity (EC) were within normal range were determined by 1: 2 (soil: water) suspension method of Jackson (1967). The available N determined by

Table 1. Monthly meteorological data from February to June (30-year average).

Month	Mean air temperature (°C)		Mean relative humidity (%)		Rainfall (mm)		Evaporation (mm)	
	2011	2012	2011	2012	2011	2012	2011	2012
February	15.3	13.3	81	69	44.2	4.6	55.6	70.2
March	20.4	19.4	72	62	6.5	0.0	117.9	137.0
April	25.7	26.0	49	54	26.5	38.6	187.0	173.9
May	32.2	31.1	45	33	34.4	1.6	277.1	295.9
June	30.3	33.9	68	45	352.9	3.5	180.5	320.2

modified alkaline potassium permanganate method (Subbiah and Asija, 1956) was found low (157 kg ha^{-1}) and organic carbon determined by Walkley and Black's rapid titration method (Piper, 1966) was also found low (0.11%). While available P (14.6 kg ha^{-1}) and K (284.7 kg ha^{-1}) were in the medium range were determined by 0.5 N Sodium bicarbonate extractable P by Olsen's method (Olsen *et al.,* 1954) and ammonium acetate extractable K (Jackson, 1967), respectively.

Experimental Design and Treatments

Eleven (9+2) treatments were laid out in a randomized block design with three replications. Nine treatments (T_1 to T_9) were the combinations from three levels of Cumulative Pan Evaporation (CPE) i.e. replenishment of 60% (DI_{60}), 80% (DI_{80}) and 100% (DI_{100}) of base (30 mm) CPE through drip irrigation and three planting methods i.e. 1Row/Ridge, 1Row/Bed, and 1Row (zigzag)/Bed. The other two treatments (T_{10} and T_{11}) were kept as control and these were the combination of flat sowing and border method of irrigation at irrigation water(*IW)/CPE* ratio 1.0 (T_{10}) and ridge sowing and furrow irrigation at *IW/CPE* ratio 1.0 (T_{11}). The treatment details are given in Table 2.

Agronomic Practices

Planting was done on top of east-west laid ridges or beds or on flat surface depending on the treatment, on February 10 and 11 in 2011 and 2012, respectively. The row to row spacing under ridge and flat sowing was 60 cm, with plant spacing of 20 cm. Beds were laid at a spacing of 67.5 cm (37.5 cm bed and 30 cm furrow) and plants spacing was 17.8 cm in case of 1Row/Bed. In all these planting patterns the sown was undertaken by dibbling seed in straight line, while in case of 1Row (zigzag)/Bed seed was dibbled in a zigzag pattern (Figure 1). The plant population in all the treatments was maintained uniform. On the basis of soil test, Nitrogen (N), Phosphorus (P_2O_5), potassium (K_2O) and zinc sulfate heptahydrate (21%) were added to the soil at 156.3, 60, 30 and 25 kg ha^{-1}, respectively. Entire quantity of P,

Table 2. Detail of the experimental treatments.

S No	Treatment	S No	Treatment
T_1	DI_{60} + 1Row/Ridge	T_7	DI_{100} + 1Row/Ridge
T_2	DI_{60} + 1Row/Bed	T_8	DI_{100} + 1Row/Bed
T_3	DI_{60} + 1Row (zigzag)/Bed	T_9	DI_{100} + 1Row (zigzag)/Bed
T_4	DI_{80} + 1Row/Ridge	T_{10}	Control-I (Flat sown)*
T_5	DI_{80} + 1Row/Bed	T_{11}	Control-II (Ridge sown)**
T_6	DI_{80} + 1Row (zigzag)/Bed		

* 100% replenishment of *IW/CPE* ratio= 1.0 through border method of irrigation, taking depth of irrigation as 75 mm. ** 100% replenishment of *IW/CPE* ratio= 1.0 through furrow irrigation, taking depth of irrigation as 60 mm.

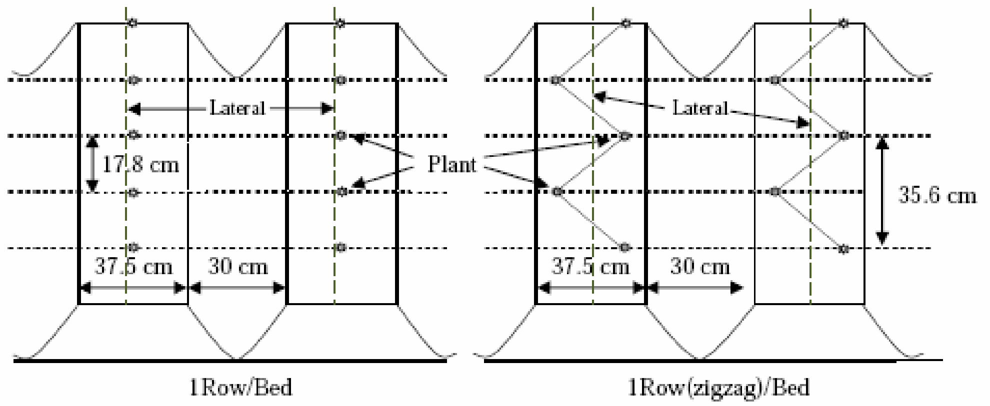

Figure 1. Layout of bed planting treatments.

K, and zinc sulfate with one third of N was applied at sowing and remaining N was applied in two equal splits i.e. at knee high and at pre-tasselling stages of crop growth. All the fertilizers were broadcasted before the field preparatory tillage. Detail of irrigation water applied to the different treatments is shown in Table 3. Crop was harvested manually on 12th June when more than 80 per cent of the cob husk turned yellowish brown and grains became hard.

Observations Recorded

Crop phenology studies were recorded as days taken from planting to the date of collar of the 8th leaf was visible, tasselling, silking, dough stage, and physiological maturity on 50% of plants in the plot. Duration of reproductive phase in days was recorded from silking to physiological maturity. Randomly selected plants were harvested from each plot and plants were dried in an oven at 60°C to a constant weight for recording dry matter accumulation which was then expressed as grams plant^{-1}.

All the cobs from net harvested plot were sun dried for three days and shelled. Moisture content of grains from each plot was determined. The grain yield was adjusted to 15% moisture level and expressed as kg ha^{-1}.

Statistical Analysis

Statistical analysis of the data recorded was done as per factorial experiment with additional treatments (Rangaswamy, 1995). The split up of degrees of freedom (df) for different sources of variation are given in Table 4.

RESULTS AND DISCUSSION

Crop Phenology

Days Taken to Visibility of the 8th Leaf Collar

Crop plants under DI_{100} and DI_{80} took

Table 3. Detail of irrigation water applied.

Treatments	Irrigation water applied (mm)	
	2011	2012
DI_{60}	319	372
DI_{80}	406	444
DI_{100}	492	540
Control-I (Flat sown)	600	675
Control-II (Ridge sown)	600	660

Table 4. ANOVA table for the experiment.

Source of variation	Degrees of freedom (df)	
Replications (3)	(r-1)	3-1 = 2
Total Treatments (11)	(t-1)	11-1 = 10
Irrigation (3)	(a-1)	3-1 = 2
Planting methods (3)	(b-1)	3-1 = 2
Irrigation×Planting methods (9)	(a-1) × (b-1)	2 × 2 = 4
Control-I *vs* Control-II (2)		2-1 = 1
Treatments *vs* Controls (2)		2-1 = 1
Error	(r-1) × (t-1)	2 × 10 = 20
Total	(n-1)	33-1 = 32

statistically the same time to reach the visibility of the 8th leaf collar, but crop plants under both regimes took significantly less time to reach this stage as compared to DI_{60} in both years (Table 5). Collar of the 8th leaf was visible early by 3.1 and 3.0 days under DI_{100} as compared to DI_{60} in 2011 and 2012, respectively. NeSmith and Ritchie (1992) have also reported that water deficits delayed leaf tip emergence and reduced leaf area.

Planting methods and the two control treatments (flat sown and ridge sown) did not influence the time taken by the crop to reach collar of the 8th leaf visible significantly during the two years of study. Averaged over two controls, visibility of collar of the 8th leaf was delayed as compared to the drip irrigated crop in both years, but it was significant in 2012 only.

Days Taken to 50% Tasselling and Silking

Time taken by the crop to reach 50% tasselling and silking decreased significantly with increase in irrigation regime (Table 5). The regime DI_{100} advanced 50% tasselling over DI_{60} by 2.6 and 2.4 days in 2011 and 2012, respectively. Similarly, 50% silking under DI_{100} irrigation regime was earlier by a significant margin of 2.9 and 2.8 days over DI_{60} in both years of study. Results are in conformity with those obtained by Farre and Faci (2006) who reported the delay in flowering from 73 Days after sowing (DAS) in well watered crop to 90 DAS in stressed crop. Wang *et al.* (1993) and Moser *et al.* (2006) observed a delay of 2 days in 50% silking in stressed crop as compared to well irrigated crop. Under water deficit condition, carbohydrate content in maize can also be low enough to limit silk osmotic adjustment (Westgate and Boyer, 1985). Wopereis *et al.* (1996) and Winkel *et al.* (1997) also reported delay in flowering (anthesis) with drought stress. Time taken to silking stage was negatively related (with R^2 values of 0.982 and 0.984 in 2011 and 2012, respectively) to increase in irrigation water (Figure 2-a).

In case of planting methods,Days taken to 50% tasselling and silking did not differ significantly. This might be due to similar micro-climatic conditions under various planting methods. Singh (2011) reported that days taken for 50% silking were statistically the same in case of ridge and bed planted crop during the two years of study.

Among the two control treatments, 50% tasselling was early by 2.7 and 2.3 days under ridge sown control as compared to flat sown control in 2011 and 2012, respectively. Similarly, 50% silking under ridge planting was also significantly early by 3.0 and 2.7 days over that of flat planted crop in both years. Sandhu and Hundal (1991) reported earliness in tasselling and silking in ridge planted winter maize as compared to flat beds.

Frequent drip irrigated treatments on an average reached the 50% tasselling and silking stage significantly earlier as compared to the two controls in both years of study. Management of frequent drip irrigation promoted the growth of crop with better water and photosynthates balance in

Table 5. Effect of drip irrigation regimes and methods of planting on phenological stages in spring maize during 2011 and 2012.

Treatment	Phenological stages									
	Days to visibility of 8th leaf collar		Days to 50% tasselling		Days to 50% silking		Days to 50% dough		Days to physiological maturity	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Drip irrigation regimes										
DI_{60}	61.7	61.8	80.4	80.6	83.8	83.9	104.6	103.0	119.2	117.8
DI_{80}	59.6	59.8	77.9	78.1	80.9	81.1	106.7	105.0	121.9	120.3
DI_{100}	58.6	58.8	76.4	76.7	79.1	79.3	108.3	106.6	123.9	122.2
CD (P= 0.05)	1.1	1.1	1.4	1.2	1.5	1.2	1.4	1.5	1.6	1.7
Planting methods										
1Row/Ridge	60.1	60.3	78.8	79.0	81.8	82.0	106.2	104.1	121.2	119.7
1Row/Bed	59.8	60.0	78.1	78.3	81.1	81.3	106.6	105.2	121.7	120.4
1Row (zigzag)/Bed	59.9	60.0	77.9	78.0	80.9	81.0	106.8	105.2	122.1	120.2
CD (P= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Control *vs* Control										
Control-I (Flat sown)	61.7	62.0	81.0	81.0	84.3	84.3	106.7	105.0	121.7	119.7
Control-II (Ridge sown)	60.0	60.3	78.3	78.7	81.3	81.7	103.7	102.0	118.3	116.3
CD (P= 0.05)	NS	NS	2.4	2.1	2.5	2.1	2.51	2.6	2.8	2.9
Treatments *vs* Controls										
Treatment mean[a]	59.9	60.1	78.3	78.4	81.3	81.4	106.5	104.9	121.7	120.1
Control mean[b]	60.8	61.2	79.7	79.8	82.8	83.0	105.2	103.5	120.0	118.0
CD (P= 0.05)	NS	1.0	1.3	1.2	1.4	1.1	NS	NS	1.5	1.6

[a] Mean of all combination of drip irrigation and planting method treatments. [b] Mean of flat and ridge planted control treatments.

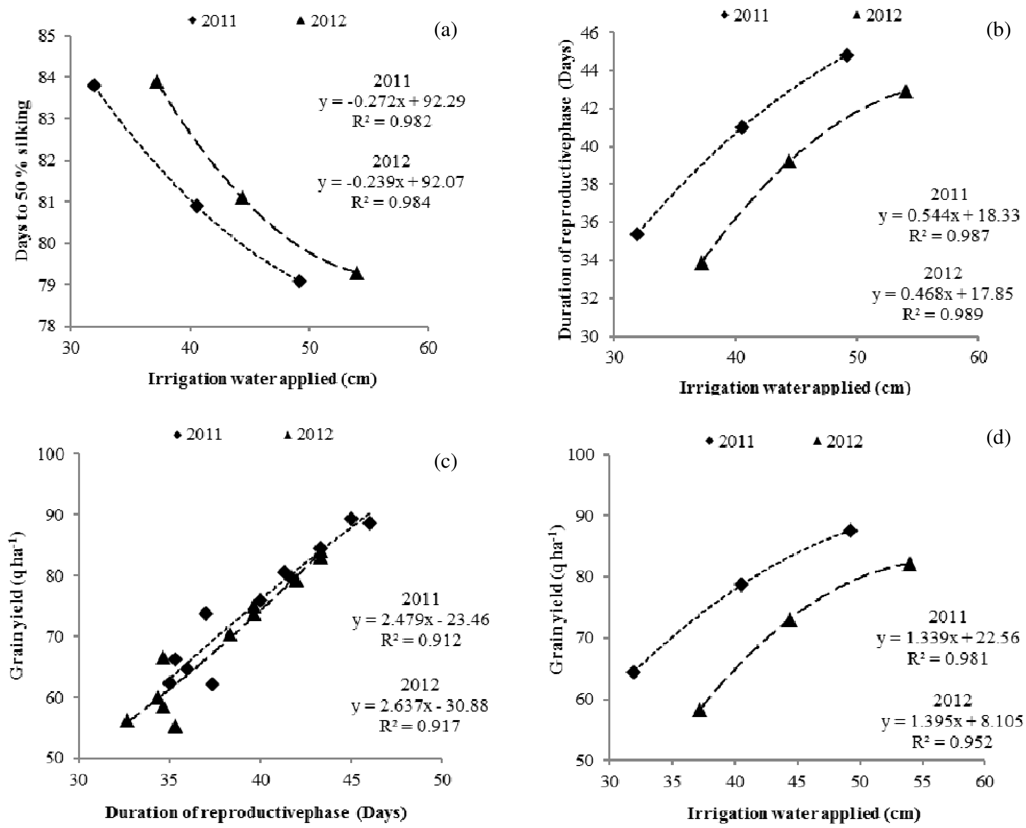

Figure 2. (a) Relationship between irrigation water applied and days to 50% silking; (b) Relationship between irrigation water applied and duration of reproductive phase; (c) Relationship between duration of reproductive phase and grain yield, and (d) Relationship between irrigation water applied and grain yield.

plant and quickened the growth and development as compared to the two conventional irrigation methods (Mwale *et al.,* 2007a, b).

Days Taken to Dough Stage and Physiological Maturity

Dough stage and physiological maturity were delayed significantly with increase in irrigation regime from DI_{60} to DI_{100} through DI_{80} (Table 5). Dough stage reached earlier by 2.0 and 2.1 days in case of DI_{60} over that of DI_{80}, which in turn was reached earlier by 1.7 and 1.6 days over DI_{100} in 2011 and 2012, respectively. Similarly, water stress under DI_{60} caused significant earliness in maturity i.e. by 2.7 and 2.6 days in comparison to DI_{80} which in turn recorded significant earliness by 2 and 1.9 days over DI_{100}, in 2011 and 2012, respectively. Canopy temperature maintained under frequent water supply, which curtailed the grain filling period after silking. Water deficit after anthesis shortens the duration of grain filling by causing premature desiccation of the endosperm and by limiting embryo volume due to higher canopy temperature (Mahant and Aggarwal, 1991; Westgate, 1994). Traore *et al.* (2000) also reported that stress during reproduction stages hastens maturity.

Like the days taken to 50% tasselling and silking, the days taken by the crop to reach dough stage and physiological maturity were not affected significantly by planting methods. Results are in conformity with those obtained by Singh (2011) who found that ridge and bed planted crop took statistically similar periods to reach 50% dough stage and physiological maturity.

Among the two control treatments, ridge sown control took significant short period to attain dough stage and physiological maturity in comparison to flat sown crop. Physiological maturity was significantly earlier by 3.4 days in both years of study in ridge planted crop as compared to flat planted crop. Results are supported by findings of Singh (2005) who observed the delay in dough stage in flat planted crop as compared to crop planted on ridges. Sandhu and Hundal (1991) have also reported similar results.

The drip irrigated treatments and the two control treatments did not differ significantly for the time taken by the crop to reach 50% dough stage in both of the years. More frequent irrigated crop under drip causes significantly late physiological maturity by 1.7 and 2.1 days during 2011 and 2012, respectively, as compared to the two control treatments. Mahant and Aggarwal (1991) have reported higher canopy temperature in case of decreased irrigation frequency to maize as a reason for induction of early maturity in crop.

Reproductive Phase (From Silking to Physiological Maturity)

Duration of reproductive phase was significantly longer by 5.6 and 5.3 days under DI_{80} and by 9.3 and 9.0 days under DI_{100} as compared to DI_{60} during the two years of study (Table 6). Water deficit after anthesis shortens the duration of grain filling by causing premature desiccation of the endosperm and by limiting embryo volume (Westgate, 1994). Duration of this phase linearly correlated with applied irrigation water with high R^2 values of 0.987 and 0.989 in 2011 and 2012, respectively (Figure 2-b).

Duration (Days)= 0.544 (Irrigation water in cm)+18.33 during 2011

Table 6. Duration of reproductive phase, Dry Matter (DM) and grain yield as affected by drip irrigation regimes, planting methods and control treatments.

Treatment	Duration of reproductive phase (Days)		DM at 90 DAS (g plant^{-1})		Grain yield (kg ha^{-1})	
	2011	2012	2011	2012	2011	2012
Drip irrigation regimes						
DI_{60}	35.4	33.9	133.13	122.79	6440	5831
DI_{80}	41.0	39.2	160.93	152.18	7871	7309
DI_{100}	44.8	42.9	177.80	170.47	8754	8219
CD (P= 0.05)	2.6	2.3	12.32	11.79	574	594
Planting methods						
1Row/Ridge	39.4	37.7	153.06	144.44	7428	6868
1Row/Bed	40.6	39.1	158.50	149.87	7870	7309
1Row(zigzag)/Bed	41.2	39.2	160.30	151.12	7767	7182
CD (P= 0.05)	NS	NS	NS	NS	NS	NS
Control *vs* Control						
Control-I (Flat sown)	35.7	35.3	130.72	119.63	6226	5538
Control-II (Ridge sown)	38.7	34.7	154.75	143.23	7379	6670
CD (P =0.05)	NS	NS	21.33	20.42	994	1029
Treatments *vs* Controls						
Treatment mean[a]	40.4	38.7	157.29	148.48	7688	7120
Control mean**	37.2	35.0	142.74	131.43	6803	6104
CD (P= 0.05)	2.5	2.2	11.79	11.29	549	569

[a] Mean of all combination of drip irrigation and planting method treatments. [b] Mean of flat and ridge planted control treatments.

Duration (Days)= 0.468 (Irrigation water in cm)+17.85 during 2012

Similar amount of irrigation water applied under various planting methods and two control treatments (flat and ridge sown) may have led to a similar duration of reproductive phase. Drip irrigated crop had significantly longer reproductive phase by the margin of 3.2 and 3.7 days as compared to the two control treatments. Frequent drip prolongs the grain filling period as compared to control irrigation (conventional irrigation method) methods.

Dry Matter Accumulation

Dry matter (DM) accumulation was significantly higher with every increase in drip irrigation regime in the order DI_{100}> DI_{80}> DI_{60} in both study years (Table 6). The increased DM under well watered regimes (DI_{100}) was indicated by quick growth of crop as evident from earlier visibility of the 8^{th} leaf, tasselling, and silking (Table 5) as compared to DI_{60}. The results confirm the findings of Yang *et al.* (1993), Farre and Faci (2006) and Wang *et al.* (2008) who reported marked decrease in shoot dry weight with water stress in maize plants in comparison to well watered plants. Differences among various planting methods were statistically not significant in both years. Among the two control treatments, the DM was statistically higher under ridge sown control as compared to flat sown control treatment in both study years.

The mean DM was significantly higher in drip irrigated treatments than mean of the control treatments. Frequent drip irrigation during the cooler period of growth must have modified the microclimate in terms of temperature in favor of crop which lengthens the duration. Similar findings were reported by Narang *et al.* (1989), Hussaini *et al.* (2001) and Mugalkhod *et al.* (2011).

Grain yield

Grain yield increased significantly with each increase in drip irrigation regime (Table 6). The grain yield was higher by 35.9 and 40.9% under DI_{100} over that of DI_{60} in 2011 and 2012, respectively. Similarly, grain yield was also higher by 22.2 and 25.3% under DI_{80} over that of DI_{60} in 2011 and 2012, respectively. There was a high correlation between irrigation water applied and grain yield of maize with higher R^2 values of 0.981 and 0.951 in 2011 and 2012, respectively (Figure 2-d). Grain yield was related to duration of reproductive phase with higher coefficient of determination (R^2) of 0.912 and 0.917 in 2011 and 2012, respectively (Figure 2-c). Greater numbers of days were taken by the crop to reach dough stage and physiological maturity (Table 5) under DI_{100}, which further strengthen the explanation that active production and translocation of photosynthates must have existed for longer period to fill the sink to its capacity. Stress during reproductive stages will hasten maturity and reduce yields (Traore *et al.,* 2000). These findings are in conformity with those reported by El-Tantawy *et al.* (2007) and Jat *et al.* (2008).

Grain yield was not affected significantly by the planting methods, although numerical values were higher by 6.0 and 6.4% under 1Row/Bed and by 4.6 and 4.6% under 1Row (zigzag)/Bed as compared to 1Row/Ridge during the two years, respectively. This might be due to better root development and better moisture condition in the bed planting. Similar grain yield under bed and ridge planting was also reported by Singh (2011).

Among the two control treatments, grain yield (Table 6) was significantly higher under ridge sown control by a margin of 18.5 and 20.4% during the two years, respectively, as compared to flat sown control treatment. Significantly higher yield under ridge planting may be due to the light and frequent irrigations which must have avoided any moisture stress at any crop growth stage. Ahmed *et al*. (2002) also reported higher grain yield in case of ridge planted crop as compared to flat planted crop of maize.

The grain yield (Table 6) when averaged over drip irrigated treatments was significantly higher by the margin of 13.0 and 16.6% than the mean grain yield obtained from the two control treatments during 2011 and 2012, respectively. In addition to given significant higher grain yield, drip irrigation method also saved 19.4 and 22.4 cm water (about 33 % of water applied by conventional methods of irrigation) applied to crop as compared to the two control treatments. This saved amount of irrigation water can be used for 1/3rd more area for crop production. Significantly higher accumulation of dry matter by the plants and better micro-climatic conditions due to frequent irrigations under drip irrigated treatments expanded reproductive phase (from silking to physiological maturity) leading to longer grain filling period, which resulted in a significantly higher grain yield. These results are in line with those reported by Bergez *et al.* (2002) and El-Hendawy *et al.* (2008).

CONCLUSIONS

Results of the two years study showed that all the phenological stages of maize were significantly affected by drip irrigation regimes i.e. under water stressed regime (DI_{60}); visible color of the 8^{th} leaf, tasselling, and silking stages were delayed and there was advancement in dough stage and physiological maturity, which led to shorter reproductive stage as compared to well watered regime (DI_{100}). Meanwhile, crop under well watered drip irrigation regime (DI_{100}) showed earlier tasselling and silking and delay in physiological maturity was recorded. Applied irrigation water was linearly and positively related to the duration of reproductive phase and to the grain yield. The grain yield was linearly and positively related having a higher coefficients of determination (R^2= 0.981 and 0.951) with applied irrigation water. Higher dry matter accumulation and longer reproductive phase under well watered regime (DI_{100}) led to significantly higher grain yield. Grain yield was higher by margin of 35.9 and 40.9% under well watered regime (DI_{100}) over that of water stressed regime (DI_{60}) in 2011 and 2012, respectively. All the phenological stages were delayed under flat sown conditions as compared with ridge sown, except the visibility of the 8^{th} leaf. Ridge sown crop was better than flat sown with respect to crop dry matter and grain yield production. Data averaged over the combinations of drip irrigation regimes and planting methods showed earlier tasselling and silking with longer reproductive phase due to late physiological maturity. All these led to significantly higher grain yield (by 13.0 and 16.6% in 2011 and 2012, respectively) averaged over drip irrigation regimes than that averaged over two conventional control treatments (flat sown and ridge sown with flood and furrow irrigation). Drip irrigation system saved an average of 21 cm irrigation water per hectare per season (2100 m^3 ha^{-1}) compared to conventional methods of irrigation.

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گذار شناسی (فنولوژی) و عملکرد ذرت بهاره (*Zea mays* L.) در مدیریت های مختلف آبیاری قطره ای و روش های کاشت

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چکیده

در این پژوهش، واکنش ذرت به کم آبی و روش های کاشت برای ارزیابی مراحل رشد فنولوژیکی و عملکرد در شرایط پنجاب بررسی شد. آزمایش مربوطه ۱۱ تیمار (۹+۲) داشت که ۹ تیمار آن ها ترکیبی از سه مقدار آب آبیاری بر اساس تبخیرتجمعی از طشت (CPE) و سه روش کاشت بودند. تیمارهای آبیاری قطره ای (DI) برای تامین ۶۰٪، ۸۰٪ و ۱۰۰٪ تبخیر تجمعی مبنا (۳۰ میلی متر) و تیمارهای روش کاشت شامل یک ردیف کاشت روی پشته باریک (ridge) ، یک ردیف کاشت مستقیم روی پشته عریض(bed)، و یک ردیف کاشت زیگزاگ روی پشته عریض بود. علاوه بر این تیمارها، دو تیمار اضافی به صورت کاشت مسطح و کاشت پشته ای به عنوان تیمارهای شاهد نگهداری شدند.. بر اساس نتایج، هر گام افزایش از DI_{60}تا DI_{100} به طور معنی داری منجر به زودرسی در ظهور یقه برگ هشتم، مرحله تاسلینگ، و ظهور کاکل (سیلکینگ) شد ولی مراحل خمیری شدن و رسیده شدن فیزیولوژیکی به طور معنی دار به تعویق می افتاد. مقدار آب آبیاری داده شده به طور خطی با طول دوره زایشی و عملکرد دانه رابطه داشت. تولید ماده خشک (DM) بیشتر و طولانی شدن مرحله زایشی منجر به افزایش معنی دار عملکرد دانه در تیمار DI_{100} شد. در تیمارهای شاهد، همه مراحل فنولوژیکی در کاشت مسطح در مقایسه با کاشت پشته ای به تعویق افتاد.همچنین، از نظر عملکرد ماده خشک و دانه، کاشت پشته ای شاهد بهتر از کاشت مسطح بود. تیمارهای آبیاری قطره ای موجب جلو افتادن مراحل رشد تاسلینگ و ظهور کاکل شد ولی مرحله رسیده شدن فیزیولوژیکی وطول دوره رشد زایشی در آنها به به طور معنی داری به تعویق افتاد و در نتیجه، ماده خشک و عملکرد دانه این تیمارها در مقایسه با میانگین دو تیمار شاهد بیشتر شد.بر این اساس، فنولوژی گیاه تحت تاثیر مدیریت های آبیاری قطره ای قرار گرفت و عملکرد دانه در آن ها به طور معنی داری با زیاد شدن مقدار آب در رژیم آبیاری قطره ای افزایش یافت و با طول دوره رشد زایشی به طور خطی و مثبتی رابطه داشت.اما، فنولوژی و عملکرد گیاه چندان تحت تاثیر روش کاشت گیاه قرار نگرفتند.