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Effect of moisture Stress management practices and irrigation regimes on the growth and yield of maize (*Zea mays* L.)

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Abstract
The field experiment was conducted at Agricultural Research Station, Bhavanisagar, Tamil Nadu, India during *rabi* 2017 and 2018 to study the influence of moisture stress management practices on plant growth and yield of maize. Study revealed that irrigation scheduling at IW/CPE ratio of 1.0 produced significantly higher crop growth rate (3.09 g m^{-2} day^{-1}), dry matter production (17315 kg ha^{-1}) and yield (7188 kg ha^{-1}) and was comparable with IW/CPE ratio of 0.8. Among the foliar application of treatments PPFM 1% recorded significantly higher crop growth rate (3.03 g m^{-2} day^{-1}), dry matter production (16736 kg ha^{-1}) and yield (6847 kg ha^{-1}) followed by silicic acid 0.2%. Higher water use efficiency was recorded in IW/CPE ratio of 0.6 (19.41 kg ha^{-1} mm^{-1}). Foliar application of PPFM 1% recorded significantly higher water use efficiency (18.63 kg ha^{-1} mm^{-1}). Under water deficit irrigation IW/CPE ratio of 0.6 with foliar application of PPFM 1% produced higher yield (6842 kg ha^{-1}) which was comparable with that of normal irrigation of IW/CPE ratio of 0.8. Results from the study indicated there is no superiority in IW/CPE ratio of 1.0 over 0.8 hence, under normal water availability situation, irrigating at IW/CPE ratio of 0.8 is good enough to produce higher yield while under water scarcity condition IW/CPE ratio of 0.6 with foliar application of PPFM 1% is suitable for obtaining optimum yield and higher water use efficiency.

Keywords: Deficit irrigation, irrigation scheduling, PPFM, silicic acid, brassinolide

Introduction
Maize (*Zea mays* L.) is the third most important cereal crop in India after rice and wheat and plays an important role in agricultural economy as food for larger section of population, raw material for industries and feed for animals. Drought is the main constraint for maize crop, causing severe yield reductions by 40% on a global scale (Daryanto *et al*., 2016) [3]. Irrigation water is becoming critical scarce resource and expensive due to higher demand by industry and urban consumption. The ground water is depleting at an alarming rate (GOR, 2007) [11]. and therefore framing strategies to reduce irrigation water losses and enhance crop water productivityhas driven special attention. Deficit irrigation is an option where water availability limits conventional irrigation and reduces the risk of yield reduction due to terminal dry spell (Singh *et al*., 2010) [15].
Pink pigmented facultative methylobacteria (PPFM) are associated with the roots, leaves and seeds of most terrestrial plants and utilize volatile C_1 compounds such as methanol generated by growing plants at cell division phase (Irvine *et al*., 2012) [13]. increasing CO_2 concentration inside stomata leading to accelerated rate of photosynthesis and decreased the rate of photorespiration in C_3 plants. During dry spell PPFM exudates osmoprotectants (sugars and alcohols) on the surface of host plants and this matrix helps to protect the plants from desiccation and high temperature (Irvine *et al*., 2012) [13].
Silicon is an important element, and plays an important role in inducing tolerance to the plants from environmental stresses (Tripathi *et al*., 2014) [17]. Increased Silicon (Si) supply improves the structural integrity of crops and may also improve plant tolerance to diseases, drought and metal toxicities (Doncheva,, 2009) [6]. Si-induced growth improvement under water-deficit conditions has been observed in different species such as wheat (Gong *et al*., 2012) [10], rice (Chen *et al*., 2011) [2], and soybean (Shen *et al*., 2010) [14].
Brassinolide is a steroidal growth regulator has emerged as a new phytohormone with pleiotropic effect (Das *et al*., 2013) [4], and influences varied physiological processes like germination, growth, flowering, senescence and confers resistance to the plant against various abiotic stresses. Brassinosteroids have been identified to improve the resistance of plants against environmental stresses such as water stress, salinity stress, low temperature stress and high temperature stress (Fariduddin *et al*., 2014) [7].

Moreover brassinolides have also been picked out as plant growth and development signals (Sun *et al*., 2010) [16].
In this regard the present study was aimed at identifying suitable irrigation regime and investigatingthe effect of moisture stress management practices on the plant growth and yield stability of maize.

Materials and Methods

The experiment was conducted at Agricultural Research Station, Bhavanisagar (11º29` N, 77º08` E, and 256 m above the mean sea-level), Tamil Nadu, India during 2017 and 2018. The soil at experimental site was sandy loam (21.2% course sand, 33.1% fine sand, 19.8 % silt and 25.9 % clay) medium in organic carbon (0.43%), low in available nitrogen (191kg ha^{-1}), medium in phosphorus (11.2kg ha^{-1}) and potassium (389.8kg ha^{-1}). During the crop growth (November – Feb) of 2017 and 2018, monthly mean maximum and minimum temperature ranged between 31.4ºC and 21.5ºC; 30.8ºC and 22.7ºC respectively. The experimental site received an rainfall of 54.6 mm in 3consecutive rainy days during rabi 2017 and 31 mm in 1 rainy days during rabi 2018. The mean evaporation was5.1 mm and 4.4 mm in rabi 2017 and 2018 respectively. The rainfall and evaporation have given graphically in figure 1.

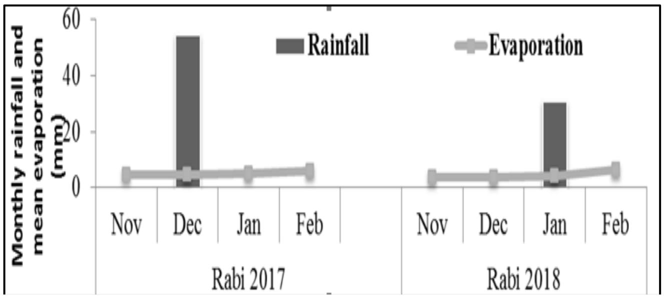

Fig 1: Monthly rainfall and mean evaporation during *rabi* 2017 and 2018

The experiment was laid out in split plot design comprised of four irrigation regimes as main factor based IW/CPE ratio of 1.0 ($I_{1.0}$), 0.8($I_{0.8}$), 0.6 ($I_{0.6}$) and 0.4 ($I_{0.4}$) and four moisture stress management treatments *viz*., foliar application of pink pigmented facultative methylobacteria at 1% (F_{PPFM}), Brassinolide 0.1 ppm (F_{Br}), Silicic acid 0.2% (F_{SI}) and control (F_{cont}) as a sub factor. Foliar application was given on 25 and 45 DAS for each treatments in the sub plot. Maize cultivar CO(H)M 6 was used as a test variety with 60 cm row spacing and 25 cm between the plants. Recommended dose of NPK for maize hybrid 250:75:75 kg $ha^{-1}$was adopted as per crop management practices. Irrigation was given at the time of sowing and the life irrigation on the fifth day and following subsequent irrigations were scheduled based on the irrigation regimes of the main plot as per the IW/CPE ratio and irrigated at a depth of 50 mm measured using parshall flume.
The ratio of yield from different treatments to respective water applied was worked out and expressed as WUE in kg ha^{-1} mm^{-1} (Viets, 1962) [18].

Where,

$$\text{WUE} = \frac{\text{Yield}}{\text{Water applied} + \text{Effective Rainfall}}$$

Statistical Analysis of variance (ANOVA) was performed using the Fischer's method as described by Gomez and Gomez (1984) [9]. Critical difference (CD) at 5% level of probability and LSD values were calculated wherever 'F' test was significant. Since, the trends in treatment effects on parameters studied were non-significant between years the data were pooled for presentation.

Results and Discussion

Dry Matter Production and Crop growth rate

Irrigation scheduling and drought management practices significantly influenced the crop dry matter production (Table 1). IW/CPE ratio of 1.0 recorded significantly higher dry matter production (17315 kg ha^{-1}) and crop growth rate (3.09 g m^{-2} day^{-1}) and was on par with IW/CPE ratio of 0.8. Lower dry matter production (13837 kg ha^{-1}) and crop growth rate (2.50 g m^{-2} day^{-1}) was recorded in IW/CPE ratio of 0.4. Reduction in dry matter accumulation under lower irrigation regime is because of reduced water availability which led to water deficit condition for most of the crop growing period. Biomass accumulation is sensitive to water stress and the degree of reduction of biomass accumulation depended on the severity of water stress. The results are in line with the Guo *et al*. (2010) [12].
Foliar spray of PPFM produced significantly higher DMP (16736 kg ha^{-1}) and crop growth rate (3.03 g m^{-2} day^{-1}) followed by foliar application of silicic acid. Among the foliar application treatments Brassinolide 0.1 ppm recorded significantly lower dry matter production and crop growth rate and was significantly higher than the control.
Foliar application of PPFM produced increased dry matter production and crop growth rate but non-significant with other foliar treatments as well as control in IW/CPE ratio of 1.0 and 0.8. In water deficit irrigation IW/CPE ratio of 0.6 with foliar application of PPFM recorded significantly higher dry matter production of (16132kg ha^{-1}) and crop growth rate (2.99g m^{-2} day^{-1}) and was comparable with foliar application of silicic acid 0.2%. At IW/CPE ratio of 0.4, foliar application of PPFM 1% produced significantly higher dry matter production (15366kg ha^{-1}) and crop growth rate (2.79g m^{-2} day^{-1}) than other chemical treatments. The increase in foliar application of PPFM might have been due to the production of growth hormones *viz*., IAA, cytokinin and gibberellic acid influencing dry matter production. Moreover cytokinin antioxidant properties protected the leaves from stress induced oxidation. This was justified by finding of Zhang and Ervin (2008) [20].

Table 1: Effect of moisture stress management practices and irrigation regimes on dry matter production and crop growth rate of maize of moisture stress management practices and irrigation regimes on yield and water use efficiency of maize (Pooled data of 2 year)

	Dry matter production (kg ha^{-1})					Crop growth rate (kg ha^{-1} mm)				
Treatments	$I_{1.0}$	$I_{0.8}$	$I_{0.6}$	$I_{0.4}$	**Mean**	$I_{1.0}$	$I_{0.8}$	$I_{0.6}$	$I_{0.4}$	**Mean**
F_{PPFM}	17792	17653	16132	15366	16736	3.17	3.15	2.99	2.79	3.03
F_{Br}	17279	16681	14722	13128	15452	3.08	3.01	2.76	2.41	2.81
F_{Sl}	17478	16973	15557	14301	16077	3.12	3.07	2.90	2.56	2.91
Fcont	16709	16725	14510	12555	15125	2.98	2.98	2.55	2.24	2.69
Mean	17315	17008	15230	13837		3.09	3.05	2.80	2.50	
	I	F	I x F	F x I		I	F	I x F	F x I	
SEM (±)	204	138	314	275		0.04	0.03	0.06	0.05	
CD (P=0.05)	705	402	987	804		0.12	0.08	0.18	0.15	

Yield

Irrigation scheduling and drought management significantly influenced the yield of the crop (Table 2). IW/CPE ratio of 1.0 and 0.8 recorded significantly higher yield (7188 and 7142kg ha^{-1}) and significantly lower yield was recorded in IW/CPE ratio of 0.4. The increase in yield could be attributed to greater and consistent available soil moisture due to increased level of irrigation that resulted in better crop growth and yield components. Similar findings were reported by Zhao *et al*. (2010) [19]. The lower yield in irrigation at IW/CPE of 0.4 might be attributed to the decrease in synthesis of metabolites and reduction in absorption and translocation of nutrients from soil to plant under deficit moisture supply.

Among the foliar application treatments foliar application of PPFM 1% recorded significantly higher grain yield of 6847 kg ha^{-1}followed by foliar application of silicic acid 6600 kg ha^{-1}. Significantly lower yield (6098 kg ha^{-1}) was recorded in control.

In normal irrigation condition (IW/CPE ratio of 1.0 and 0.8) foliar application treatment did not influenced significantly while at IW/CPE ratio of 0.6 foliar application of PPFM 1% and silicic acid 0.2 % produced significantly higher yield. Under IW/CPE ratio of 0.4, PPFM produced significantly higher yield with the increase of 30.4% over control. The yield increase with the foliar application of PPFM was due to the increased plant growth parameters like plant height, leaf area, and total biomass, corroborating the results of Gashti *et al.* (2014) [8].

Table 2: Effect of moisture stress management practices and irrigation regimes on dry matter production and crop growth rate of maize of moisture stress management practices and irrigation regimes on yield and water use efficiency of maize (Pooled data of 2 year)

	Yield (kg ha^{-1})					Water use efficiency (kg ha^{-1} mm^{-1})				
Treatments	$I_{1.0}$	$I_{0.8}$	$I_{0.6}$	$I_{0.4}$	**Mean**	$I_{1.0}$	$I_{0.8}$	$I_{0.6}$	$I_{0.4}$	**Mean**
F_{PPFM}	7372	7289	6842	5886	6847	16.05	17.63	20.75	20.11	18.63
F_{Br}	7163	7107	6318	5002	6398	15.59	17.19	19.16	17.09	17.26
F_{Sl}	7195	7213	6538	5454	6600	15.66	17.44	19.83	18.66	17.90
Fcont	7021	6958	5902	4513	6098	15.28	16.83	17.90	15.42	16.36
Mean	7188	7142	6400	5214		15.65	17.27	19.41	17.82	
	I	F	I x F	F x I		I	F	I x F	F x I	
SEM (±)	78	62	132	123		0.21	0.23	0.45	0.46	
CD (P=0.05)	270	180	411	359		0.71	0.67	1.36	1.34	

Note: $I_{1.0}$, $I_{0.8}$, $I_{0.6}$ and $I_{0.4}$ are irrigation regimes of IW/CPE ratio 1.0, 0.8, 0.6 and 0.4 respectively; F – Foliar application at 25 and 40 DAS. PPFM – Pink pigmented facultative methylobacteria 1%; Sl-Silicic acid 0.2%; Br – Brassinolide 0.1ppm and C – Control.

Water Use Efficiency

Among the irrigation regimes IW/CPE ratio of 0.6 recorded significantly higher water use efficiency (19.41kg ha^{-1} mm^{-1}) and the lower water use efficiency was recorded in IW/CPE ratio of 1.0 (15.65kg ha^{-1} mm^{-1}) (Table 2). Water use efficiency (WUE) was found to be increased either by increasing the yield or reducing the quantity of water applied or both. The increased water use efficiency in IW/CPE ratio of 0.6can be attributed to the reduced quantity of water application with minimum decline in yield. Similar findings were reported by Djurovic (2016) [5], at full irrigation the yield was higher, but WUE was lower than that of deficit irrigation.

In foliar application treatments foliar application of PPFM recorded higher and significant WUE (18.63kg ha^{-1} mm^{-1}) irrespective of irrigation regimes followed by foliar application of silicic acid.

Under water deficit condition the WUE was greatly influenced by PPFM. Irrigation with IW/CPE ratio of 0.6 with foliar application of PPFM recorded highest WUE of 20.75kg ha^{-1} mm at par with irrigation of IW/CPE ratio of 0.4 with foliar application of PPFM (20.11kg ha^{-1} mm^{-1}) and IW/CPE ratio of 0.6 with foliar application of silicic acid. This could be attributed to maintaining good yield even at water deficit condition.

Conclusion

From the present study it can be concluded that irrigating at IW/CPE ratio of 0.8 is ideal for obtaining higher yield at normal condition. Under water scarcity condition irrigating at IW/CPE ratio of 0.6 with foliar application of PPFM was found to be suitable for obtaining optimum yield and higher water use efficiency.

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