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# Effect of Moisture Stress Management Practices and Irrigation Regimes on Yield and Physiology of Maize (*Zea mays* L.)

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**Abstract** The field experiment was conducted during *rabi* season of 2017 and 2018 to study the influence of moisture stress management practices on plant physiology and yield of maize. Study revealed that, irrigation scheduling at IW/CPE ratio of 1.0 produced significantly higher relative leaf water content (80.1%), transpiration rate (4.31 mmol $m^{-2}s^{-1}$) stomatal conductance (0.304 mmol $m^{-2}s^{-1}$) and was followed by IW/CPE ratio of 0.8. while, lower values were recorded in IW/CPE of 0.4. In terms of yield and net photosynthetic rate IW/CPE ratio of 1.0 out performed with 7,188 kg $ha^{-1}$ and 44.4 µmol $m^{-2}s^{-1}$ respectively which was comparable with IW/CPE ratio of 0.8 (7,142 kg $ha^{-1}$, µmol $m^{-2}s^{-1}$). Among the foliar application of treatments PPFM @ 1% recorded significantly higher relative leaf water content (73.7%), transpiration rate (3.97 mmol $m^{-2}s^{-1}$) stomatol conductance (0.287 mmol $m^{-2}s^{-1}$) and net photosynthetic rate (40.2 µmol $m^{-2}s^{-1}$) followed by silicic acid @ 0.2%. Foliar application of PPFM @ 1% and silicic acid 0.2% produced significantly higher and comparable yield (6,847 and 6,600 kg $ha^{-1}$). From the study, irrigation at IW/CPE ratio of 0.8 realized a net return of Rs 63,960 with B : C ratio of 3.11. Similarly, PPEM @ 1% attained a net return of Rs 60, 923 with B : C ratio of 3.02. On comparison with water productivity, IW/CPE ratio of 0.6 noted Rs 257 $ha^{-1}$ $mm^{-1}$ of water applied to the crop. Likewise Rs 248 $ha^{-1}$ $mm^{-1}$ was realized with the application of PPFM @ 1%. Irrigation at IW/CPE ratio of 0.8 along with foliar application of PPFM @ 1% enhanced the production and profit in comparison with other treatments.

**Keywords** Deficit irrigation, Water productivity, Relative water content, Transpiration rate, Photosynthetic rate.

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## Introduction

Maize (*Zea mays* L.) is the 3rd 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). Irrigation intervals play a direct role in soil moisture availability which directly influences the growth and development of crops. Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Stomatal

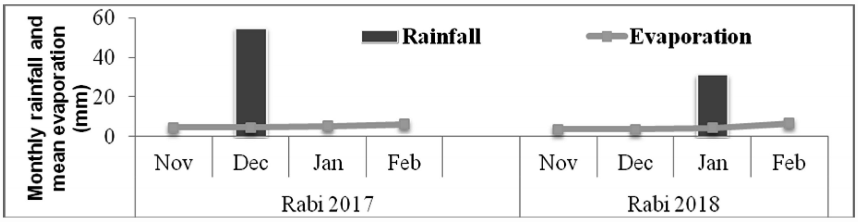


**Fig. 1.** Monthly rainfall and mean evaporation during *rabi* 2017 and 2018.

closure decreases water loss, and the movement of $CO_2$ into the plant moreover photosynthetic rate of the leaves decreases as the relative water content and leaf water potential decrease ((Lawlor and Cornic 2002). Under moderate stress, the photosynthetic rate remained unaffected with significant decrease in the carboxylation. While, under severe water deficit both photosynthetic rate and concentration of $CO_2$ at the site of carboxylation decreases.

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), increasing $CO_2$ concentration inside stomata leading to accelerated rate of photosynthesis and decreased rate of photorespiration in $C_3$ plants (Wingler et al. 2000). 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). Sivakumar et al. (2017) revealed that foliar application of PPFM at 2% was found to superior in improving relative water content and photosynthetic rate.

Silicon can alleviate water stress by decreasing transpiration as it gets deposited beneath the leaf cuticle forming a Si-cuticle double layer preventing cuticular transpiration (Ma 2004). Plant growth regulators like benzyladenine and brassinolide significantly increased leaf water potential and improved chlorophyll content in maize under water deficit condition (Goa et al. 2017). Study with Robinia pseudoacacia seedlings with 0.2 mg $L^{-1}$ of brassinolide decreased the transpiration rate, stomatal conductance and malondialdehyde (MDA) content of seedlings growing under moderate or severe water stress compared to untreated seedlings (Li et al. 2008). Therefore, the present study was aimed at identifying the suitable irrigation regime and investigating the effect of moisture stress management practices on the yield and physiology of maize.

## Materials and Methods

The experiment was conducted at Agricultural Research Station (11°29´N, 77°08´ E and 256 m above the mean sea level), Bhavanisagar, 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 (191.0 kg $ha^{-1}$), medium in phosphorus (11.2 kg $ha^{-1}$) and potassium (389.8 kg $ha^{-1}$). During the crop growth period (November–February) of 2017 and 2018, monthly mean maximum and minimum temperature ranged between 31.4°C and 21.5°C, 30.8°C and 22.7°C respectively. The experimental site received an rainfall of 54.6 mm in three consecutive rainy days during *rabi* 2017 and 31 mm in a single rainy day during *rabi* 2018. The mean evaporation was 5.1 mm and 4.4 mm in *rabi* 2017 and 2018 respectively. The rainfall and evaporation represented in Figure 1.

The experiment was laid out in split plot design comprised of main plot with four irrigation regimes viz., 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 sub plot with four moisture stress management treatments viz., foliar application of pink pigmented facultative methylobacteria (PPFM) @ 1% ($F_{PPFM}$), brassinolide @ 0.1 ppm ($F_{Br}$), silicic acid @ 0.2% ($F_{S1}$) and control ($F_{cont}$). Foliar application was given on 25 and 45 DAS for all treatments prescribed

**Table 1.** Effect of moisture stress management practices and irrigation regimes on relative leaf water content and transpiration rate of maize (pooled mean of 2 year).

| | Relative leaf water content % | | | | | Transpiration rate (mmol $m^{-2}s^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| $F_{PPFM}$ | 81.0 | 76.3 | 72.3 | 65.2 | 73.7 | 4.43 | 4.38 | 3.89 | 3.16 | 3.97 |
| $F_{Br}$ | 79.9 | 72.9 | 66.5 | 59.5 | 69.7 | 4.24 | 3.92 | 3.33 | 3.02 | 3.63 |
| $F_{SI}$ | 78.2 | 75.2 | 69.3 | 61.3 | 71.0 | 4.36 | 4.12 | 3.44 | 2.87 | 3.70 |
| F cont | 81.2 | 73.2 | 63.9 | 54.5 | 68.2 | 4.22 | 3.64 | 2.93 | 2.76 | 3.39 |
| Mean | 80.1 | 74.4 | 68.0 | 60.2 | | 4.31 | 4.01 | 3.40 | 2.96 | |
| | I | F | I × F | F × I | | I | F | I × F | F × I | |
| SEm (±) | 1.3 | 1.0 | 2.1 | 1.9 | | 0.08 | 0.07 | 0.14 | 0.14 | |
| CD (p= 0.05) | 3.1 | 2.0 | 4.7 | 4.0 | | 0.21 | 0.14 | 0.32 | 0.28 | |

in the sub plot. Maize cultivar CO (H) M 6 was used as a test variety spaced with 60 × 25. Recommended dose of NPK for maize hybrid 250 : 75 : 75 kg $ha^{-1}$ was applied to all the experimental plots. Irrigation was given at the time of sowing followed by life irrigation on the 5th—7th day. Subsequent irrigations were scheduled based on the irrigation regimes of the main plot as per the IW/CPE ratio. All the plots were irrigated at a depth of 50 mm and were measured using parshall flume.

Relative leaf water content

Fully expanded 3rd leaf from the apex was punched and collected 50 leaf discs in the plastic vial at noon and the fresh weight was recorded immediately. Later, it was floated in distilled water for 6 h later the leaf discs were collected and surface dried with a filter paper for recording leaf turgid weight. Then the leaf discs were oven dried at 65 ± 5°C and taken the dry weight. Using these observations RLWC was determined by modified method of Barrs and Weatherly (1962).

$$\text{RLWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Physiological parameters

Transpiration rate (E : mmol $H_2O$ $m^{-2}$ $s^{-1}$), Stomatal conductance ($g_s$ : mol $H_2O$ $m^{-2}s^{-1}$) and Net photo-

**Table 2.** Effect of moisture stress management practices and irrigation regimes on stomatal conductance and net photosynthetic rate of maize (pooled mean of 2 year). $I_{1.0}$, $I_{0.8}$, $I_{0.6}$ 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 0.1 ppm and C–Control.

| | Stomatal conductance (µmol $m^{-2}s^{-1}$) | | | | | Net photosynthetic rate (µmol $m^{-2}s^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| $F_{PPFM}$ | 0.306 | 0.311 | 0.277 | 0.254 | 0.287 | 44.5 | 44.0 | 39.4 | 32.9 | 40.2 |
| $F_{BR}$ | 0.301 | 0.278 | 0.237 | 0.215 | 0.258 | 44.6 | 43.4 | 35.1 | 29.7 | 38.2 |
| $F_{SI}$ | 0.304 | 0.293 | 0.244 | 0.224 | 0.266 | 44.2 | 43.4 | 35.4 | 30.6 | 38.4 |
| F cont | 0.306 | 0.258 | 0.228 | 0.217 | 0.252 | 44.4 | 42.5 | 30.3 | 28.7 | 36.5 |
| Mean | 0.304 | 0.285 | 0.246 | 0.228 | | 44.4 | 43.3 | 35.0 | 30.5 | |
| | I | F | I × F | F × I | | I | F | I × F | F × I | |
| SEm (±) | 0.007 | 0.004 | 0.009 | 0.007 | | 0.6 | 0.6 | 1.2 | 1.2 | |
| CD (p= 0.05) | 0.017 | 0.008 | 0.022 | 0.015 | | 1.4 | 1.2 | 2.5 | 2.4 | |

**Table 3.** Effect of moisture stress management practices and irrigation regimes on yield and water productivity of maize (pooled mean of 2 year).

| Treatments | Yield kg ha$^{-1}$ | | | | | Water productivity (Rs ha$^{-2}$mm$^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $I_{1.0}$ | $I_{0.8}$ | $I_{0.6}$ | $I_{0.4}$ | Mean | $I_{1.0}$ | $I_{0.8}$ | $I_{0.6}$ | $I_{0.4}$ | Mean |
| $F_{PPFM}$ | 7372 | 7289 | 6842 | 5886 | 6847 | 211 | 233 | 277 | 270 | 248 |
| $F_{Br}$ | 7163 | 7107 | 6318 | 5002 | 6398 | 206 | 225 | 252 | 232 | 229 |
| $F_{SI}$ | 7195 | 7213 | 6538 | 5454 | 6600 | 207 | 229 | 264 | 258 | 239 |
| F cont | 7021 | 6958 | 5902 | 4513 | 6098 | 201 | 221 | 236 | 211 | 217 |
| Mean | 7188 | 7142 | 6400 | 5214 | | 207 | 227 | 257 | 242 | |
| | I | F | I × F | F × I | | I | F | I × F | F × I | |
| SEm (±) | 110 | 87 | 187 | 174 | | 5 | 5 | 10 | 10 | |
| CD (p= 0.05) | 270 | 180 | 411 | 359 | | 13 | 10 | 22 | 20 | |

synthetic rate ($P_n$ : µmol $CO_2$ m$^{-1}$s$^{-1}$) were measured on-field at 45 DAS by using portable photosynthesis system (PPS).

Water productivity

Water productivity (WP) was calculated as a function of gross income to the total water used by the crop throughout its growth and expressed in Rs ha$^{-1}$ mm.

$$WP = \frac{\text{Gross income (Rs / ha)}}{\text{Total water use (mm)}}$$

Total water use (mm) was a sum of total water applied and the effective rainfall received during the cropping period.

Statistical analysis of variance (ANOVA) was performed using the Fischer's method as described by Gomez and Gomez (1984). 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

Relative leaf water content (RLWC)

Water deficit directly affected the plant relative leaf water content to the frequency of water supplied (Table 1). Significantly higher Relative Leaf Water Content of 80.1% was recorded in IW/CPE ratio of 1.0 followed by 0.8 (74.4%) while, the lowest was recorded in IW/CPE ratio of 0.4 with 60.2% This could be attributed to the optimum availability resulting in continues maintenance of soil moisture content subsequently increase the relative leaf water content of the crop. Similar result was reported by Nayyar and Gupta (2006) when plants were subjected to drought exhibited large reductions in RLWC and water potential.

Among the foliar treatments, foliar application of PPFM 1% recorded higher RLWC irrespective of irrigation regines (73.7%) followed by silicic acid 0.2%. In normal irrigated condition of IW/CPE ratio 1.0 and 0.8 foliar treatments did not produce significant influence while, at water deficit condition (IW/CPE ratio of 0.6 and 0.4) foliar application of PPFM 1% and silicic acid 0.2% produced significantly higher and comparable relative leaf water content. The increase in relative leaf water content in PPFM applied plots might have been due to the stomatal regulation which resulted in reduced transpiration loss under water deficit condition. The results are in concordance with the findings of Madhaiyan et al. (2012).

Transpiration rate and stomatal conductance

Under water stress, transpiration and stomatal conductance decreased as a reflex to the stimulation of drought (Tables 1 and 2). Significantly, higher level

**Table 4.** Effect of moisture stress management practices and irrigation regimes on net return and BC ratio of maize (pooled mean of 2 year). $I_{1.0}$, $I_{0.8}$, $I_{0.6}$ 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 0.1 ppm and C–Control.

| Treatments | Net return | | | | | B : C ratio | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $I_{1.0}$ | $I_{0.8}$ | $I_{0.6}$ | $I_{0.4}$ | Mean | $I_{1.0}$ | $I_{0.8}$ | $I_{0.6}$ | $I_{0.4}$ | Mean |
| $F_{PPFM}$ | 65825 | 66151 | 61835 | 49880 | 60923 | 3.09 | 3.17 | 3.09 | 2.72 | 3.02 |
| $F_{BR}$ | 63202 | 62792 | 53337 | 38457 | 54447 | 2.99 | 3.04 | 2.79 | 2.31 | 2.78 |
| $F_{SI}$ | 63678 | 64372 | 57434 | 46451 | 57984 | 3.01 | 3.10 | 2.94 | 2.59 | 2.91 |
| F cont | 62242 | 62524 | 49438 | 33804 | 52002 | 3.05 | 3.13 | 2.74 | 2.21 | 2.79 |
| Mean | 63737 | 63960 | 55511 | 42148 | | 3.03 | 3.11 | 2.89 | 2.46 | |

of transpiration rate (4.32 mmol $m^{-2}$ $s^{-1}$) and stomatal conductance (0.304 µmol $m^{-2}$ $s^{-1}$) was recorded in IW/CPE ratio of 1.0 followed by IW/CPE ratio of 0.8. Likewise lower transpiration rate and stomatal conductance was recorded in IW/CPE ratio of 0.4. The results are in similarity to the results of Anjum et al. (2011).

Among the stress management practices foliar application of PPFM @ 1% recorded higher and significant transpiration rate (3.97 mmol $m^{-2}$ $s^{-1}$) and stomatal conductance (0.287 µmol $m^{-2}$ $s^{-1}$) which was followed by silicic acid @ 0.2%. Foliar application at IW/CPE ratio of 1.0 did not significantly influence transpiration rate and stomatal conductance. At IW/CPE ratio of 0.8 foliar application of PPFM @ 1% recorded significantly higher transpiration rate and stomatal conductance (4.38 mmol $m^{-2}$ $s^{-1}$ ; 0.311 respectively) and was followed by foliar application of silicic acid @ 0.2%. At IW/CPE ratio of 0.6 and 0.4 foliar application of PPFM @ 1% produced significantly, higher transpiration rate and stomatal conductance. The increase in transpiration rate may be due to conservation and uniform maintenance of water potential from the produced osmoprotectants (sugars and alcohols) on the surface of host plants. Similar results were observed by Irvine et al. (2012).

Photosynthetic rate

Within the irrigation regimes IW/CPE ratio of 1.0 recorded higher photosynthetic rate (44.4 µmol $m^{-2}$ $s^{-1}$) and was comparable with IW/CPE ratio of 0.8 (43.3 µmol $m^{-2}$ $s^{-1}$) and lower rate was recorded in IW/CPE ratio of 0.4 (30.5 µmol $m^{-2}$ $s^{-1}$) (Table 2). The results show of that the transpiration rate was affected by 32 and 30% in IW/CPE ratio of 0.4 compare to IW/CPE ratio of 1.0 and 0.8 respectively. This could be due to moisture stress that reduced net photosynthetic rate of the crop eventually affecting the crop performance. The results are similar to Shah et al. (2010), Akhkha et al. (2011).

In foliar application treatments significantly higher photosynthetic rate was recorded in PPFM @ 1% applied treatment with 40.2 µmol $m^{-2}$ $s^{-1}$ followed by foliar application of silicic acid 0.2%. In interaction effect, IW/CPE ratio of 1.0 and 0.8 foliar application did not significantly influence while IW/CPE ratio of 0.6 and 0.4 varied upon the different stress regulators. Foliar application of PPFM 1% recorded increased photosynthetic rate of 39.4 µmol $m^{-2}$ $s^{-1}$ and 32.9 µmol $m^{-2}$ $s^{-1}$ in IW/CPE ratio of 0.6 and 0.4 respectively and was followed by foliar application of silicic acid @ 0.2%. PPFM utilize volatile $C_1$ compounds such as methanol generated by growing plants at cell division phase (Irvine et al. 2012) and increasing $CO_2$ concentration inside stomata leading to accelerated rate of photosynthesis and decreased the rate of photorespiration in $C_3$ plants. Similar reports were reported by Sivakumar et al. (2017).

Yield

Irrigation scheduling and drought management significantly influenced the yield of the crop (Table 3). IW/CPE ratio of 1.0 and 0.8 recorded significantly higher and comparable yield (7188 and 7142 kg $ha^{-1}$) and significantly lower yield was recorded in IW/CPE ratio of 0.4. The increase in yield could be attributed to consistent soil moisture availability due to increased level of irrigation that resulted in better crop growth and yield components. Similar findings were reported by Zhao et al. (2010). 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 significantly influence 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 as a result of increased water potential in the plant. The results are in corroboration to the findings of Madhaiyan et al. (2005).

Water productivity

Significantly higher water use productivity was recorded in IW/CPE ratio of 0.6 (Rs 257 $ha^{-1}$ $mm^{-1}$) while lower water productivity was recorded in IW/CPE ratio of 1.0 (Rs 207 $ha^{-1}$ $mm^{-1}$) (Table 3). Water use productivity was found to be increased either by increasing the yield or reducing the quantity of water applied or both. The increased water productivity in IW/CPE ratio of 0.6 can be attributed to the reduced frequency with which water was applied subsequently without reducing the yield. The results are in line with Kar and Verma (2005).

In foliar application treatments foliar application of PPFM recorded significantly higher and comparable values (Rs 248 $ha^{-1}$ $mm^{-1}$) with silicic acid 0.2% (Rs 239 $ha^{-1}$ $mm^{-1}$). Irrigating at IW/CPE ratio of 0.6 with foliar application of PPFM 1% recorded significantly higher water productivity (Rs 277 $ha^{-1}$ $mm^{-1}$) and was at par with IW/CPE ratio of 0.4 along with foliar application of PPFM @ 1% IW/CPE ratio of 0.6 with foliar application of silicic acid @ 0.2% and IW/CPE ratio of 0.4 with foliar application of silicic acid @ 0.2% were also found at par with IW/CPE ratio of 0.6 with foliar application of PPFM 1%. This could be attributed to the better management practice with reduced water consumption with promising yield increase.

Economics

Higher net return (INR 63,960) and B : C ratio (3.11) was attained under IW/CPE ratio 0.8 and was followed by IW/CPE ratio of 1.0 (Table 4). Among the foliar application treatments foliar application of PPFM @ 1% recoded higher net return and BC ratio (INR 60,923, 3.02 respectively) and was followed by silicic acid 0.2% (INR 57,984, 2.91). In interaction effect irrigating at IW/CPE ratio of 0.8 with foliar application of PPFM 1% recorded higher net return (Rs 66,151) and BC ratio (3.17).

## Conclusion

From the present study it can be concluded that optimizing irrigation with IW/CPE ratio of 0.8 is best suited for obtaining higher yield and net return. Under inadequate availability of water irrigating at IW/CPE ratio of 0.6 coupled with foliar application of PPFM @ 1% could stabilize the yields and realize higher water productivity.

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