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### Impact of Deficit Irrigations on Yield and Water Productivity of Maize (*Zea mays* L.) under Drip Irrigation

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#### ABSTRACT

In water-scarce conditions of the country, enhancement of maize yield and Crop Water Productivity (CWP) is vital. The objective of the research was to study evapotranspiration and irrigation under drip irrigation system for maize crop. A field experiment with 100%, 90%, 80%, and 70% application of irrigation water based on real-time ETo was designed at Water Management Research Farm, Renala Khurd, Okara, Punjab-Pakistan under drip irrigation system. A hybrid (30T60) maize was sown under the RCB layout on beds in the Kharif seasons of 2022 and 2023. In one hectare 86,485 plants were sown on 80 cm wide beds with 46 cm wide furrow in 67.72 m x 10.62 m experimental plot for each treatment. Data about fresh ears weight, grain yield, number of grain rows per ear, number of grains per row, 1000 grain weight, above-ground biomass were taken. During Kharif 2022, depth of water applied was 329.2 mm for 100% ETo, 296.3 mm for 90% ETo, 263.3 mm for 80% ETo, and 230.4 mm for 70% ETo. Grain yield of 9.20 tons/ha and CWP of 2.75 Kg/m<sup>3</sup> at 100% applied water was observed, while 9.20 tons/ha with 3.11 Kg/m<sup>3</sup>, 8.33 tons/ha with 3.16 Kg/m<sup>3</sup> and 9.33 tons with 4.05 Kg/m<sup>3</sup> at 90%, 80% and 70% applied respectively. However, during Kharif 2023, 11.3 tons/ha with 2.99 Kg/m<sup>3</sup>, 10.4 tons/ha with 3.06 Kg/m<sup>3</sup>, 10.3 tons/ha with 3.41 Kg/m<sup>3</sup>, 10.0 tons/ha with 3.78 Kg/m<sup>3</sup> of grain yield and CWP was found at 100%, 90%, 80% and 70% depth applied, respectively. So, 70% of ETo based water application for maize would be suitable for its better yield and CWP.

**Keywords:** hybrid maize, deficit irrigation, grain yield, biomass, water use efficiency

#### INTRODUCTION

Maize (*Zea mays* L.) belongs to the Poaceae family and is one of the major agronomic crops worldwide. Ali et al. (2022) described the conditions of water shortage for agriculture in the country. Comas et al. (2019) described limiting factor in agricultural crop production would be water scarcity. As evapotranspiration is influenced by soil moisture, therefore water management strategies would be required for better maize production. Cao et al. (2022) described a two years field experiment where the scarcity of water adversely affects the growth parameters and grain yield of summer maize. It was demonstrated that the alternate surface and subsurface drip irrigation grain yield was 6939.5 kg ha<sup>-1</sup>, corresponding to increases of

4.8% and 13.3% from 6625.0 and 6126.5 kg ha<sup>-1</sup> for subsurface drip irrigation and conventional surface drip irrigation, respectively. For WP, the difference between treatments followed a similar pattern in 2018 and 2019, i.e., the alternate surface and subsurface drip irrigation was significantly higher than the subsurface drip irrigation, while the subsurface drip irrigation was significantly higher than the conventional surface drip irrigation.

In terms of crop output in relation to the availability of water supply at various spatial scales, water productivity (WP) is a reliable benchmark (Edreira et al., 2018). Oiganji et al. (2016) worked on the yield and water productivity of maize and proved that grain yield and

biomass yield varied from 0.41 to 0.63 and 1.33 to 1.98 kg/m<sup>3</sup>. It was concluded that no yield and water productivity increase was observed in water deficit regimes. Kasem et al. (2015) recommended 80% ETo based applied water through a research trial for yield and water use efficiency compared to 100% of ETo. Zwart and Bastiaanssen, (2004) stated that agriculture is one of the most water-consuming sectors. So, water saving is pivotal for agricultural crop production. Based on a number of research studies range for crop water productivity of 1.1–2.7 kg m<sup>-3</sup> of maize was observed. Trout and DeJonge (2017) conducted consecutive four years of research trials on highlands in the United States. The objectives of this study were to evaluate the impact of deficit irrigations on the yield and water productivity of *Zea mays* L. under drip irrigation with an average, water 2.5 Kg/m<sup>3</sup> crop water productivity. It was observed that 125 tons' ha<sup>-1</sup> grain yields 630 mm of crop evapotranspiration. Beseli et al. (2020) found that crop water productivity was changes with weather and climatic conditions, soil texture, and vapor pressure deficit (VPD) (Mahbbob et al., 2022).

In maize water productivity enhancement is a challenge for food security under changing climatic scenarios Drip irrigation is better than surface/gravity irrigation for enhancing water use efficiency and water productivity (Oker et al., 2018; Roja et al., 2020). So, irrigation scheduling is important for crop water productivity improvement (Kadasiddappa and Rao, 2018).

## MATERIALS AND METHODS

A hybrid (30T60) was sown in consecutive two Kharif (autumn) seasons of 2022 and 2023 during August. The experiment was executed on a laser-level field at Water Management Research Farm, Renala Khurd, Okara (GPS Coordinates N 30°51.297' E073°32.589' with an altitude of 146 m). Seeds were treated with Imidacloprid 70 WS @ 5-7 g per Kg. In one hectare 86,485 plants were sown on 80 cm wide beds with 46 cm wide furrow in 67.72 m x 10.62 m experimental plot for each treatment Pendimethalene E 330 @ 5 L/ha + Atrazin 720 SC @ 2000 ml/ha was applied through irrigation within 20 hours of sowing for pre-emergence control of weeds. For control of narrow-leaf weeds, halo-sulforan methyl 75% WDG@ 50g/ha was applied. All treatments were irrigated according to the actual ETo up to 44 days for the normal growth of maize. Armyworm was controlled through Chlorpyrifos 40 EC 1000 ml/ha.

After 44 days the water applied was T1=100% of ETo, T2=90% of ETo, T3 80% of ETo, and T4 70% of ETo. 5 bags of SOP and 5 bags of DAP were applied as basal dose per hectare basis. 4 bags of urea per hectare were applied through drip irrigation (fertigation). Each treatment was replicated three times in a Randomized Complete Design (RCBD). Irrigation flow was measured by an Analog Flow meter attached with the head unit of the drip irrigation system. A handy moisture meter was used to verify the moisture contents of the soil. Crop water requirement was determined by following

$$\text{Crop Water Requirement} = K_c \times ETo$$

Data about fresh ears weight, grain yield, number of grain rows per ear, number of grains per row, 1000 grain weight, above-ground biomass was collected.

Table 1. Detail of irrigation water applied in recommended and different deficit irrigation levels irrigation water applied in each irrigation according to real-time ETo during Kharif 2022 and 2023.

Sr. No	Treatments	Depth of water applied (mm)	Volume of water applied per hectare
1	Application of 100% water calculated through ETo	329	3292 m <sup>3</sup>
2	Application of 90% water calculated through ETo	296	2963 m <sup>3</sup>
3	Application of 80% water calculated through ETo	263	2633 m <sup>3</sup>
4	Application of 70% water calculated through ETo	230	2304 m <sup>3</sup>

## Statistical Analysis

Analysis of variance was computed by Statistics 8.1 software. The significance of the means for each treatment was compared by the HSD Tukey Test. To find the relation between dependent variables, Pearson's correlation was used.

## RESULTS

### Fresh ears mass per hectare (Kg) (FEMPH)

Fresh ear mass per hectare was found significantly (P ≤ 0.05) affected by various deficit irrigation regimes. During the Kharif 2022, the fresh ears mass was 13.063

tons/ha at 100% irrigation level. The maximum fresh ears mass was 13.613 tons/ha at 70% water applied. The minimum fresh ear mass was 12.160 tons/ha produced by 80% of irrigation applied. However, during the Kharif 2023 fresh ear mass of 14.610 tons/ha was observed in 70% water applied and other treatment results were in line with Kharif 2023 (Figure 1).

#### **Number of grains rows per ear (NGRpE)**

During the Kharif 2022, 100% of irrigation water applied resulted 12.0-grain rows per ear, while 90% of irrigation water was 12.1. However, the maximum number of grain rows per ear was 12.7 at 80%, whereas the minimum of 11.7 grain rows per ear was observed at 70% irrigation level. During the Kharif 2023, the maximum average grain rows of 13.5 per ear were observed at 90% water applied (Figure 2).

#### **Number of grains per row (NGpR)**

When 100% irrigation water was applied the number of grains per row on a maize cob was 28.9, with 90% was 29.7, with 80% was 29.1, and with 70% was 28.9. During the Kharif season in 2023, the maximum average number of grains per row 29.65 per ear was observed with 90% water applied (Figure 3).

#### **1000-grain mass (g) (TGMg)**

During Kharif 2022, 1000 grain weight of 100% applied water was 430 g, while 90%, 80% showed 402 g, and 413 g, respectively. The minimum 1000 grain weight was revealed by 70% (2304 m<sup>3</sup>) of recommended water application was 385 g. During Kharif 2023, the maximum 1000-grain mass of 440 g was observed at 100% and 90% irrigation level (Figure 4).

#### **Above-ground biomass (AGBM)**

During the Kharif 2022, above ground, biomass of 100% applied water is 40.90 tons, while 90% and 80% showed 41.380 tons, and 39.25 tons, respectively. The maximum above-ground biomass was revealed by 70% of the recommended water application of 43.42 tons. During Kharif 2023, the maximum above-ground biomass of 50 tons/ha was observed in 100% applied water (Figure 5).

#### **Grain yield per hectare (GYpHa)**

During Kharif 2022, it was observed that there was a significant difference ( $P \leq 0.05$ ) among various treatments applied. The maximum grain yield per hectare (9.33 tons) was observed at 70% irrigation water followed by 9.20 and 8.33 tons at 90%, and 80% irrigation, respectively. Similarly, the minimum (9.04 tons) was shown by 100% water application.

However, during Kharif 2023, water application

according to 100% ETo was 11.3 tons/ha, water application according to 90% ETo was 10.4 tons/ha, water application according to 80% ETo was 10.3 tons/ha, and water application according to 70% ETo was 10.0 tons/ha was observed (Figure 6).

#### **Crop Water productivity (CWP) (Kg/m<sup>3</sup>)**

Water productivity showed a significant difference ( $P \leq 0.05$ ) among various treatments applied. Water productivity of 100% applied water was 2.75 Kg/m<sup>3</sup>, while 90% and 80% showed 3.11 Kg/m<sup>3</sup>, 3.16 Kg/m<sup>3</sup>, respectively. The maximum water productivity was 4.05 Kg/m<sup>3</sup> revealed by 70% of recommended water application. While during Kharif 2023, 2.99 Kg/m<sup>3</sup> was observed under 100%, WP of 3.06 Kg/m<sup>3</sup> under 90%, WP of 3.41 Kg/m<sup>3</sup> under 80%, and CWP of 3.78 Kg/m<sup>3</sup> under 70% of recommended irrigation compared with ETo (Figure 7).

#### **Correlation**

Fresh ears weight per hectare (FEWpH), number of grains per row (NGpR), WPKpM<sup>3</sup>, and grain yield per hectare (GYpHa) showed a positive correlation with above-ground biomass (AGBM). In contrast, it showed a negative correlation with cubic meter water applied (CMpHa). Grain yield per hectare (GRpE) had a negative correlation with above-ground biomass (AGBM), cubic meter water applied per hectare (CMpHa), and fresh ears weight per hectare (FEWpH). The number of ears per hectare (NEpHa) and thousand-grain weight (TGWgm) showed a positive correlation with CMpHa and a negative correlation with above-ground biomass (AGBM) and grain yield per ear (GRpE). The number of ears per hectare (NEpHa), number of grains per row (NGpR), water productivity (WPKpM<sup>3</sup>), and grain yield per hectare (GYpHa) expressed a positive correlation with fresh ears weight per hectare (FEWpH). The number of grains per row (NGpR) has a negative correlation with the number of ears per hectare (NEpHa) and thousand-grain weight (TGWgm). The number of grains per row (NGpR) and thousand-grain weight (TGWgm) revealed a positive correlation with grain yield per ear (GRpE). Thousand-grain weight (TGWgm) and grain yield per hectare (GYpHa) have a positive correlation with the number of ears per hectare (NEpHa). Water productivity (WPKpM<sup>3</sup>) and grain yield per hectare (GYpHa) have a positive correlation with the number of grains per row (NGpR). The values for grain yield per hectare (GYpHa) showed a positive correlation with water productivity (WPKpM<sup>3</sup>) (Figure 8).

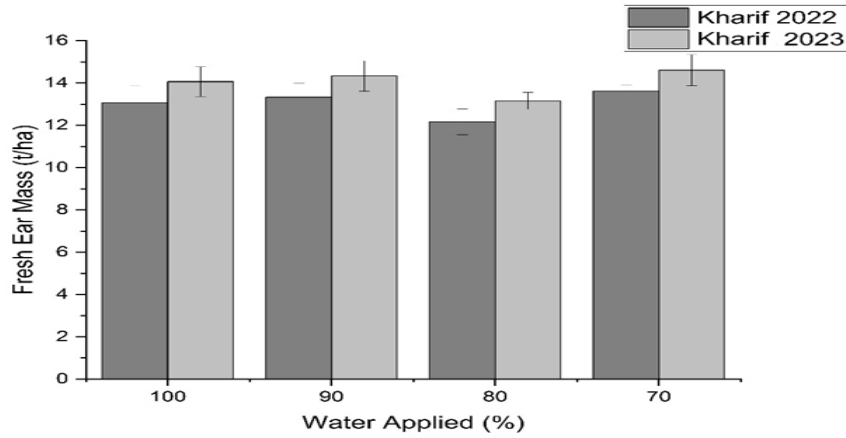


Figure 1. Influence of water deficit levels on ear mass per hectare of hybrid maize under drip irrigation in comparison with 100% irrigation as deficit by ETo.

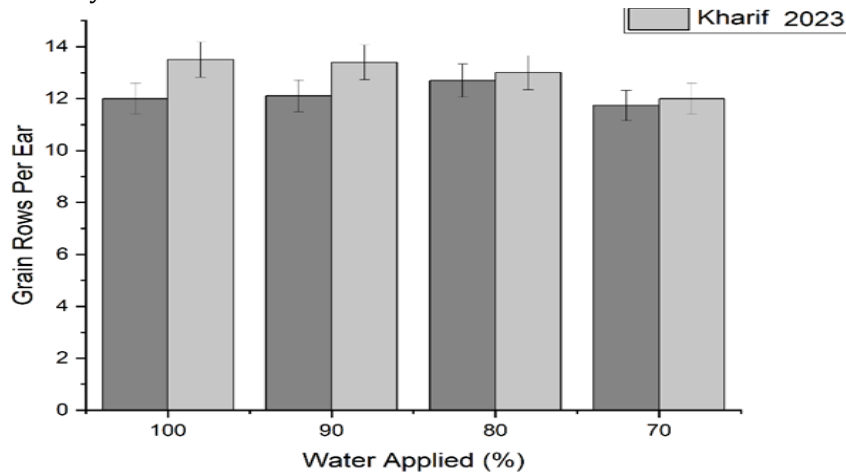


Figure 2. Influence of water deficit levels on grain rows per ear of hybrid maize under drip irrigation in comparison with 100% irrigation as a deficit by ETo.

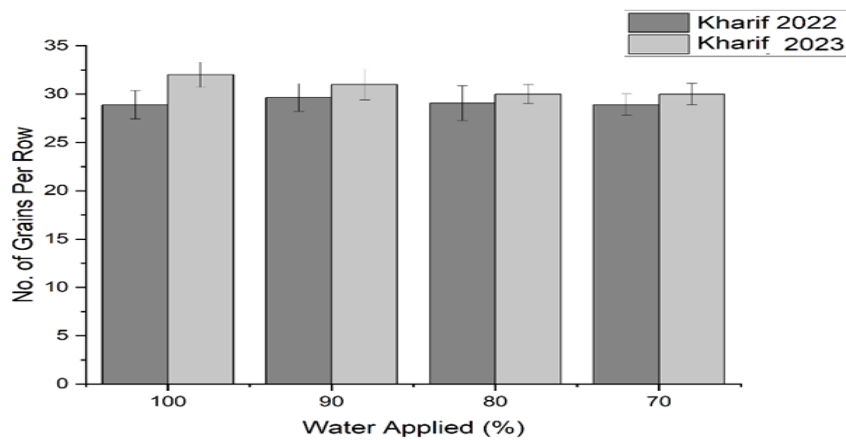


Figure 3. Influence of water deficit levels on number of grain per row of hybrid maize under drip irrigation in comparison with 100% irrigation as deficit by ETo.

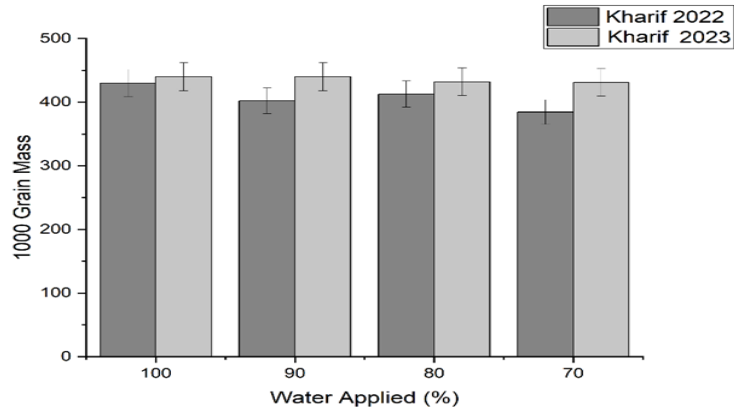


Figure 4. Influence of water deficit levels on thousand grain weight of hybrid maize under drip irrigation in comparison with 100% irrigation as deficit by ETo.

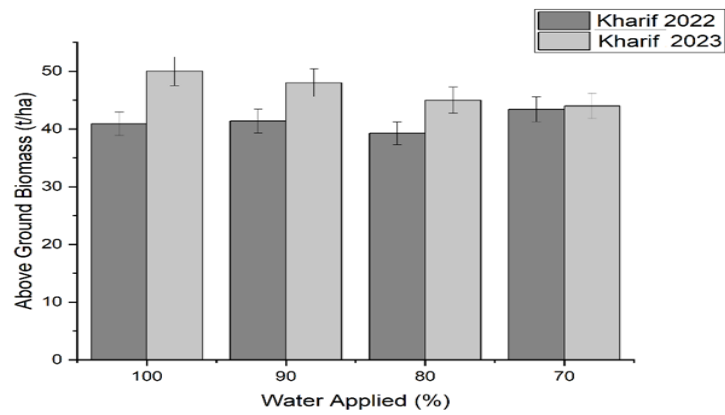


Figure 5. Influence of water deficit levels on above-ground biomass of hybrid maize under drip irrigation in comparison with 100% irrigation as deficit by ETo.

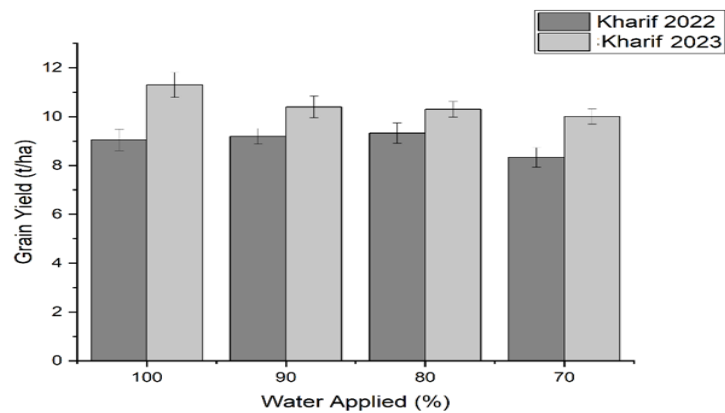


Figure 6. Influence of water deficit levels on grain yield per hectare of hybrid maize under drip irrigation in comparison with 100% irrigation as deficit by ETo.

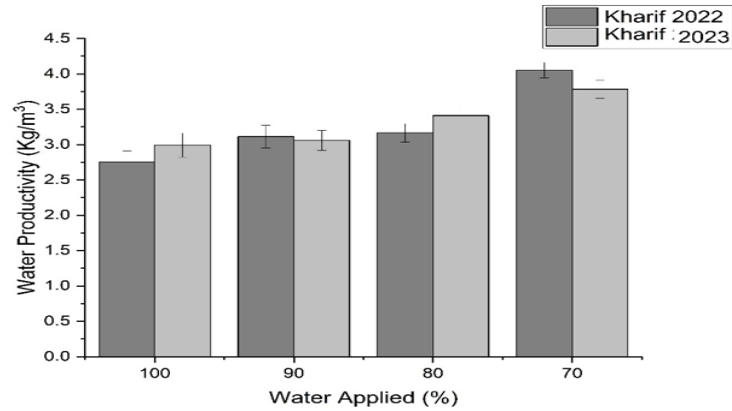


Figure.70. Influence of water deficit levels on water productivity (Kg/m<sup>3</sup>) of hybrid maize under drip irrigation in comparison with 100% irrigation as deficit by ETo

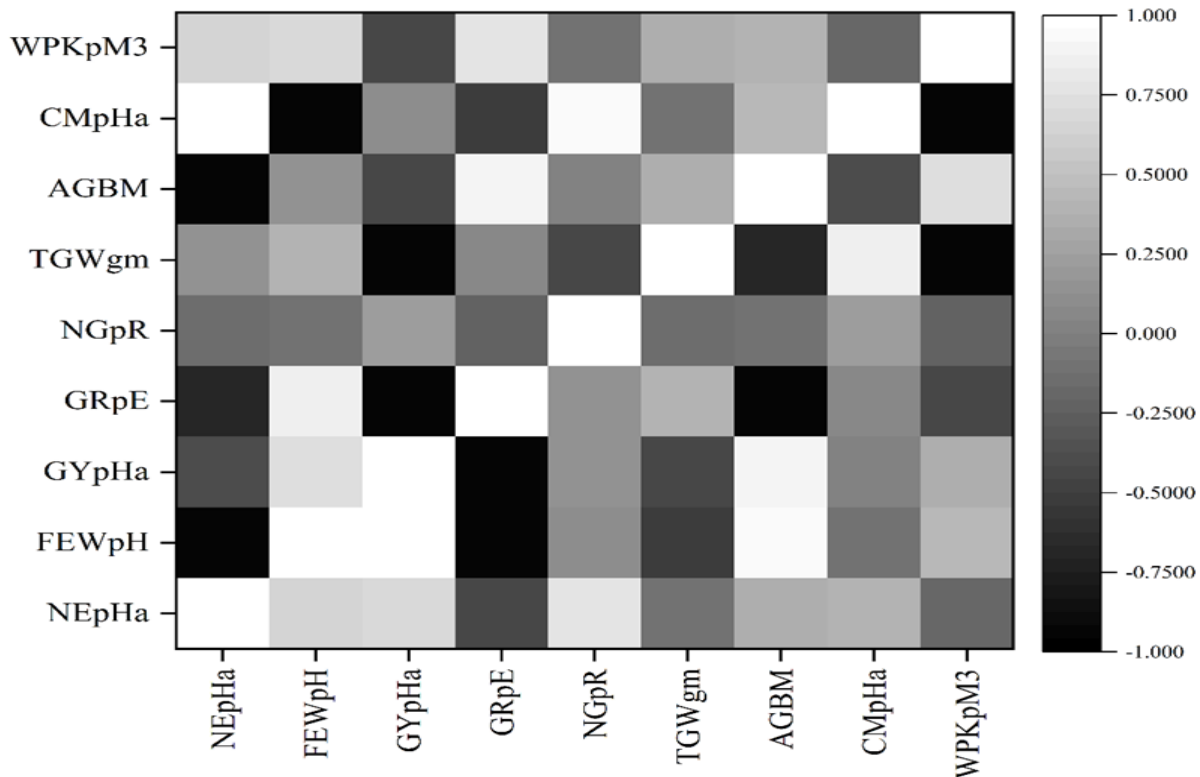


Figure.80. Pearson's Correlation Map of various attributes under study on maize under four irrigation levels.

**DISCUSSION**

Grain yield in maize is influenced by ears/unit area, number of kernels/ear (comprising number of kernel/rows and kernels/row), and weight of kernel. Every of these yield constituents is noted at various phases in the lifecycle of the plant. Adequate water and nutrients are necessary for canopy size and ampule yield. The initial reproductive structures' numeral is often

superior to what the plant is later proficient in supporting. The size of yield components is then influenced by the environmental and management stresses of the growing season (Harrison et al., 2014). The present research was executed to probe the CWP of maize hybrid under different water depletion levels. Controlled deficit irrigation is the method of dropping the quantity of water applied/irrigation at certain crop growth phases

with the purpose of saving water and energy under prevailing energy crises. Results revealed that the maximum number of grain rows/ear was 12.7, while the minimum i.e., 11.7 grain rows/ear was observed when 70% irrigation water was applied. 1000-grain weight (g) was 430 g by 100% irrigation, while the minimum 1000-grain weight (385 g) was revealed by 70% (2304 m<sup>3</sup>) of recommended water application. The maximum above-ground biomass (43.42 tons) was revealed by 70% (2304 m<sup>3</sup>) of recommended water application. The highest grain yield per hectare (9.33 tons) was observed at 70% (2304 m<sup>3</sup>) irrigation water whereas the minimum (9.04 tons) was shown by 100% water application. Other irrigation levels showed intermediate results. Maximum crop water productivity was 4.05 Kg/m<sup>3</sup> revealed by 70% (2304 m<sup>3</sup>) of recommended water application while minimum i.e., 2.75 Kg/m<sup>3</sup> was recorded in the case of 100% applied water.

The results of CWP in the present research work were supported by HY et al. (2000) who recorded water productivity as 2.11-3.37 kg m<sup>-3</sup> at Changwu. Lai et al. (2023) WUE recorded WUE (3.42 kg m<sup>-3</sup>) for the QS51 maize hybrid, the value was close to our findings of WUE (3.16 Kg/m<sup>3</sup>). A slight difference in values might be due to different geographical conditions, types of soil, and maize hybrids. Dumet-Montoya et al. (2013) recorded water productivity of maize ranged from 1.84 to 2.79 kg m<sup>-3</sup> in Azul, Argentina. Other researchers i.e., Roygard (2002), Szalokine (2002), Jin et al. (2016), and Victor et al. (2018) China, 2.34-2.88 kg m<sup>-3</sup> at Fundulea, Romania, 1.28-2.44 kg m<sup>-3</sup> at Szarvas, 1.49-2.67 kg m<sup>-3</sup> at Wangtong and 1.26-2.31 kg m<sup>-3</sup> at Xifeng, respectively. Normally, 50% of water is being saved through drip irrigation compared with the flood. Our findings are in line with Chaudhary et al. (2020) who executed research work on maize under drip irrigation and recorded water irrigation savings of up to 48% close to our research work. Oiganji et al. (2016) executed research work on maize crops under drip irrigation using different depletion levels and noted crop productivity of maize crop ranged 0.41-1.98 kg/m<sup>3</sup> lower than our research work. This might be due to variations in edaphic and varietal features in both studies. Fresh ears weight was 13.063 tons/ha, which was shown by 100%. The maximum fresh ears weight was 13.613 tons/ha at 70% water applied. The minimum fresh ear weight was 12.160 tons/ha produced by 80% of irrigation applied. Fresh ears weight of 13.613 tons/ha was revealed by 70%

irrigation water.

The fresh weight of ears in the current research was recorded as 13,063 (100% irrigation), 13,613 (70% irrigation level), and 12,160 kg/ha (80% irrigation level). Our results were close to the findings of Lai et al. (2023) who recorded an average 15,693 kg/ha corn ear weight for the QS51 maize hybrid. The difference in values may be due to difference of maize hybrid, topographical, and other climatic conditions. Yield in our research work was maximum (13,613 kg/ha) with the lowest water depletion of 70%. The results were supported by El-Labad et al. (2019) who recorded unmarketable tomato yield with a water depletion irrigation level of 60% whereas the lowermost values were documented with depletion levels of 80 and 100 % same trend was recorded in our research. Our results were contrary to Ragab et al. (2018) who evaluated the impact of deficit irrigation 100, 85, 70, and 55% of the underusing surface and sub-surface drip irrigation. Outcomes showed that full irrigation treatment 100% produced the maximum values of vegetables and yield characteristics of tomato crops. The difference may be due to different crops, drip irrigation methods, and geographical situations in the two studies. Our results of highest crop yield under the highest water depletion level were supported by Biswas et al. (2015) who recorded an increased yield of tomato under drip irrigation with a maximum depletion level. The grain-filling procedure is an important to determining factor of 1000-grain weight and overall population grain weight. Conferring to our study, the grain weight at 100% irrigation was comparatively greater than 90, 80, and 70% depletion levels. Our results were confirmed by the research of Dumet-Montoya et al. (2013), El-Labad et al. (2019), and Lai et al. (2023).

## CONCLUSION

Based on the above results it could be concluded that crop water productivity of maize was inversely affected by the rate of water applied to certain extent. Based on above results it was suggested that water application is important to keep in view ETo and grain yield for maize. So, 70% of ETo based water application for maize would be suitable for its better yield and CWP in loamy soils of semi-arid regions.

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