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Influence of CWSI-Based Irrigation Scheduling on Agronomic Traits (*Zea mays* L.) and Sustainable Water Use in Maize

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed to optimize irrigation scheduling for maize (*Zea mays L.*) using the crop water stress index (CWSI) to improve water use efficiency and yield. The study was conducted in the South farm of the School of Agricultural Sciences, Karunya Institute of Technology and Sciences, Coimbatore during the *Kharif* and *Rab*i seasons of 2022.
A randomized block design was used with seven treatments, including a control T_1 no irrigation). Irrigation at all critical stages (T_2) and other five irrigation treatments ($T_{3\ to}\ T_7$) based on different CWSI values ranging from 0.2 to 1.0. Infrared thermometry was used to measure canopy temperatures for estimating the CWSI.

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The results showed that irrigation at 0.2 CWSI (T3) had a significant positive effect on kernel and stover yield when compared with all the other treatments during both the seasons, with the highest kernel yield of 7138.83 Kg ha^{-1} and 8014.8 Kg ha^{-1}, stover yield of 11134 Kg ha^{-1} and 12765 Kg ha^{-1}, respectively and lowest kernel yield of 2267 Kg ha^{-1} and 2325 Kg ha^{-1}, stover yield of 8156 Kg ha^{-1} and 6491 Kg ha^{-1}, respectively. The other treatments had intermediate values and did not show any consistent pattern. Irrigation at 0.2 CWSI resulted in the highest water use efficiency (WUE) of 14.7 Kg ha-cm^{-1} and 17.6 Kg ha-cm^{-1}, and irrigation usage of 31.73% and 22.26% during the Kharif and Rabi seasons of 2022, respectively and the lowest water use efficiency (WUE) of 7.72 Kg ha-cm^{-1} and 17.6 Kg ha-cm^{-1} was found in T_7 during the Kharif and Rabi seasons of 2022, respectively. The results suggest that irrigation at 0.2 CWSI could be a promising option for achieving higher kernel and stover yields with minimal water use and maximum WUE and IUE.

Keywords: Crop Water Stress Index (CWSI); Water Use Efficiency (WUE); agronomic traits; irrigation scheduling; maize.

1. INTRODUCTION

Maize (*Zea mays L.*) is considered as the third most important cereal after rice and wheat, globally as well as in India. Maize is a versatile crop that can be grown in diverse environmental conditions and has multiple uses. It is a significant source of carbohydrates, with around 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal 100g^{-1} [1]. Ranum et al. [1] reported that According to FAO, the global production of maize in 2021 was 1.19 billion metric tons. Globally, around 15 million farmers work in maize production in India, and by 2022, the country will need to produce 45 million metric tonnes of the crop. Water stress in maize crops has a direct impact on their biomass and production, with a linear relationship between crop production and water use influenced by various factors such as irrigation and soil management, climate, soil type, hybrid plant characteristics, plant population, and disease pressure [2]. Infrared thermometry has several advantages in precise management of irrigation water. It enables continuous monitoring of crop water status and can integrate both soil water status and climatic conditions [3]. Canopy temperature (Tc) has received considerable attention in detecting and diagnosing crop water stress as it is non-destructive and continuous, and scalable from plant to field [3–5]. Among the indices derived by using Tc, the most common is the crop water stress index (CWSI) [6–8]. Crop water stress index (CWSI) is a well-established method for monitoring crop water stress and determining irrigation schedules [9–11]. It is based on the difference between plant surface temperature and air temperature and atmospheric vapor pressure deficit. Infrared thermometers are commonly used to measure these parameters used in irrigation scheduling [12,13]. There are various approaches to determining CWSI, including an empirical approach [6], a theoretical approach [7,8], and the use of canopy reference surfaces (artificial or actual) [3,14]. Therefore, this study was taken up to formulate the irrigation scheduling for maize crop based on the CWSI; to enhance its yield by improving the water use efficiency and irrigation usage of the crop.

2. MATERIALS AND METHODS

2.1 Study Area Location

The field experiments were conducted in two consecutive seasons of Kharif and Rabi 2022, at the South farm, School of Agricultural Sciences, Karunya Institute of Technology and Sciences, Coimbatore, India. The farm is geographically situated in Tamil Nadu's North Western Agroclimatic Zone at 10°55'57.5"°N latitude, 76°45'02.2" E longitude, and at an altitude of 516.97 m above mean sea level. Throughout the crop growing seasons of Kharif 2022 and Rabi 2022, average maximum and the minimum temperatures were 26.6°C & 18.4°C and 32.6°C & 16.2°C respectively, the total rainfall received during the cropping periods of Kharif 2022 and Rabi 2022were 230.8 mm and 95.2mm respectively. Similarly, for the mentioned cropping periods the average relative humidity recorded were 85.0 per cent and 65.3 per cent respectively, the average bright sunshine hours were 5.8 and 5.93 hours respectively, the average evaporation were 4.8 and 5.2mm day^{-1} respectively and the mean solar radiation recorded were 356.3 and 355.9 Cal cm^{-2} day^{-1} respectively.

2.2 Experimental Details

Field experiments were laid out in Randomized block design and the treatments were replicated thrice. The treatments followed for the field experiments conducted during the course of the study were the T_1- Control (No irrigation), T_2 - Irrigation at all crucial stages of Maize, T_3 - Irrigation at 0.2 CWSI, T_4 - Irrigation at 0.4 CWSI, T_5 - Irrigation at 0.6 CWSI, T_6 - Irrigation at 0.8 CWSI, T_7 - Irrigation at 1.0 CWSI. In all the CWSI based treatments (T_3 to T_7), irrigations were given only when the treatment attains its respective CWSI threshold values. For the treatment T_2, irrigations were given during the crucial stages of the crop growth viz. germination, flowering and maturity stages and for Treatment T_1 no irrigation was given for the crop and it grew only as natural rains occurred. "V" notches were installed in the irrigation channels to measure total flow distributed to all the treatments plots in each replication. Quantum of water applied was calculated by working out the consumptive water use and by adding the quantity of effective rainfall water to it.

Canopy temperatures (Tc) were measured using a hand-held infrared thermometer (HTC MTX^{-1}) that detects radiation in the 8–14 μ wave band and has a field of view of 3º. The temperature readings were taken at a horizontal angle of 30–40º, ensuring only the crop canopy was within the viewed area. Measurements were taken between 12:00 and 14:00 h (Indian standard time) under clear skies when the sun was unobscured by clouds.

2.3 WUE and CWSI Estimation

Water use efficiency (WUE) was worked out from the yield of maize and the amount of water used [15] and expressed in kg $ha^{-1}cm^{-1}$. WUE= Grain yield (kg ha^{-1}) / Quantity of total water applied (cm) (1)

The CWSI was assessed by using the formula by following the prescribed standard procedures [16]. CWSI = [(Tc –Ta) – (TNWS – TA)] / [(TMWS – TA) – (TNWS – TA)] (2)

Where, TC is the canopy temperature, TA is the air temperature, TNWS is the non-water-stressed canopy temperature, and TMWS is the maximum water-stressed canopy temperature.

2.4 Statistical Analysis

Fisher's method of analysis of variance (ANOVA) was used to statistically analyse the experimental data acquired, according to Gomez & Gomez [17]. Critical Difference (CD) values were calculated wherever the 'F' test was found significant at 5 percent level.

3. RESULTS AND DISCUSSION

3.1 Impact of CWSI Based Irrigation Scheduling on Maize Yield and Harvest Index

Table 1 presents the results of different irrigation treatments on kernel yield, stover yield, and harvest index (HI) of maize recorded during the consecutive seasons of Kharif and Rabi 2022-23. In Kharif 2022-23, the control treatment (T_1) had the lowest kernel and stover yield, with 2267 Kg ha^{-1} and 8156 Kg ha^{-1}, respectively. On the other hand, the irrigation treatment at 0.2 CWSI (T_3) had the highest kernel and stover yield, with 7138.8 Kg ha^{-1} and 11134 Kg ha^{-1}, respectively. The other treatments had intermediate values for kernel and stover yield. The harvest index (HI) values for all treatments were lower than 0.4, with T_3 having the highest HI (0.39) and T_1 having the lowest HI (0.21). In the second season of Rabi 2022-23, similar trend was observed as in the Kharif 2022-23 for kernel and stover yield, with T_3 having the highest yield (8014.8 Kg ha^{-1} and 12765 Kg ha^{-1}, respectively) and T_1 having the lowest yield (2325.17 Kg ha^{-1} and 6491.05 Kg ha^{-1}, respectively). The HI values for all treatments were slightly higher during the second season of Rabi 2022-23 when compared to Kharif 2022-23, with T_2 having the highest HI (0.39) and T_1 having the lowest HI (0.26).

The results indicated that irrigation at 0.2 CWSI (T_3) had a significant positive effect on kernel and stover yield of maize when compared with other treatments during both the seasons, by registering a higher kernel and stover yield. The control treatment (T_1) registered the lowest value. The other treatments had intermediate values and did not show a consistent pattern. The higher HI values observed in the second season indicated that the plants were able to allocate more resources to kernel production. These findings imply that irrigation at 0.2 CWSI may be a promising strategy for increasing kernel and stover yields while consuming minimal water. These findings were consistent with the previous research that had demonstrated the benefits of using CWSI as a tool for efficient irrigation management [2]. The control treatment had the lowest kernel and stover yields in both seasons, which highlights the importance of irrigation in achieving optimal yields in maize production. Irrigating at all critical stages (T2) resulted in significantly higher kernel and stover yields compared to the control treatment, but the harvest index was not significantly different from the control in either season. This suggests that this treatment may have resulted in a less efficient use of water, as more water was used to produce a higher biomass but not necessarily a higher proportion of kernels. Irrigating at 0.4, 0.6, and 0.8 CWSI also resulted in higher yields compared to the control treatment, but not as high as the yields obtained with irrigation at 0.2 CWSI. Similar results were also reported from another research which suggested a seasonal mean CWSI value of 0.26 and a harvest index value of 0.40 to start irrigations in soybean plants [18].

3.2 Effect of CWSI Based Irrigation Scheduling on Water Use and Irrigation Use Efficiency of Maize Crop

Table 2 provides the information on water use efficiency and irrigation use efficiency of different treatments for the two seasons of maize crop. In the first season of Kharif 2022-23, the control treatment (T_1) received no irrigation and had a total water usage of 230.9 mm ha^{-1}. The other treatments, which received varying levels of irrigation based on crop water stress index (CWSI), had recorded a total water usage of amounts ranging from 365.9 mm ha^{-1} (T_7) to 515.9 mm ha^{-1} (T_2). The highest water use efficiency was observed in T_3 (14.7 Kg ha^{-1}cm^{-1}) followed by T_4 (13.2 Kg ha^{-1}cm^{-1}) and T_5 (9.5 Kg ha^{-1}cm^{-1}). The lowest water use efficiency was observed in T7 (7.72 Kg ha^{-1}cm^{-1}) and T6 (8.49 Kg ha^{-1}cm^{-1}). In the second season, the control treatment (T_1) again had the lowest total water usage of 140.3 mm ha^{-1}, while T_2 had the highest total water usage of 590.25 mm ha^{-1} (see Table 3). The water use efficiency ranged from 12 Kg ha^{-1}cm^{-1} in T_2 to 17.6 Kg ha^{-1}cm^{-1} in T_3. The irrigation usage varied from 0% in T_1 to 31.7% in T_3 for the first season (as shown Table 2), and from 0% in T_1 to 22.3% in T3 for the second season (as presented in Table 3).

The results shown have that irrigating the maize crop at 0.2 CWSI (T_3) had highest water use efficiency during both the seasons. This was even superior than the treatment T_2, which received irrigation at all the critical stages of maize. This demonstrates that, irrigating the maize crop at 0.2 CWSI level could be more effective. The higher irrigation use efficiency observed in 0.2 CWSI (T_3), indicates that the water has been effectively utilized by the crop for its growth and development, when the crop gets irrigated to that level. Overall, the results suggest that irrigation at 0.2 CWSI could be an effective strategy for improving water use efficiency and irrigation usage in maize production. You [19] also suggested that an increase in high volume irrigation limits boosted plant height and yield components.

3.3 Economics of Maize as Influenced by CWSI Based Irrigation

Table 4 presents the economics of maize crop as influenced by CWSI based irrigation during *Kharif* 2022-23 and *Rabi* 2022-23 seasons, showing the grain returns, stover returns, net returns, and B:C ratio of different treatments for two seasons. The treatments are the different irrigation levels, ranging from no irrigation to irrigation at 1.0 CWSI. In the first season, the highest grain returns were observed for irrigation at 0.2 CWSI (₹157,054 ha^{-1}) (T3), followed by irrigation at 0.4 CWSI (₹141,306 ha^{-1}) (T4) and then irrigation at all critical stages (₹139,832 ha^{-1}) (T2). The lowest grain returns were obtained from the control treatment with no irrigation (₹49,874 ha^{-1}). The highest values were observed for irrigation at 0.2 CWSI (T3), and the lowest values for the control treatment (T1). The B:C ratio was highest for irrigation at 0.2 CWSI (2.70) and lowest for the control treatment (1.03). In the second season, the trend was similar to the first season. The highest grain returns were again observed for irrigation at 0.2 CWSI (₹176,326 ha^{-1}), followed by irrigation at 0.4 CWSI (₹163,358 ha^{-1}) and irrigation at all critical stages (₹156,096 ha^{-1}). The lowest grain returns were again obtained from the control treatment with no irrigation (₹51,154 ha^{-1}). The highest values were observed for irrigation at 0.2 CWSI and the lowest values for the control treatment. The B:C ratio was highest for irrigation at 0.2 CWSI (3.03) and lowest for the control treatment (1.01). Overall, the results indicate that irrigation at 0.2 CWSI provided the highest grain and stover returns, net returns, and B:C ratio. When compared with conventional methods, infrared thermometers used in this study was one of the most economical and non-destructive techniques [3,20].

Table 1. Effect of CWSI based irrigation scheduling on yield of maize crop during 2022 *kharif* and 2023 *Rabi* seasons

Treatments	Kharif 2022-23			Rabi 2022-23		
	Kernel yield (Kg ha^{-1})	Stover yield (Kg ha^{-1})	Harvest Index (HI)	Kernel yield (Kg ha^{-1})	Stover yield (Kg ha^{-1})	Harvest Index (HI)
T1: Control (No irrigation)	2267	8156	0.21	2325.2	6491.1	0.26
T2: Irrigation at all critical stages of Maize	6356	10265	0.38	7095.3	10876.	0.39
T3: Irrigation at 0.2 CWSI	7138.8	11134.	0.39	8014.8	12765.	0.39
T4: Irrigation at 0.4 CWSI	6423	10564.	0.38	7425.4	11134.	0.4
T5: Irrigation at 0.6 CWSI	4318	9394.	0.31	6245.3	10387.	0.38
T6: Irrigation at 0.8 CWSI	3489	10159.	0.25	4746.8	9159.	0.34
T7: Irrigation at 1.0 CWSI	2823.	7564.	0.27	3891.11	8483.	0.31
Mean	4687.83	9605.14	0.31	5677.69	9899.29	0.35
SE(d)	529.15	793.73	0.01	673.78	881.92	0.01
CD (5%)	1152.92	1729.38	0.03	1468.05	1921.53	0.03

Table 2. Effect of CWSI based irrigation scheduling on Water use of maize crop during 2022 *Kharif season*

Treatments	Kharif 2022-23				
	ER (mm ha^{-1})	IW (mm ha^{-1})	TW (mm ha^{-1})	Water use efficiency (Kg ha^{-1}cm^{-1})	Irrigation usage (%)
T1: Control (No irrigation)	230.9	0	230.9	9.8	0
T2: Irrigation at all critical stages of Maize	230.9	285	515.9	12.3	22.3
T3: Irrigation at 0.2 CWSI	230.9	225	485.9	14.7	31.7
T4: Irrigation at 0.4 CWSI	230.9	255	485.9	13.2	25.2
T5: Irrigation at 0.6 CWSI	230.9	210	455.9	9.5	20.6
T6: Irrigation at 0.8 CWSI	230.9	180	410.9	8.5	19.4
T7: Irrigation at 1.0 CWSI	230.9	135	365.9	7.7	20.9

**ER- effective rainfall, IW- irrigation water, TW- total water (water use), CWSI- Crop Water Stress Index and Water saved was calculated based on quantity of water applied for irrigation excluding rainfall*

Table 3. Effect of CWSI based irrigation scheduling on Water use of maize crop during 2023 *Rabi* season

Treatments	Rabi 2022-23				
	ER (mm ha^{-1})	IW (mm ha^{-1})	TW (mm ha^{-1})	Water use efficiency (Kg ha^{-1}cm^{-1})	Irrigation usage (%)
T1: Control (No irrigation)	95.3	0	140.3	16.6	0
T2: Irrigation at all critical stages of Maize	95.3	495	590.3	12	14.3
T3: Irrigation at 0.2 CWSI	95.3	360	455.3	17.6	22.3
T4: Irrigation at 0.4 CWSI	95.3	405	500.3	14.8	18.3
T5: Irrigation at 0.6 CWSI	95.3	315	410.3	15.2	19.8
T6: Irrigation at 0.8 CWSI	95.3	270	365.3	13	17.6
T7: Irrigation at 1.0 CWSI	95.3	225	320.3	12.2	17.3

**ER- effective rainfall, IW- irrigation water, TW- total water (water use), CWSI- Crop Water Stress Index and Water saved was calculated based on quantity of water applied for irrigation excluding rainfall*

Table 4. Effect of CWSI based irrigation scheduling on the economics of maize crop during Kharif 2022-23 and Rabi 2022-23 seasons

	Kharif 2022-23				Rabi 2022-23			
Treatment	**Grain Returns (₹ ha⁻¹)**	**Stover Returns (₹ ha⁻¹)**	**Net returns (₹ ha⁻¹)**	**B:C ratio**	**Grain Returns (₹ ha⁻¹)**	**Stover Returns (₹ ha⁻¹)**	**Net returns (₹ ha⁻¹)**	**B:C ratio**
T1: Control (No irrigation)	49874	12234	1768	1.03	51154	9737	5517	1.01
T2: Irrigation at all critical stages of Maize	139832	15398	89430	2.36	156096	16314	106610	2.62
T3: Irrigation at 0.2 CWSI	157054	16701	109315	2.70	176326	19148	131034	3.03
T4: Irrigation at 0.4 CWSI	141306	15846	91952	2.41	163358	16701	114859	2.76
T5: Irrigation at 0.6 CWSI	94996	14091	44647	1.69	137397	15581	88538	2.37
T6: Irrigation at 0.8 CWSI	76758	15239	27637	1.43	104430	13739	53809	1.84
T7: Irrigation at 1.0 CWSI	62106	11346	9112	1.14	85604	12725	33989	1.53

4. CONCLUSION

Based on the discussions made, earlier it is concluded that irrigating the maize crop at 0.2 CWSI (T3) proves effective in terms of improving maize grain yield, stover yield, net returns, and B:C ratio, Further, the study categorically demonstrates that irrigating the maize crop at 0.2 CWSI is significantly superior, economically viable and ecologically sustainable approach with the increased crop yields, improved profits and reduced utilization of water for irrigation, than irrigating the maize crop at the critical stages of its growth, Therefore, irrigation at 0.2 CWSI proves to be the most effective and economically viable strategy for enhancing maize yield and profitability.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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