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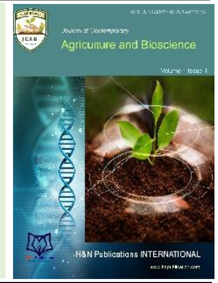

Research Article **Open Access**

Impact of Stage-Specific CROPWAT Irrigation Scheduling on Water Use Efficiency and Yield of Maize

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A B S T R A C T

Water scarcity and declining groundwater levels necessitate efficient irrigation strategies for sustainable maize production in the drought-prone Barind Tract of Bangladesh. This study evaluated the effects of stage-specific irrigation scheduling derived from the FAO CROPWAT 8.0 model on maize growth, yield, grain quality, and water use efficiency during the Rabi season of 2023–2024 at the University of Rajshahi. Eight irrigation treatments, including continuous deficit, full CROPWAT-based irrigation, stage-specific deficit strategies, and the standard farmer practice, were evaluated in a split-plot design with three replications. Compared with the standard irrigation practice (I_8), treatments I_3, I_6, and I_7 showed comparable performance for key parameters. At 120 DAS, plant height under I_3 and I_6 was only about 2–3% lower than I_8, while I_7 showed a moderate reduction of about 6%. Total dry matter accumulation at 120 DAS under I_3 and I_6 remained within about 1–2% of I_8, and I_7 within about 5%, indicating sustained biomass production under stage-specific irrigation. Grain yield under I_3 and I_6 was closely comparable to I_8, with reductions of about 3–8%, while I_7 recorded yields within about 14% of the standard practice. Similar trends were observed for straw yield, where I_3 and I_6 maintained yields within about 3–6% of I_8 and I_7 within about 18%. Grain quality was also preserved under optimized irrigation, as carbohydrate content under I_3 and I_6 was only about 2–3% lower than I_8, while protein content under I_6 and I_7 remained comparable to the standard practice. In contrast, severe and continuous deficit irrigation treatments resulted in marked reductions across all parameters. Overall, the findings indicate that CROPWAT-based stage-specific irrigation strategies can maintain maize yield, biomass, and grain quality close to conventional irrigation while reducing water use, offering a practical approach for improving water productivity and conserving groundwater in water-scarce regions of Bangladesh.

Keywords: Maize; CROPWAT 8.0; Stage-specific irrigation; Water use efficiency; Drought-prone and Barind region.

INTRODUCTION

Bangladesh is widely recognized as one of the countries most vulnerable to climate change, with rising temperatures, erratic monsoon rainfall and recurrent droughts increasingly constraining agricultural production. The north-western Barind Tract of Bangladesh, including Rajshahi District, is widely recognized as one of the country's most drought-prone agro-ecological zones. Long-term analyses show that the Barind region receives the lowest rainfall in Bangladesh, with highly variable monsoon precipitation and a growing frequency of meteorological and agricultural droughts driven by climate change. Afrin et al., (2024) describe the Barind as a climate "hotspot" with high sensitivity and limited adaptive capacity, while recent social–ecological assessments and rainfall-based drought indices confirm recurrent moderate to extreme drought over large parts of the tract. In Rajshahi and surrounding upazilas, declining and erratic rainfall, rising temperatures and prolonged dry spells are already constraining crop production and shortening the effective growing season, particularly in the dry (Rabi/Boro) period (Rashed et al., 2024).

Agriculture in the Barind Tract is heavily dependent on groundwater-based irrigation. Expansion of dry-season Boro rice, supported by deep tube wells, has been central to regional food security but has also driven unsustainable abstraction. Case studies from Rajshahi document rapid groundwater table decline—up to several tens of metres in some rural areas—as irrigated area and pumping intensity have expanded (Aziz et al., 2015). Hydrogeological and sustainability assessments conclude that current groundwater use for irrigation in north-west Bangladesh is approaching or exceeding renewable limits in many locations, with recharge constrained by the Barind's hard clay soils and decreasing rainfall (Khan, 2021). Recent vulnerability studies further show that terminal droughts increasingly coincide with critical crop stages, exacerbating production risk for farm households (Rahaman et al., 2025).

Against this backdrop of water scarcity, there is strong policy interest in shifting at least part of the Barind production system away from water-intensive Boro rice towards relatively water-efficient crops. Maize (*Zea mays* L.) has emerged as one of the most promising alternatives in Bangladesh due to its high yield potential, versatility as food–feed–industrial raw material, and suitability for the dry season under irrigation. Recent reviews and empirical studies indicate that maize cultivation in Bangladesh is consistently profitable, often outperforming Boro rice and wheat in terms of net returns and benefit–cost ratios (Begum et al., 2024). National and regional analyses show rapid growth in maize area and production over the past two decades, driven primarily by demand from the poultry and livestock sectors but increasingly also by human consumption and processing industries (Sayed et al., 2020a). However, on-farm yields in Bangladesh remain below those in leading maize-producing countries, reflecting constraints in input use, variety choice and especially water and nutrient management (Bhuiyan et al., 2015).

Water use efficiency (WUE)—the ratio of biomass or grain yield to water consumed or applied—has become a key performance indicator for sustainable maize production under limited water supplies. Global syntheses highlight that maize shows substantial scope for improving WUE through integrated genetic and agronomic strategies, including optimized irrigation, nutrient management and conservation tillage (Gobezie et al., 2025). Experimental work from semi-arid and sub-humid regions demonstrates that well-designed deficit irrigation can significantly increase WUE while maintaining or only modestly reducing grain yield, especially when water stress is avoided during highly sensitive stages such as tasseling and grain filling (Bayisa et al., 2021a). In Bangladesh, field experiments under conservation and minimum tillage systems show that appropriate irrigation management can enhance both water productivity and environmental sustainability of irrigated maize on red-brown terrace soils similar to those of the Barind (Sayed et al., 2020b). Nonetheless, local studies also indicate that severe water stress at critical stages leads to sharp yield and quality reductions, underscoring the importance of precise timing and amount of irrigation (Xing & Wang, 2024).

In water-scarce environments like Rajshahi, farmers' irrigation decisions for maize are often guided by experience rather than quantitative estimates of crop water requirements or soil water balance. This can result in both over-irrigation—wasting scarce groundwater and increasing pumping costs—and under-irrigation, which reduces yield and input-use efficiency. Stage-based irrigation management, where water is strategically concentrated at phenologically sensitive periods, offers a promising pathway to reconcile yield and water-saving objectives. Studies from various semi-arid regions have shown that prioritizing irrigation around flowering and grain filling, while allowing moderate stress at less sensitive stages, can improve WUE and water productivity compared with uniform full irrigation (Bayisa et al., 2021b; Faloye et al., 2024; Gheysari et al., 2015). However, the optimum distribution of limited water among growth stages is highly context-specific, depending on local climate, soil, cultivar and management.

The CROPWAT decision-support model, developed by FAO, has been widely used to estimate crop water requirements and design irrigation schedules based on climate, soil and crop parameters. Model-based studies across different regions report that CROPWAT 8.0 can reasonably simulate maize evapotranspiration, effective rainfall and irrigation needs and can be used to derive practical irrigation schedules, including those tailored to specific growth stages (Bhat et al., 2017). Recent work has applied CROPWAT to assess changing irrigation demands of maize under climate change scenarios, as well as to optimize irrigation scheduling and improve WUE in diverse agro-ecosystems (Reta et al., 2024; Şen, 2023). A growing body of research indicates that integrating CROPWAT-derived schedules with field experimentation can help reduce applied water by 20–30% without compromising yield in maize and other field crops (Gabr, 2022; Hessain Yagoob, 2015).

Despite these advances, empirical evidence from Bangladesh's drought-prone Barind region remains limited. Most local studies focus either on characterizing drought and groundwater depletion or on the profitability and agronomic performance of maize, while relatively few directly link model-based stage-specific irrigation scheduling to yield and WUE outcomes under Barind conditions (Dey et al., 2017; Islam & Hoshain, 2022). A recent experiment at the University of Rajshahi used CROPWAT 8.0 to evaluate different irrigation levels for maize, and another study from the same site examined the effects of deficit irrigation on yield quality and WUE, but neither explicitly optimized or systematically compared irrigation schedules targeted to distinct phenological stages under the prevailing groundwater constraints of Rajshahi (Yaismin et al., 2025). This reveals a critical knowledge gap: how different stage-specific CROPWAT irrigation schedules affect both water use efficiency and grain yield of maize when implemented under real field conditions in a severely water-stressed environment.

Addressing this gap is essential for designing irrigation recommendations that are both agronomically sound and hydrologically sustainable in drought-prone areas of Bangladesh. Therefore, the present study aims to evaluate the impact of stage-specific CROPWAT irrigation scheduling on water use efficiency and yield of maize in Rajshahi, with a view to identifying irrigation strategies that can maintain competitive yields while markedly reducing pressure on scarce groundwater resources.

MATERIALS AND METHODS

Experimental Location, Soil and Climate

The field experiment was carried out at the Agronomy Field Laboratory of the University of Rajshahi, Bangladesh, during the Rabi season from December 2023 to April 2024. The study was designed to evaluate the impact of stage-specific CROPWAT-based irrigation scheduling on water use efficiency and yield of maize. The experimental site is geographically located at 24°22′36″ N latitude and 88°38′27″ E longitude, at an elevation of approximately 71 ft above mean sea level. The area belongs to Agro-Ecological Zone 11 (AEZ-11), commonly known as the High Ganges River Floodplain, which is characterized by drought proneness during the dry season. The region experiences a subtropical monsoon climate, marked by distinct seasonal variations. The kharif season (April–September) is dominated by high temperatures and heavy rainfall, while the rabi season (October–March) is comparatively cool and dry, necessitating irrigation for crop production. The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.6), well-drained, and classified as medium-high land, making it suitable for maize cultivation under controlled irrigation conditions. During the experimental period, monthly mean air temperature varied from 10.9°C to 36.2°C (Figure 1A). Total effective rainfall amounted to approximately 705.7 mm. Monthly average relative humidity ranged between 59.4% and 83.2% (Figure 1B). These prevailing climatic conditions, combined with low rainfall and high evaporative demand, provided an appropriate environment for evaluating stage-specific irrigation scheduling and its influence on maize water use efficiency and yield under drought-prone conditions.

Experimental Design and procedure

The experiment was conducted using hybrid maize varieties, Bayer 9217, in a split-plot design with three replications, involving eight irrigation treatments (I_1 = 50% of the CROPWAT 8.0–recommended irrigation applied throughout the crop growth period; I_2 = 75% of the CROPWAT 8.0–recommended irrigation applied throughout the season; I_3 = 100% of the CROPWAT 8.0–recommended irrigation (full irrigation based on the model); I_4 = 50% of the CROPWAT-recommended irrigation applied up to the tasseling stage, followed by 75% thereafter; I_5 = 50% of the CROPWAT-recommended irrigation up to tasseling, followed by 100% thereafter; I_6 = 75 % of the CROPWAT-recommended irrigation up to tasseling, followed by 100% thereafter; I_7 = 50% of the CROPWAT-recommended irrigation up to tasseling, 75% up to 45 days after sowing, and 100% thereafter; and I_8 = standard irrigation practice commonly followed by local farmers). Land preparation included plowing and laddering, with drainage channels created around the plots. Recommended fertilizers such as urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate, and boric acid were applied. Seeds were treated with provax-200 and sown in furrows at a rate of 30 kg ha^{-1}. Irrigation was given as per treatments, and standard practices such as weeding, thinning, gap filling, and earthing up were followed. Pest management involved controlling armyworm insects by hand removal. Jackals, squirrels, and parakeets posed threats to the crops during the booting and cob stages, and guards were appointed to protect the plants. Five plants per plot were marked for data collection on growth and yield. At maturity, the crops were harvested on April 16, 2024, with sample plants uprooted from each plot for yield data. Post-harvest, crops were sun-dried, shelled, cleaned, and their grain and stover yields were recorded and adjusted to 14% moisture content before converting to tons per hectare.

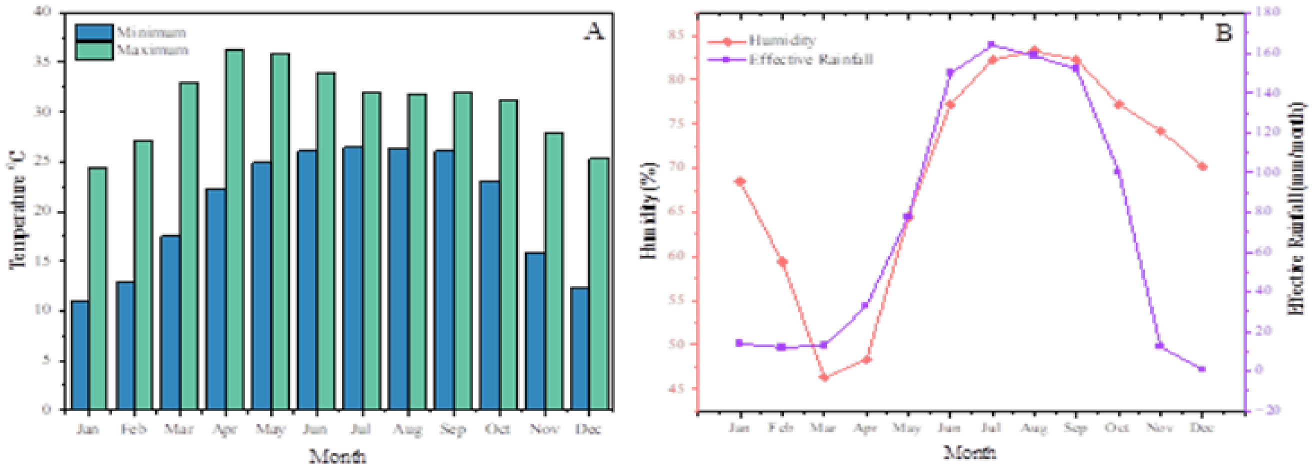


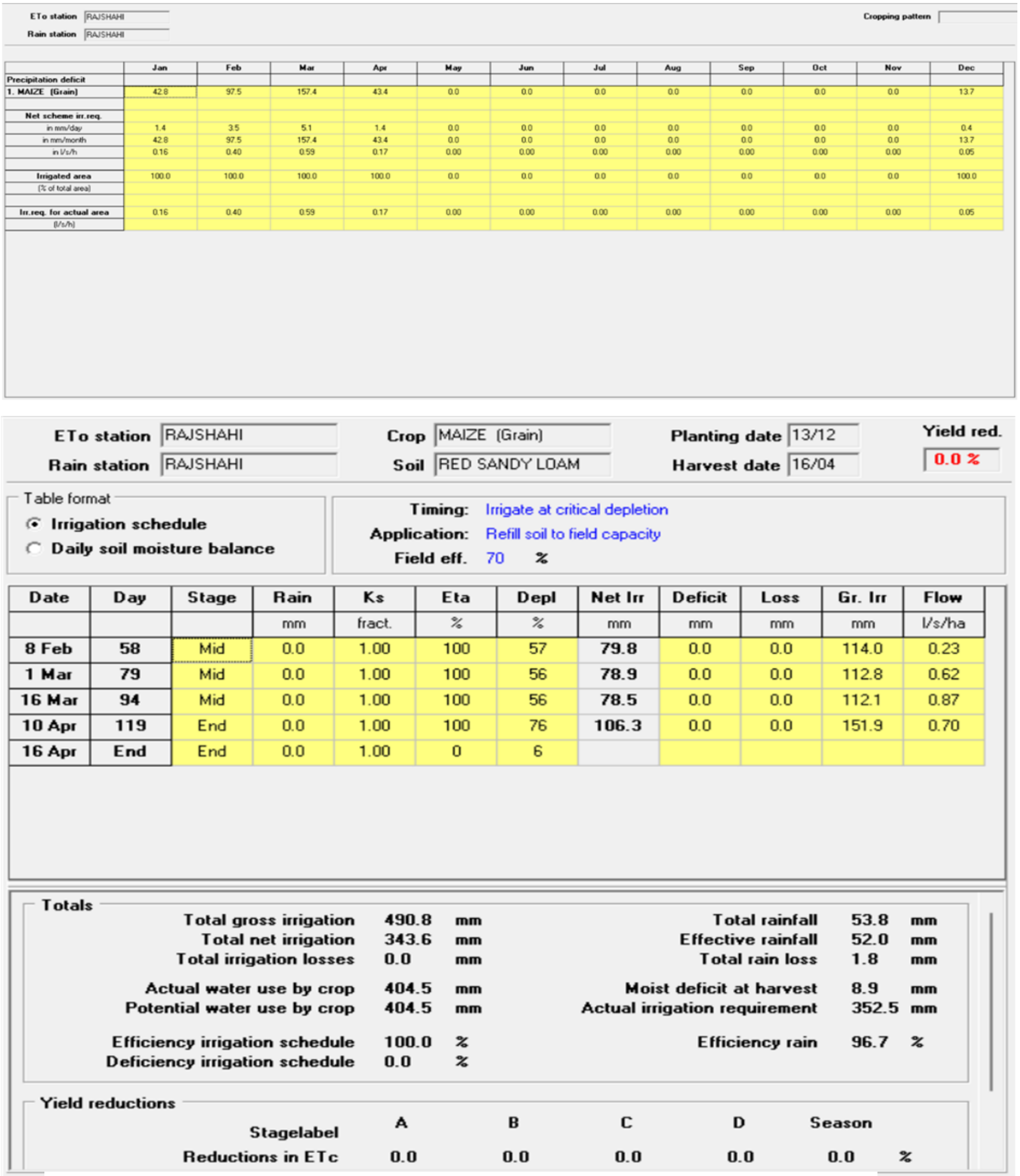
Figure 1: Minimum and Maximum temperature (A), Humidity and Effective Rainfall (B) of study area.

Calculation of irrigation water requirement using FAO CROPWAT 8.0 model

rrigation scheduling recommendations for maize were developed using the FAO CROPWAT 8.0 model through a comprehensive and sequential procedure integrating climatic, crop, soil and management information within a soil–water balance framework. Long-term and experimental-period meteorological data for Rajshahi, including maximum and minimum air temperature, relative humidity, wind speed, sunshine duration and rainfall, were entered into the climate and rainfall modules of CROPWAT, and reference evapotranspiration (ETo) was estimated using the FAO Penman–Monteith method. Maize (grain) was selected from the model's crop database, and standard crop parameters such as crop growth stages (initial, development, mid-season and late season), stage-specific crop coefficient (Kc) values, effective rooting depth, allowable soil moisture depletion fraction and yield response factor (Ky) were adopted. The actual planting date (13 December) and harvest date (16 April) were specified to ensure accurate simulation of crop water demand over the growing period. Soil characteristics of the experimental field were defined as red sandy loam, with appropriate values for total available water, infiltration rate and initial soil moisture status, assuming a well-drained profile. The irrigation management option was set to "irrigate at critical depletion," meaning irrigation was applied when soil moisture depletion reached the allowable limit, and the application method was defined to refill the root zone to field capacity. Field application efficiency was assumed to be 70% to reflect prevailing surface irrigation practices in the study area. Based on daily soil moisture balance calculations, CROPWAT estimated crop evapotranspiration (ETc) as the product of ETo and stage-specific Kc, computed effective rainfall, and quantified precipitation deficits and net irrigation requirements throughout the season. The model then generated an irrigation schedule specifying the timing of irrigations, net and gross irrigation depths, flow rates, total irrigation requirement, actual crop water use and potential yield reduction. The outputs showed that irrigation demand was concentrated mainly during the mid and late growth stages of maize, while effective rainfall contributed only marginally to crop water requirements, resulting in no simulated yield reduction under the recommended schedule. These stage-specific CROPWAT outputs were used as the scientific basis for developing full and deficit irrigation treatments in the field experiment to assess their effects on maize yield and water use efficiency under drought-prone conditions of Rajshahi.

Data collection and analysis

Data were collected on a wide range of plant growth attributes, physiological traits, yield components, yield, and grain quality parameters to evaluate the response of maize to different irrigation treatments. Growth parameters included plant height, leaf area index (LAI), total dry matter (TDM), crop growth rate (CGR), relative water content (RWC), canopy cover, and leaf chlorophyll content. Plant height was measured periodically from the soil surface to the tip of the tallest leaf, while LAI was estimated using standard nondestructive methods. Total dry matter was determined by oven-drying sampled plant materials at 70 °C to constant weight, and CGR was calculated from successive dry matter measurements over time. Relative water content was determined using fresh leaf samples collected at key growth stages following the standard procedure: leaf discs were weighed immediately to obtain fresh weight (FW), then floated in distilled water for 24 h to achieve full



ETo station RAJSHAHI
Rain station RAJSHAHI
Cropping pattern

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. MAIZE (Grain)	42.8	97.5	157.4	43.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7
Net scheme irr.req.												
in mm/day	1.4	3.5	5.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
in mm/month	42.8	97.5	157.4	43.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7
in l/s/h	0.16	0.40	0.59	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Irrigated area	100.0	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
(% of total area)												
Irr.req. for actual area	0.16	0.40	0.59	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
(l/s/h)												

ETo station RAJSHAHI
Rain station RAJSHAHI
Crop MAIZE (Grain)
Soil RED SANDY LOAM
Planting date 13/12
Harvest date 16/04
Yield red. 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
8 Feb	58	Mid	0.0	1.00	100	57	79.8	0.0	0.0	114.0	0.23
1 Mar	79	Mid	0.0	1.00	100	56	78.9	0.0	0.0	112.8	0.62
16 Mar	94	Mid	0.0	1.00	100	56	78.5	0.0	0.0	112.1	0.87
10 Apr	119	End	0.0	1.00	100	76	106.3	0.0	0.0	151.9	0.70
16 Apr	End	End	0.0	1.00	0	6					

Totals

Total gross irrigation	490.8	mm	Total rainfall	53.8	mm
Total net irrigation	343.6	mm	Effective rainfall	52.0	mm
Total irrigation losses	0.0	mm	Total rain loss	1.8	mm
Actual water use by crop	404.5	mm	Moist deficit at harvest	8.9	mm
Potential water use by crop	404.5	mm	Actual irrigation requirement	352.5	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	96.7	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%

Figure 2. Cropwat recommanded irrigation schedule.

turgidity and weighed to obtain turgid weight (TW), after which they were oven-dried at 70 °C to constant weight to obtain dry weight (DW); RWC was calculated as (FW−DW)/(TW−DW)×100. Leaf chlorophyll content was estimated using the 80% acetone extraction method, and absorbance was measured spectrophotometrically. Canopy cover was assessed by analyzing digital images of the crop canopy using Adobe Photoshop software. Yield components were evaluated through measurements of cob length, number of grains per cob, and 1000-grain weight, while yield parameters included grain yield, stover

Table 1. Effect of different irrigation levels on plant height and leaf area of maize.

Irrigation	Plant height (cm)			Leaf Area (cm^2)	
	60DAS	90DAS	120DAS	60DAS	90DAS
I_1	99.33±2.24d	194.14±3.15c	203.37±9.36c	1669.88±28.33e	3758.21±53.99e
I_2	105.64±0.59abcd	207.4±3.95abc	230.51±5.26ab	1825.1±32.08bcd	4049.36±97.81cd
I_3	110.72±2.65a	218.5±5.52a	243.77±4.57a	1922.31±36.17ab	4330.71±89.14ab
I_4	101.66±1.74cd	196.61±3.57bc	207.46±9.37c	1704.69±33.08de	3834.03±62.11de
I_5	103.85±0.95bcd	201.56±1.54bc	219.69±5.21bc	1751.9±40.75cde	3896.67±72.16de
I_6	110.08±2.67ab	216.92±4.79a	241.97±3.23a	1903.91±32.58ab	4280.98±91.5abc
I_7	106.19±0.79abc	208.92±4.16ab	233.42±4.88ab	1844±30.06abc	4089.08±76.88bcd
I_8	112.14±3.05a	219.84±5.38a	248.68±8.26a	1969.87±71.69a	4358.72±87.17a
LS	0.05	0.05	0.05	0.05	0.05
CV	3.33	4.1	5.04	3.83	3.41

Mean values in a column having the same letters or without letters do not differ significantly as per Duncan's multiple range test (DMRT) NS= Non-significant, CV= Co-efficient of variation, LS= Level of significant, DAS=Day's after sowing, I_1 = 50% of CropWat 8.0–recommended irrigation, I_2 = 75% of CropWat 8.0–recommended irrigation, I_3 = 100% of CropWat 8.0–recommended irrigation, I_4 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 75% thereafter, I_5 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_6 = 75% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_7 = 50% of CropWat 8.0–recommended irrigation up to tasseling, 75% up to 45 days, then 100% thereafter, and I_8 = Standard Irrigation.

yield, biological yield, and harvest index. Grain and stover yields were recorded at harvest, adjusted to standard moisture content, and expressed on a tons per hectare basis. Grain quality analysis included determination of protein and carbohydrate contents. Grain protein content was estimated using the Kjeldahl method, which involved digestion of finely ground grain samples with concentrated sulfuric acid in the presence of a catalyst to convert organic nitrogen into ammonium sulfate, followed by distillation and titration to quantify total nitrogen; protein content was calculated by multiplying nitrogen percentage by a conversion factor of 6.25. Total carbohydrate content was determined using the anthrone method, where grain samples were hydrolyzed with acid, reacted with anthrone reagent, and the resulting green color intensity was measured spectrophotometrically to estimate carbohydrate concentration using a standard curve. All measurements were taken at appropriate growth stages to capture treatment effects throughout the crop cycle. The collected data were subjected to statistical analysis using analysis of variance (ANOVA), and treatment means were compared using Duncan's Multiple Range Test (DMRT) at an appropriate level of significance.

RESULTS

Maize growth in terms of plant height was markedly influenced by irrigation level at all stages, with the standard practice I_8 consistently producing the highest values and therefore used as the reference. At 60 DAS, plant height under I_8 reached 112.14 cm, whereas I_1 recorded only 99.33 cm, corresponding to a reduction of about 11.4%. Noticeable declines were also observed in I_4 with 101.66 cm and I_5 with 103.85 cm, representing reductions of about 9.3% and 7.4%, respectively. Moderate reductions were evident in I_2 and I_7, which recorded 105.64 cm and 106.19 cm, translating to decreases of about 5.8% and 5.3%. In contrast, I_3 and I_6 showed plant heights of 110.72 cm and 110.08 cm, with only 1.3% and 1.8% reductions compared to I_8, indicating minimal early-stage growth limitation. At 90 DAS, I_8 maintained the highest plant height of 219.84 cm. The lowest value was again observed under I_1 at 194.14 cm, reflecting an 11.7% reduction. Substantial decreases were also noted in I_4 and I_5 with heights of 196.61 cm and 201.56 cm, corresponding to reductions of about 10.6% and 8.3%. Intermediate responses were found in I_2 and I_7, which achieved 207.40 cm and 208.92 cm, or about 5.7% and 5.0% lower than I_8. Plant height under I_3 and I_6 remained close to the standard practice, reaching 218.50 cm and 216.92 cm, with marginal reductions of only 0.6% and 1.3%, respectively. By 120 DAS, cumulative water stress effects were clearly expressed. I_8 produced the tallest plants at 248.68 cm, while I_1 and I_4 recorded much lower heights of 203.37 cm and 207.46 cm, showing large reductions of 18.2% and 16.6%. Moderate declines were observed in I_5 at 219.69 cm and I_2 at 230.51 cm, equating to reductions of about 11.6% and 7.3%. In comparison, I_3 and I_6 sustained high plant heights of 243.77 cm and 241.97 cm, only 2.0% and 2.7% lower than I_8, while I_7 reached 233.42 cm, representing a 6.1% reduction.

Leaf area exhibited a response pattern similar to plant height. At 60 DAS, the maximum leaf area was recorded under I_8 at 1969.87 cm². The smallest canopy development occurred under I_1 with 1669.88 cm², indicating a 15.2% reduction. Considerable reductions were also noted in I_4 and I_5, which recorded 1704.69 cm² and 1751.90 cm², corresponding to decreases of about 13.5% and 11.1%. Intermediate reductions were evident in I_2 and I_7 with leaf areas of 1825.10 cm² and 1844.00 cm², or about 7.4% and 6.4% lower than I_8. Leaf area under I_3 and I_6 remained comparatively high at 1922.31 cm² and 1903.91 cm², reflecting only 2.4% and 3.4% reductions. At 90 DAS, I_8 again recorded the highest leaf area of 4358.72 cm². The lowest value was observed under I_1 at 3758.21 cm², a reduction of 13.8%. Treatments I_4 and I_5 also showed marked reductions, recording 3834.03 cm² and 3896.67 cm², or about 12.0% and 10.6% lower than I_8. Moderate decreases were found in I_2 and I_7 with leaf areas of 4049.36 cm² and 4089.08 cm², corresponding to reductions of approximately 7.1% and 6.2%. In contrast, I_3 and I_6 remained very close to the standard practice, producing 4330.71 cm² and 4280.98 cm², with minimal reductions of only 0.6% and 1.8%.

Total dry matter (TDM) accumulation and crop growth rate of maize were strongly influenced by irrigation levels at successive growth stages, with the standard practice I_8 consistently recording the highest values and therefore taken as the reference. For TDM at 60 DAS, I_8 produced 22.43 g m^{-2}, while I_1 recorded the lowest value of 19.87 g m^{-2}, showing a reduction of about 11.4%. Noticeable declines were also observed under I_4 with 20.33 g m^{-2} and I_5 with 20.77 g m^{-2}, corresponding to reductions of about 9.4% and 7.4%, respectively. Moderate reductions occurred under I_2 and I_7, which recorded 21.13 and 21.24 g m^{-2}, reflecting decreases of about 5.8% and 5.3%. In contrast, I_3 and I_6 closely approached I_8

with values of 22.14 and 22.02 g m⁻², showing only 1.3% and 1.8% lower TDM, respectively. At 90 DAS, TDM increased substantially across all treatments, with I_8 recording the maximum of 102.14 g m⁻². The lowest accumulation was observed in I_1 at 89.33 g m⁻², corresponding to a reduction of about 12.5%. Treatments I_4 and I_5 recorded 91.66 and 93.85 g m⁻², indicating reductions of about 10.3% and 8.1%. Intermediate reductions were noted under I_2 and I_7 with values of 95.64 and 96.19 g m⁻², equating to decreases of about 6.4% and 5.8%. Similar to earlier stages, I_3 and I_6 maintained TDM values very close to I_8, recording 100.72 and 100.08 g m⁻², which were only about 1.4% and 2.0% lower than the standard practice. By 120 DAS, cumulative effects of irrigation became more evident. I_8 produced the highest TDM of 229.84 g m⁻², whereas I_1 recorded only 204.14 g m⁻², reflecting a marked reduction of about 11.2%. Substantial declines were also seen in I_4 and I_5, which accumulated 206.61 and 211.56 g m⁻², corresponding to reductions of about 10.1% and 8.0%. Moderate reductions were observed under I_2 and I_7, with values of 217.40 and 218.92 g m⁻², representing decreases of about 5.4% and 4.8%. In contrast, I_3 and I_6 sustained high dry matter accumulation at 228.50 and 226.92 g m⁻², only about 0.6% and 1.3% lower than I_8.

For crop growth rate (CGR) during 60–90 DAS, I_8 recorded the highest rate of 2.69 g m⁻² day⁻¹. The lowest CGR was observed under I_1 at 2.30 g m⁻² day⁻¹, showing a reduction of about 14.5%. Treatments I_2, I_4, I_5, and I_7 recorded CGR values ranging from 2.44 to 2.48 g m⁻² day⁻¹, corresponding to reductions of about 7.8–9.3%. I_6 showed a slightly lower reduction of about 6.3% with a CGR of 2.52 g m⁻² day⁻¹, while I_3 closely matched I_8 at 2.63 g m⁻² day⁻¹, only 2.2% lower. During 90–120 DAS, CGR ranged from 3.90 to 4.33 g m⁻² day⁻¹, with I_8 again recording the maximum value of 4.33 g m⁻² day⁻¹. Although I_1 to I_7 showed reductions of about 3–10% compared to I_8, differences among treatments during this period were statistically non-significant, indicating a convergence of growth rates during the later growth phase.

Yield-contributing characters of maize were markedly influenced by irrigation levels, with the standard practice I_8 consistently recording the highest values for all parameters and therefore serving as the benchmark. For canopy cover, I_8 achieved a maximum of 89.30%, while I_1 recorded the lowest canopy cover of 69.32%, reflecting a substantial reduction of about 22.4%. Considerable reductions were also observed under I_4 and I_5, which recorded 71.67% and 73.75%, corresponding to decreases of about 19.7% and 17.4%, respectively. Moderate reductions occurred in I_2 and I_7, which achieved 78.99% and 80.79%, representing reductions of about 11.5% and 9.5%. In contrast, I_3 and I_6 showed canopy cover values of 87.75% and 87.18%, only about 1.7% and 2.4% lower than I_8, indicating near-optimal canopy development. For chlorophyll content at 60 DAS, I_8 recorded the highest value of 0.72 mg g⁻¹. The lowest chlorophyll concentration was observed in I_1 at 0.44 mg g⁻¹, indicating a sharp reduction of about 38.9%. Similar low values

Table 2. Effect of different irrigation levels on TDM and CGR of maize.

Irrigation	TDM (g m⁻²)			CGR (g m⁻² day⁻¹)	
	60DAS	90DAS	120DAS	60-90 DAS	90-120 DAS
I_1	19.87±0.45d	89.33±2.24d	204.14±3.15c	2.3±0.06d	4.11±0.14
I_2	21.13±0.12abcd	95.64±0.59abcd	217.4±3.95abc	2.44±0.03cd	4.18±0.28
I_3	22.14±0.53a	100.72±2.65a	228.5±5.52a	2.63±0.08ab	4.11±0.35
I_4	20.33±0.35cd	91.66±1.74cd	206.61±3.57bc	2.48±0.02bcd	3.92±0.31
I_5	20.77±0.19bcd	93.85±0.95bcd	211.56±1.54bc	2.48±0.07cd	3.9±0.03
I_6	22.02±0.53ab	100.08±2.67ab	226.92±4.79a	2.52±0.05abc	3.96±0.1
I_7	21.24±0.16abc	96.19±0.79abc	218.92±4.16ab	2.46±0.04	3.97±0.22
I_8	22.43±0.61a	102.14±3.05a	229.84±5.38a	2.69±0.08a	4.33±0.17
LS	0.05	0.05	0.05	0.05	NS
CV	4.22	4.47	3.33	3.8	9.57

Mean values in a column having the same letters or without letters do not differ significantly as per Duncan's multiple range test (DMRT) NS= Non-significant, CV= Co-efficient of variation, LS= Level of significant, DAS=Day's after sowing, I_1 = 50% of CropWat 8.0–recommended irrigation, I_2 = 75% of CropWat 8.0–recommended irrigation, I_3 = 100% of CropWat 8.0–recommended irrigation, I_4 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 75% thereafter, I_5 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_6 = 75% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_7 = 50% of CropWat 8.0–recommended irrigation up to tasseling, 75% up to 45 days, then 100% thereafter, and I_8 = Standard Irrigation.

Table 3. Effect of different irrigation levels on yield contributing characters of maize.

Irrigation	Canopy Cover (%)	Chlorophyll 60 (mg g⁻¹)	Chlorophyll 90 (mg g⁻¹)	Cob length (cm)	Grain per cob
I_1	69.32±1.74d	0.44±0.01d	1.22±0.03c	12.62±1.05d	352.33±23.48c
I_2	78.99±2.87bcd	0.56±0.07bc	1.39±0.06bc	16.03±0.51ab	426.11±9.43ab
I_3	87.75±3.63ab	0.71±0.01a	1.58±0.06a	17.25±0.34ab	462.45±13.79a
I_4	71.67±2.79cd	0.45±0.02d	1.26±0.04bc	13.91±0.99cd	371.67±25.47c
I_5	73.75±1.92cd	0.47±0.02cd	1.31±0.03bc	15.11±0.54bc	400.89±10.13bc
I_6	87.18±3.47ab	0.71±0.01a	1.57±0.06a	17.07±0.4ab	448.78±8.2ab
I_7	80.79±2.69abc	0.63±0.07ab	1.45±0.06ab	16.35±0.26ab	431.78±10.53ab
I_8	89.3±4.49a	0.72±0.01a	1.61±0.08a	17.9±0.79a	467.89±18.36a
LS	0.05	0.05	0.05	0.05	0.05
CV	6.66	10.79	7.03	7.38	6.67

Mean values in a column having the same letters or without letters do not differ significantly as per Duncan's multiple range test (DMRT) NS= Non-significant, CV= Co-efficient of variation, LS= Level of significant, DAS=Day's after sowing, I_1 = 50% of CropWat 8.0–recommended irrigation, I_2 = 75% of CropWat 8.0–recommended irrigation, I_3 = 100% of CropWat 8.0–recommended irrigation, I_4 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 75% thereafter, I_5 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_6 = 75% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_7 = 50% of CropWat 8.0–recommended irrigation up to tasseling, 75% up to 45 days, then 100% thereafter, and I_8 = Standard Irrigation.

were found in I_4 and I_5 with 0.45 and 0.47 mg g^{-1}, corresponding to reductions of about 37.5% and 34.7%. Intermediate reductions were evident in I_2 and I_7, which recorded 0.56 and 0.63 mg g^{-1}, showing decreases of about 22.2% and 12.5%. Treatments I_3 and I_6 closely matched the standard practice, both recording 0.71 mg g^{-1}, with negligible reductions of around 1–2%. A comparable trend was observed for chlorophyll content at 90 DAS, where I_8 recorded the maximum value of 1.61. The minimum chlorophyll content occurred under I_1 at 1.22, representing a reduction of about 24.2%. Treatments I_4 and I_5 recorded 1.26 and 1.31, corresponding to reductions of about 21.7% and 18.6%. Moderate declines were observed in I_2 and I_7 with values of 1.39 and 1.45, equating to reductions of about 13.7% and 9.9%. In contrast, I_3 and I_6 maintained chlorophyll contents of 1.58 and 1.57, only about 1.9% and 2.5% lower than I_8. For cob length, I_8 produced the longest cobs at 17.9 cm. The shortest cobs were recorded under I_1 with a length of 12.62 cm, reflecting a reduction of about 29.5%. Considerable reductions were also evident in I_4 and I_5, which recorded cob lengths of 13.91 cm and 15.11 cm, corresponding to decreases of about 22.3% and 15.6%. Intermediate values were observed in I_2 and I_7, recording 16.03 cm and 16.35 cm, or about 10.4% and 8.7% lower than I_8. Treatments I_3 and I_6 showed cob lengths of 17.25 cm and 17.07 cm, with only about 3.6% and 4.6% reductions relative to the standard practice. Similarly, grains per cob followed the same pattern. I_8 recorded the maximum number of grains per cob at 467.89. The lowest grain number was observed in I_1 with 352.33 grains, showing a large reduction of about 24.7%. Treatments I_4 and I_5 also showed notable declines with 371.67 and 400.89 grains per cob, corresponding to reductions of about 20.6% and 14.3%. Moderate reductions were evident in I_2 and I_7, which recorded 426.11 and 431.78 grains, representing decreases of about 8.9% and 7.7%. In contrast, I_3 and I_6 produced 462.45 and 448.78 grains per cob, only about 1.2% and 4.1% lower than I_8.

Maize yield and its components were strongly influenced by irrigation levels, with the standard practice I_8 consistently producing the highest values and therefore used as the reference. For 1000-grain weight, I_8 recorded the maximum value of 254.53 g. The lowest grain weight was observed under I_1 with 188.22 g, reflecting a reduction of about 26.1%. Marked reductions were also evident in I_4 at 191.95 g and I_5 at 213.51 g, corresponding to decreases of about 24.6% and 16.1%, respectively. Moderate reductions were recorded in I_2 and I_7, which achieved 226.87 g and 231.22 g, indicating reductions of about 10.9% and 9.2%. In contrast, I_3 and I_6 closely approached the standard practice with values of 249.48 g and 245.74 g, showing only about 2.0% and 3.4% lower grain weight than I_8. For grain yield, I_8 produced the highest yield of 13.40 t ha^{-1}. Severe yield reduction was observed under I_1, which recorded only 7.17 t ha^{-1}, representing a decline of about 46.5%. Considerable reductions were also noted in I_4 and I_5, yielding 8.39 and 10.07 t ha^{-1}, corresponding to decreases of about 37.4% and 24.9%. Moderate yield reductions occurred under I_2 and I_7, which recorded 11.11 and 11.49 t ha^{-1}, reflecting decreases of about 17.1% and 14.3%. In comparison, I_3 and I_6 produced high yields of 12.97 and 12.36 t ha^{-1}, showing only about 3.2% and 7.8% reductions relative to I_8. A similar trend was evident for straw yield, where I_8 recorded the maximum value of 17.73 t ha^{-1}. The lowest straw yield occurred under I_1 at 9.98 t ha^{-1}, corresponding to a reduction of about 43.7%. Substantial declines were also observed in I_4 and I_5 with straw yields of 12.01 and 12.70 t ha^{-1}, representing reductions of about 32.3% and 28.4%. Intermediate reductions were noted under I_2 and I_7, which produced 14.29 and 14.52 t ha^{-1}, equating to decreases of about 19.4% and 18.1%. Treatments I_3 and I_6 maintained high straw yields of 17.24 and 16.64 t ha^{-1}, only about 2.8% and 6.2% lower than I_8. For biological yield, I_8 achieved the highest value of 31.13 t ha^{-1}. The lowest biological yield was recorded under I_1 at 17.16 t ha^{-1}, indicating a reduction of about 44.9%. Treatments I_4 and I_5 also showed notable reductions, producing 20.39 and 22.77 t ha^{-1}, corresponding to decreases of about 34.5% and 26.9%. Moderate reductions were observed in I_2 and I_7, which recorded 25.40 and 26.02 t ha^{-1}, or about 18.4% and 16.4% lower than I_8. In contrast, I_3 and I_6 produced high biological yields of 30.21 and 29.00 t ha^{-1}, showing only about 3.0% and 6.9% reductions. For harvest index, values ranged narrowly from about 40.83% to 44.25%, with I_8 recording 42.98%. Although I_4 showed a slight reduction of about 5.0% compared to I_8 and I_5 and I_7 showed marginal increases, differences among treatments were statistically non-significant, indicating that irrigation levels primarily influenced total biomass and yield rather than biomass partitioning.

Table 4. Effect of different irrigation levels on yield of maize.

Irrigation	1000 Grain Weight (g)	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
I_1	188.22±13.71c	7.17±1.4d	9.98±2.12c	17.16±3.51d	42.11±1.1
I_2	226.87±7.13ab	11.11±0.7abc	14.29±0.92ab	25.4±1.53abc	43.73±1.07
I_3	249.48±9.65a	12.97±0.86ab	17.24±1.07a	30.21±1.93a	42.93±0.27
I_4	191.95±12.9c	8.39±1.04cd	12.01±0.7bc	20.39±1.72cd	40.83±1.89
I_5	213.51±6.79bc	10.07±0.8bc	12.7±0.5bc	22.77±1.31bcd	44.1±0.97
I_6	245.74±9.34a	12.36±0.49ab	16.64±1.11a	29±1.56ab	42.69±0.93
I_7	231.22±6.42ab	11.49±0.38ab	14.52±0.94ab	26.02±1.27abc	44.25±0.97
I_8	254.53±9.13a	13.4±1.13a	17.73±1.14a	31.13±2.27a	42.98±0.5
LS	0.05	0.05	0.05	0.05	NS
CV	7.48	14.46	13.89	13.76	4.27

Mean values in a column having the same letters or without letters do not differ significantly as per Duncan's multiple range test (DMRT) NS= Non-significant, CV= Co-efficient of variation, LS= Level of significant, DAS=Day's after sowing, I_1 = 50% of CropWat 8.0–recommended irrigation, I_2 = 75% of CropWat 8.0–recommended irrigation, I_3 = 100% of CropWat 8.0–recommended irrigation, I_4 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 75% thereafter, I_5 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_6 = 75% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_7 = 50% of CropWat 8.0–recommended irrigation up to tasseling, 75% up to 45 days, then 100% thereafter, and I_8 = Standard Irrigation.

Plant water status and grain quality parameters were markedly affected by irrigation levels, with the standard practice I_8 consistently recording the highest values and therefore used as the reference. For relative water content (RWC), I_8 recorded a maximum of 94.44%. The lowest RWC was observed under I_1 with 76.70%, indicating a substantial reduction of about 18.8%, reflecting pronounced plant water stress. Considerable reductions were also evident in I_4 and I_5, which recorded 78.65% and 81.69%, corresponding to decreases of about 16.7% and 13.5%, respectively. Moderate reductions occurred under I_2 and I_7, with RWC values of 85.25% and 86.75%, representing reductions of about 9.7% and 8.1%. In contrast, I_3 and I_6 closely approached I_8, recording 93.39% and 92.60%, with only about 1.1% and 1.9% lower RWC, indicating effective maintenance of plant water status. For carbohydrate content, I_8 recorded the highest value of 61.15%.

Table 5. Effect of different irrigation levels on RWC, Carbohydrate and Protein content of maize.

Irrigation	RWC (%)	Carbohydrate (%)	Protein (%)
I_1	76.7±2.71d	48.6±1.71e	4.31±0.22b
I_2	85.25±1.95bc	54.77±1.65bcd	5.3±0.19a
I_3	93.39±3.1ab	60.18±2.17ab	4.58±0.13ab
I_4	78.65±2.11cd	49.67±1.46de	4.95±0.13ab
I_5	81.69±1.68cd	52.38±1.07cde	4.75±0.33ab
I_6	92.6±2.83ab	59.21±1.57ab	5.28±0.48a
I_7	86.75±2.58abc	55.98±1.13abc	4.77±0.24ab
I_8	94.44±3.04a	61.15±2.24a	5.24±0.31a
LS	0.05	0.05	0.05
CV	5.12	5.25	9.79

Mean values in a column having the same letters or without letters do not differ significantly as per Duncan's multiple range test (DMRT) NS= Non-significant, CV= Co-efficient of variation, LS= Level of significant, DAS=Day's after sowing, I_1 = 50% of CropWat 8.0–recommended irrigation, I_2 = 75% of CropWat 8.0–recommended irrigation, I_3 = 100% of CropWat 8.0–recommended irrigation, I_4 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 75% thereafter, I_5 = 50% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_6 = 75% of CropWat 8.0–recommended irrigation up to tasseling, then 100% thereafter, I_7 = 50% of CropWat 8.0–recommended irrigation up to tasseling, 75% up to 45 days, then 100% thereafter, and I_8 = Standard Irrigation.

The minimum carbohydrate content was observed under I_1 at 48.60%, reflecting a reduction of about 20.5%. Treatments I_4 and I_5 also showed notable reductions, recording 49.67% and 52.38%, corresponding to decreases of about 18.8% and 14.3%. Moderate reductions were evident in I_2 and I_7, which recorded 54.77% and 55.98%, showing declines of about 10.5% and 8.5%. In contrast, I_3 and I_6 maintained high carbohydrate contents of 60.18% and 59.21%, only about 1.6% and 3.2% lower than I_8, suggesting improved assimilate production under adequate irrigation. For protein content, values varied within a narrower range, with I_8 recording 5.24%. The lowest protein content was found under I_1 at 4.31%, corresponding to a reduction of about 17.7%. I_4 and I_5 recorded protein contents of 4.95% and 4.75%, reflecting reductions of about 5.5% and 9.4%. Moderate reductions were observed under I_3 and I_7, which recorded 4.58% and 4.77%, corresponding to decreases of about 12.6% and 9.0%. In contrast, I_2 and I_6 recorded protein contents of 5.30% and 5.28%, which were marginally higher than or comparable to I_8, indicating improved nitrogen assimilation under these irrigation regimes.

Overall, across all growth, physiological, yield, and quality parameters, the standard irrigation practice I_8 consistently recorded the highest values; however, several deficit and stage-based irrigation treatments performed comparably and were statistically non-significant to I_8. Treatments I_3 and I_6 most consistently matched I_8, showing non-significant differences for plant height, leaf area, total dry matter accumulation, crop growth rate during critical stages, yield-contributing characters, grain yield, straw yield, biological yield, relative water content, and carbohydrate content, with only marginal percentage reductions generally below 2–7% depending on the parameter. Treatment I_7 also showed performance close to I_8 for most growth traits, yield components, grain yield, and physiological parameters, with moderate reductions typically within 5–10%, and remained statistically comparable to the standard practice in many cases. Additionally, for protein content, I_2 along with I_6 performed at par with I_8, indicating that moderate irrigation levels were sufficient to maintain grain nutritional quality. In contrast, treatments I_1, I_4, and I_5 consistently showed significant reductions across parameters, reflecting the adverse impact of sustained or early-season water stress. Collectively, these results indicate that irrigation regimes represented by I_3, I_6, and I_7 can effectively sustain maize growth, productivity, and quality at levels comparable to the standard irrigation practice I_8, offering viable alternatives for water-saving irrigation management without compromising crop performance.

Conclusion

The results of this study confirm that stage-specific irrigation scheduling based on the FAO CROPWAT 8.0 model is an effective approach for improving water use efficiency while maintaining high maize productivity in the drought-prone Barind region of Bangladesh. Although the standard irrigation practice (I_8) consistently produced the highest values, treatments I_3, I_6, and I_7 performed statistically at par with it for most growth, physiological, yield, and quality parameters, with only minor reductions. These treatments successfully minimized water stress during critical stages such as tasseling and grain filling, thereby sustaining yield and crop quality while reducing irrigation water use. In contrast, continuous or early-season severe deficit irrigation treatments caused significant yield and growth losses. Overall, the findings suggest that stage-specific CROPWAT-based irrigation offers a viable, water-saving alternative to conventional irrigation practices and can contribute to sustainable maize production and groundwater conservation in water-scarce regions like the Barind Tract.

References

Afrin, R., Sultana, R., & Alam, Md. S. (2024). A Comprehensive analysis of drought vulnerability in the Barind region of Bangladesh: A socio-ecological systems approach. *Ecological Indicators*, *160*, 111863. https://doi.org/10.1016/j.ecolind.2024.111863

Aziz, M. A., Majumder, M. A. K., Kabir, M. S., Hossain, M. I., Rahman, N. M. F., Rahman, F., & Hosen, S. (2015). Groundwater depletion with expansion of irrigation in Barind tract: A case study of Rajshahi district of Bangladesh. *Int J Geol Agric Environ Sci*, *3*(1), 32–38.

Bayisa, G. D., Hordofa, T., Tezera, K., Tesfaye, A., Ashame, G., & Wondimu, T. (2021a). Maize Yield and Water Use Efficiency Under Different Irrigation Levels and Furrow Irrigation Methods in Semiarid, Tropical Region. *Air, Soil and Water Research*, *14*, 11786221211058177. https://doi.org/10.1177/11786221211058177

Bayisa, G. D., Hordofa, T., Tezera, K., Tesfaye, A., Ashame, G., & Wondimu, T. (2021b). Maize Yield and Water Use Efficiency Under Different Irrigation Levels and Furrow Irrigation Methods in Semiarid, Tropical Region. *Air, Soil and Water Research*, *14*, 11786221211058177. https://doi.org/10.1177/11786221211058177

Begum, S., Acharjee, D. C., Gosh, K., Amin, M. R., Anik, A. R., & Alam, G. M. M. (2024). Unlocking Maize (Zea mays)

Potential: Exploring Profitability and Marketing Efficiency in Bangladesh's Char Land Areas. *Annals of Bangladesh Agriculture*, *28*(1), 61–77.

Bhat, S. A., Pandit, B. A., Khan, J. N., Kumar, R., & Jan, R. (2017). Water Requirements and Irrigation Scheduling of Maize Crop using CROPWAT Model. *International Journal of Current Microbiology and Applied Sciences*, *6*(11), 1662–1670. https://doi.org/10.20546/ijcmas.2017.611.199

Bhuiyan, M. S., Bhuiyan, M. S. R., Tiwari, T. P., Rahaman, M. A., Bhowal, S. K., Uddin, R., & Paul, S. K. (2015). Performance of hybrid maize varieties as influenced by irrigation levels. *Bangladesh Agronomy Journal*, *18*(2), 23–29.

Dey, N. C., Saha, R., Parvez, M., Bala, S. K., Islam, A. S., Paul, J. K., & Hossain, M. (2017). Sustainability of groundwater use for irrigation of dry-season crops in northwest Bangladesh. *Groundwater for Sustainable Development*, *4*, 66–77. https://doi.org/10.1016/j.gsd.2017.02.001

Faloye, O. T., Ajayi, A. E., Oguntunde, P. G., Kamchoom, V., & Fasina, A. (2024). Modeling and Optimization of Maize Yield and Water Use Efficiency under Biochar, Inorganic Fertilizer and Irrigation Using Principal Component Analysis. *Agriculture*, *14*(10), 1813. https://doi.org/10.3390/agriculture14101813

Gabr, M. E.-S. (2022). Management of irrigation requirements using FAO-CROPWAT 8.0 model: A case study of Egypt. *Modeling Earth Systems and Environment*, *8*(3), 3127–3142.

Gheysari, M., Loescher, H. W., Sadeghi, S. H., Mirlatifi, S. M., Zareian, M. J., & Hoogenboom, G. (2015). *Chapter Three—Water-Yield Relations and Water Use Efficiency of Maize Under Nitrogen Fertigation for Semiarid Environments: Experiment and Synthesis* (D. L. Sparks, Ed.; Vol. 130, pp. 175–229). Academic Press. https://doi.org/10.1016/bs.agron.2014.12.001

Gobezie, A., Ademe, D., & Sharma, L. K. (2025). CERES-Maize (DSSAT) Model Applications for Maize Nutrient Management Across Agroecological Zones: A Systematic Review. *Plants*, *14*(5), 661.

Hessain Yagoob, A. (2015). Optimal Irrigation Scheduling for Summer Maize Crop: Based on GIS and CROPWAT Application in Hetao District; Inner Mongolia Autonomous Region, China. *Journal of Biology, Agriculture and Healthcare Www. Iiste. Org ISSN*, 2224–3208.

Islam, M. R., & Hoshain, S. (2022). A Brief Review on the Present Status, Problems And Prospects of Maize Production in Bangladesh. *Research in Agriculture Livestock and Fisheries*, *9*(2), 89–96. https://doi.org/10.3329/ralf.v9i2.61613

Khan, M. R. A. (2021). *Sustainability Management for Groundwater Irrigation in Barind Tract of Bangladesh* [PhD Thesis, University of Rajshahi, Rajshahi]. http://103.79.117.116:8080/handle/123456789/1088

Rahaman, H., Sarker, M. A., Rahman, M. Z., Momin, M. R., & Raihan, M. L. (2025). Vulnerability Assessment of Crop Husbandry due to Drought in North-Western Region of Bangladesh. *Journal of Environmental Science and Natural Resources*, 72–80.

Rashed, M. T., Ruman, M. S. A., Miah, T., Rahman, M. S., & Afzal, M. (2024). Analyzing Temporal Variation of Temperature and Rainfall in Rajshahi District. *Department o f Meteorology, University of Dhaka*. https://admin.bmd.gov.bd/file/2024/08/14/pdf/171462.pdf

Reta, B. G., Hatiye, S. D., & Finsa, M. M. (2024). Crop water requirement and irrigation scheduling under climate change scenario, and optimal cropland allocation in lower kulfo catchment. *Heliyon*, *10*(10). https://doi.org/10.1016/j.heliyon.2024.e31332

Sayed, A., Sarker, A., Kim, J.-E., Rahman, M., & Mahmud, Md. G. A. (2020a). Environmental sustainability and water productivity on conservation tillage of irrigated maize in red brown terrace soil of Bangladesh. *Journal of the Saudi Society of Agricultural Sciences*, *19*(4), 276–284. https://doi.org/10.1016/j.jssas.2019.03.002

Sayed, A., Sarker, A., Kim, J.-E., Rahman, M., & Mahmud, Md. G. A. (2020b). Environmental sustainability and water productivity on conservation tillage of irrigated maize in red brown terrace soil of Bangladesh. *Journal of the Saudi Society of Agricultural Sciences*, *19*(4), 276–284. https://doi.org/10.1016/j.jssas.2019.03.002

Şen, B. (2023). Determining the Changing Irrigation Demands of Maize Production in the Cukurova Plain under Climate Change Scenarios with the CROPWAT Model. *Water*, *15*(24), 4215. https://doi.org/10.3390/w15244215

Xing, Y., & Wang, X. (2024). Precision agriculture and water conservation strategies for sustainable crop production in arid regions. *Plants*, *13*(22), 3184.

Yaismin, T., Momen, M. B. H., & Islam, M. R. (2025). Evaluation of Irrigation Management for Maize Using the CROPWAT Model. *Int. J. Sci. Res. in Multidisciplinary Studies Vol*, *11*(3).

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