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Performance Evaluation of Sweet Corn Cultivated in Greenhouse in Northern Ghana

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ABSTRACT

The study assessed the effect of conventional deficit irrigation (CDI), alternate partial rootzone drying (APRD), and fixed partial rootzone drying (FPRD) at two water regimes (80 and 60% of crop water requirement), compared to full irrigation (FI), and in conjunction with two nitrogen fertilizer rates (3.2 and 5.5 g N plant-1), on water productivity (WP), nitrogen (N) uptake, and use efficiency (NUE) in maize (Zea mays L. var saccharate). The plants were grown in the greenhouse conditions, in split-root grow bags and exposed to FI, CDI, APRD and FPRD treatments from four weeks after planting (4 WAP) to harvest. Analysis across the N-fertilization treatments showed that CDI, APRD, and FPRD significantly decreased plant height, shoot and root dry mass, shoot and root N uptake compared with the FI control. Specifically, plant height and Leaf Area Index (LAI) were at their lowest with FPRD60 and APRD60, respectively, throughout the measured weeks. Additionally, shoot and root dry mass were notably reduced by 65.1% and 64.5% for FPRD60 and FPRD80, respectively, in comparison to FI. Water productivity remained consistent across all treatments. However, the CDI80 treatment exhibited a water-saving of 21.6% compared to FI and increased WP by 5.4%. Nitrogen use efficiency (NUE) significantly increased with increasing water deficit levels with FPRD60 increasing NUE by 52.5% compared to FI. Overall, CDI and APRD at mild stress had similar effect on plant growth, biomass and N uptake, with F-PRD demonstrating the lowest impact. The study revealed that water saved with deficit strategies across N fertilizer treatment did not significantly maintain or increase the water productivity (WP), but improved NUE.

INTRODUCTION

Sweet corn *(Zea mays L. var saccharate)* is a highly valuable vegetable crop that can be consumed fresh or processed (Chavan *et al*., 2020). The cultivation of sweet corn faces challenges related to water scarcity during prolonged droughts periods when this crop demands substantial water resources for optimal growth (Tafrishi *et al*., 2013; Rou *et al*., 2017). Additionally, nitrogen (N) plays a pivotal role in sweet corn vegetative growth, photosynthetic activity, and overall development (Szymanek & Piasecki, 2013). Effective management of both water and nitrogen resources is critical to ensure adequate crop yield and quality (Wang *et al*., 2013).

Agriculture accounts for over 70% of the world's freshwater (Hannah and Max, 2017). With a global population projected to surpass 7.5 billion by 2050 (FAO, 2012), the need to increase food production is undeniable. However, the availability of water resources is expected to decrease, particularly in semi-arid areas, due to climate change predictions indicating higher temperatures and reduced rainfall (Yomo *et al.*, 2020).

In northern Ghana, insufficient rainfall often results in reliance on irrigation to sustain agricultural activities (Asmamaw *et al.*, 2021). Agriculture in Ghana accounts for a significant share of water consumption, utilizing 48% of the nation's total water resources (Yeleliere *et al.*, 2018). Notably, from 2000 to 2020, there was a substantial 48% surge in water use for irrigation (Agodzo *et al.*, 2023). This heightened demand for water could be compounded by increasing population growth and climate change impact, intensifying the challenge of freshwater availability. As water scarcity becomes more pressing, the necessity for efficient utilization of agricultural water resources becomes paramount for enhanced food production (Lubajo and Karuku, 2022). Therefore, innovative irrigation management strategies are essential to meet the growing demand for food while conserving water resources (Giordano *et al.*, 2017).

Water productivity (WP) which is the ratio of biomass produced to water used, has become a critical indices in deficit irrigation management (Barideh et al., 2018). This management approach involves devising strategies to manipulate the placement of irrigation water in the soil to increase crop WP (Hedley *et al.*, 2014). In regions with limited water resources, innovations, such as conventional deficit irrigation (DI) are adopted to improve WP (Yazar *et al.*, 2009). Conventional DI implies irrigating the entire root zone below the crop evapotranspiration (ETc) requirement at mild stress and minimum effect on the yield (Sonawane and Shrivastava, 2022; Liu *et al.*, 2022). By providing less water than the crops evapotranspiration (ET) requirement, deficit irrigation aims to strike a balance between water availability and crop needs. The goal is to ensure that essential plant functions are sustained while reducing non-essential water consumption (Suna *et al.*, 2023).

Over time, a new deficit technique known as partial rootzone drying (PRD) emerged. This is a modified deficit irrigation method involving alternating wetting and drying of a portion of the root zone during irrigation (Al-Kayssi, 2023). PRD technique maintains optimal water-plant status in the wet root zone while inducing a stress response in the dry root zone. Thereby, leading to increased water productivity (WP) through partial stomatal closure under mild soil water stress conditions (Cheng *et al.*, 2021). PRD has been implemented in two primary forms; alternate partial rootzone drying (APRD) and fixed partial rootzone drying (FPRD) (Topak *et al.*, 2016; Ghafari *et al.*, 2020). In APRD, one-half of the root zone is irrigated while the other remains dry during a specific irrigation period, and this pattern alternates in subsequent intervals. In contrast, FPRD maintains one sub-part of the root zone as consistently dry and the other as continuously wet throughout the entire irrigation cycle (Al-Kayssi, 2023).

Alongside the choice of irrigation method and strategy, the rate of nitrogen (N) fertilizer application holds significant impact on sweet corn growth and productivity. Enhancing water productivity (WP) and optimizing fertilizer use efficiency represents a highly effective approach, saving water, reducing fertilizer input, and boosting farmer income (Wang and Xing, 2017). exhibits reduced performance in soils with low nitrogen levels. However, excessive N fertilizer application can lead to nutrient losses through volatilization, leaching, and denitrification (Oktem *et al.*, 2010; Fengbei *et al.*, 2017). Achieving a good balance of deficit irrigation and rational fertilizer application has been shown to increase water productivity and nitrogen use efficiency of various crops. Promising results have been reported in some crops such as; tomato (Ullah *et al.*, 2021); peanut (Rathore *et al.*, 2021); wheat (Shoukat *et al.*, 2021).

Information is limited regarding the comparative effects of PRD and DI under rational N fertilizer levels on WP and NUE for sweet corn. This study seeks to address these knowledge gaps by evaluating the influence of partial root zone drying (PRD) and conventional deficit irrigation (DI) methods at mild and sever deficit water regimes, and nitrogen fertilizer levels on the growth, water productivity, N-uptake, and nitrogen use efficiency (NUE) of sweet corn in Northern Ghana under greenhouse conditions.

MATERIALS AND METHODS

Study Area and Experimental Setup

The experiment was carried out from April to July, 2023 in a greenhouse at the Savannah Agricultural

Research Institute (SARI) at Nyankpala, Northern Ghana (9°30'0"N, 1°30'0"W). The experimental setup used 42 poly grow bags to simulate partial root zone separation and conventional deficit irrigation (Fig. 1). Pairs of grow bags were co-joined, sealing all holes at the joined sides to prevent water movement between them. Each subpart of the grow bag was filled with 20 kg of dry soil and perforated at the bottom for drainage. Seeds were planted 2 inches beneath the soil surface at the separation line for partial root zone drying (PRD). The grow bags measured 28 cm in height with corresponding top and bottom diameters of 51 cm. The soil was classified as Sandy Loam, consisting of 57.6% sand, 16.4% clay, and 26% silt, with 8.4% permanent wilting point and 20.3% field capacity. The soil pH was 5.8, 14.9 mg/kg nitrate nitrogen (NO_3^-N), 27.87 mg/kg ammonium nitrogen ($NH_4^{+-}N$), 47.87 mg/kg available phosphorus (Bray 1 P), 0.305 mg/kg potassium (K), 0.703% organic carbon, and an electrical conductivity of 0.91 µS/cm.

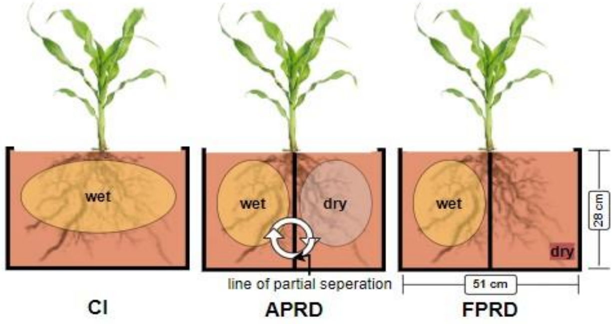

Figure 1: Schematic diagram of conventional irrigation (CI), alternate partial rootzone drying (APRD) and fixed partial rootzone drying (FPRD).
Source: Author's Construct (2023)

Irrigation and Fertilizer Treatment

The experiment comprised seven (7) irrigation treatments and two (2) nitrogen fertilizer levels, which were replicated three times (Fig. 2). The irrigation treatments comprised full irrigation (100% ETc), and three (3) deficit irrigation (DI) techniques (C-DI, A-PRD, F-PRD) at two (2) irrigation regimes (80% and 60% ETc). Nitrogen treatments levels were; 3.2 g N plant^{-1} (N1) and 5.5 g N plant^{-1} (N2). The deficit irrigation methods employed included alternate partial rootzone drying (A-PRD), fixed partial rootzone drying (F-PRD), and conventional deficit irrigation (C-DI). The crop water requirement was determined using the FAO Penman-Monteith method via the CROPWAT program (FAO, version 8.0), based on meteorological data obtained from the Savannah Agricultural Research Institute (SARI). Essential crop data, including root depth, critical depletion, yield response factor, crop height, and harvest index, were generated with CROPWAT for the 100%, 80%, and 60% water regimes were 325.6 mm, 260.5 mm, and 195.4 mm, respectively. Irrigation treatments commenced at four weeks after planting (4 WAP) and continued until harvest. Water was supplied to the plant using drip irrigation system.

For the nitrogen treatments, the recommended application rate was adopted from Bar-Yosef (2020). N2 represented an additional urea (N) fertilizer increase over the standard recommendation represented by N1. Calculations considered factors such as pot volume, soil bulk density, height of the grow bag (soil depth), soil and water chemical properties, and crop salinity tolerance. Fertilizers were applied during irrigation, using a stock solution prepared by mixing the soluble fertilizers at a 1:200 ratio. Each plant received the stock solution according to its designated treatment levels. The fertilizer treatment commenced at 4 WAP and continued every 2 to 3 days until the milking stage of the corn crop.

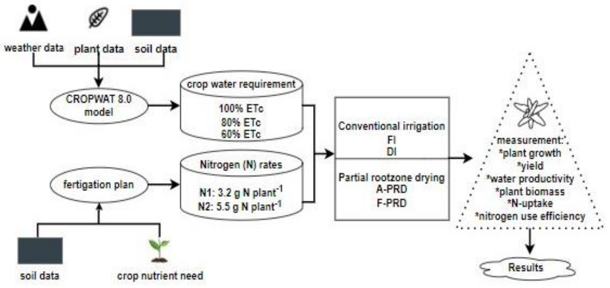

Figure 2: Flow chart of the research methodology
Source: Author's Construct (2023)

Data Collection and Analysis

Plant growth data collection started at 7 WAP and continued weekly until the milking stage at 10 WAP. The height was determined by measuring from the soil's surface to the top of the arch formed by the topmost leaf, whose tip is pointing downward. The model developed for the direct method leaf area measurement was employed (Butnan and Toomsan, 2019). The non-destructive direct method was used in the calculation of LAI, with is the ratio of leaf area to ground area. The leaf area index (LAI) was calculated as;

$$LAI\ (cm^2 cm^2) = (L \times W \times 0.75)_n/(intra\ spacing \times inter\ spacing)$$

[eq. 1]

Where; W is the maximum width of the latest expanded leaf, L is the length from base to tip of the latest expanded leaf, 0.75 is the correction factor for corn, and n is the number of all expanded leaves.

After harvesting at 10 WAP, each sampled plant was uprooted, separated into the shoot, roots, and ears and fresh weight taken. The shoots and roots were initially dried at 105°C for 30 minutes to inactivate plant enzymes and further dried at 60°C to achieve a constant mass, resulting in dry biomass. Water productivity was calculated as;

$$WP\ (kg/m^3) = yield/(total\ water\ consumption) \quad \text{[eq. 2]}$$

Following the final dry weight determination, each dry sample of the root and shoot was ground, digested with H_2SO_4/H_2O_2 and analyzed using the Kjeldahl method (Helrich, 1990) to determine the N content. N absorption differences from various root zones were independently assessed for each sub-part. To obtain the total value for the sample root, the composite value was aggregated. The nitrate (N) uptake was derived from the product of N content (% N) and the sample dry weight (g plant^{-1}). The following formula was used to calculate the N-uptake parameters;

$$Root\ N\ uptake\ (mg\ plant^{-1}) = root\ N\ content \times root\ dry\ mass \quad \text{[eq. 3]}$$

$$\text{Shoot N uptake (mg plant}^{-1}) = \text{shoot N content} \times \text{shoot dry mass} \quad \text{[eq. 4]}$$

$$\text{Total N uptake (mg plant}^{-1}) = \text{root N uptake} + \text{shoot N uptake} \quad \text{[eq. 4]}$$

Nitrogen use efficiency parameter (g mg^{-1}) was derived from the summation of the plant biomass divided by the total N uptake as;

$$\text{NUE (g mg}^{-1}) = \text{(shoot dry weight} + \text{root dry weight)/(Total N uptak}$$

[eq. 5]

Statistical Analysis

Analyses of variance (ANOVA) for split plot design was used to analyze all the data sets. The mean values of the treatments were compared for significant difference at 5% level using the least significant difference (LSD) with GENSTAT statistical package. Significant treatments means were further separated using Duncan Multiple Comparison on GENSTAT software.

RESULTS AND DISCUSSION

Plant Height and Leaf Area Index

In all observed periods, irrigation treatment significantly influenced both plant height and leaf area index, while N fertilization rate and the treatment interaction had no significant effect (Table I). Plant height was consistently highest ($p < 0.05$) under the FI treatment at 7, 8, 9, and 10 WAP, with the lowest height observed in the FPRD60 treatment during these periods. While not statistically significant, N1 fertilizer rates showed a trend towards increased plant height, and except at 7 WAP, N2 rates were associated with higher leaf area index (LAI). Throughout all observed periods, the C-DI80 treatment consistently had the highest LAI, while APRD60 had the lowest. Notably, LAI remained constant across all treatments at 9 and 10 WAP.

Table 1. Analysis of variance on the effect of irrigation treatments and N fertilization rates and their interaction on plant height and leaf area index

Factor	Plant height (cm)				Leaf Area Index (cm^{2}cm^{-2})			
	7 WAP	8 WAP	9 WAP	10 WAP	7 WAP	8 WAP	9 WAP	10 WAP
Irrigation treatment								
FI	118.8 a	166.3 a	174.2 a	175.2 a	2.60 ab	3.07 ab	3.11 ab	3.11 ab
CDI80	100 b	130.5b	142.5 b	144.8 b	2.69 a	3.24 a	3.24 a	3.24 a
APRD80	93.8 bc	123.2 b	143 b	143 b	2.47 ab	3.05 ab	3.15 ab	3.15 ab
FPRD80	88.5 bc	116.7 b	131.7 b	134.2 b	2.50 ab	2.81abc	2.81abc	2.81abc

CDI60	88.7 bc	118.8 b	129.3 b	130.2 b	2.21 bc	2.72 bc	2.72 bc	2.72 bc
APRD60	88.5 bc	115.2 b	132.5 b	134.3 b	1.87 c	2.46 c	2.46 c	2.46 c
FPRD60	77 c	85.5 c	98.8 c	104 c	2.23 bc	2.69 bc	2.69 bc	2.69 bc
p-value	<.001	<.001	<.001	<.001	0.002	0.014	0.011	0.011
N rate								
N1	95.1	125	139.1	140.7	2.37	2.82	2.83	2.83
N2	92.6	119.6	132.9	135.2	2.36	2.91	2.94	2.94
p-value	0.551	0.304	0.252	0.317	0.933	0.445	0.355	0.355
Irrigation x N rate								
p-value	0.272	0.189	0.091	0.073	0.194	0.728	0.63	0.63

Alphabetic differentiators within each column for each experimental factor denote statistically significant distinctions at $P < 0.05$ by Duncan's multiple range tests

As observed in this study, plant height decreased with all deficit irrigation treatment. This finding aligns with previous studies on maize (Kannan and Mulugeta, 2015;Wang *et al.,* 2017; Cheng *et al.,* 2021). Deficit irrigation treatment, conventional deficit irrigation, alternate and fixed partial rootzone drying had similar effect on plant height at mild stress. However, when subjected to further water stress, FPRD demonstrated significant shorter plants. This indicated that CDI and APRD can maintain vegetative growth better than FPRD. Similar observation was made by Gebreigziabher, (2020). In contrast, Hakeem et al. (2016) suggested that APRD controls vegetative growth better than FPRD and CDI. Higher plants were observed with N1 fertilizer, indicating that additional urea application did not yield to a beneficial plant growth. Leaf area index (LAI), a fundamental physiological metric indicating crop assimilation, was highest with CDI80 in our study. Conventional irrigation has been reported to have a better effect on LAI, with APRD outperforming F-PRD (Barideh *et al.,* 2018). However, our findings showed the lowest LAI with A-PRD under severe water deficit conditions. Although higher nitrogen doses promote LAI by fostering leaf growth and development, our study found a similar effect with N1 and N2 fertilizer rates. This aligns with the findings of Jaliya and Barwa (2015), where application of 120 kg ha^{-1} produced significantly higher LAI compared to lower rates, but further increase to 180 kg N ha^{-1} did not affect the LAI.

Plant Dry Biomass and Water Productivity

Irrigation treatment significantly influenced plant dry biomass, while N fertilizer rates and treatment interactions did not exhibit significant effects (Table ii). Shoot, root, and total dry mass were significantly ($p < 0.05$) highest under the FI treatment, while the F-PRD60 treatment yielded the lowest dry biomass. Plant dry biomass exhibited a higher response to the N2 fertilizer rate, but had similar effect with N1 fertilizer. Water productivity was similar for all irrigation treatments ($p = 0.214$). However, the C-DI80 treatment, compared to full irrigation, saved water by 21.6% and increased water productivity by 5.4%. Other deficit irrigation treatments resulted in marginal decreases in water productivity. Water productivity was the same for N fertilizer rates ($p = 0.164$), and treatment interactions ($p = 0.424$).

Table 2. Analysis of variance on the effect of irrigation treatments and N fertilization rates and their interaction on Plant dry biomass, and water productivity

Factor	Shoot dry mass (g plant^{-1})	Root dry mass (g plant^{-1})	Total dry mass (g plant^{-1})	WP (kg/m^3)
Irrigation treatment				
FI	1550.9 a	249.9 a	1801 a	7.39 a
CDI80	1025.1 bc	101.1 bc	1126 b	7.72 a
APRD80	1132 b	135.3 b	1267 b	6.62 a
FPRD80	952.8 bc	88.9 c	1042 bc	5.67 a
CDI60	858.3 cd	76.04 bc	984 bc	4.83 a
APRD60	672.8 de	97.6 bc	770 cd	5.67 a

FPRD60	539.1 e	101.4 bc	640 d	4.52 a
p-value	<.001	<.001	<.001	0.214
N rate				
N1	1080.15	115.11	1052.41	6.60
N2	1271.57	142.09	1127.95	5.52
p-value	0.466	0.012	0.31	0.164
Irrigation x N rate				
p-value	0.002	0.03	0.008	0.424

Alphabetic differentiators within each column for each experimental factor denote statistically significant distinctions at $P < 0.05$ by Duncan's multiple range tests.

Plant biomass was significantly highest with full irrigation compared to other deficit irrigation treatments and this is attributed to the plants under full irrigation getting adequate water supply. Nevertheless, when faced with water scarcity, plants employ various adaptive mechanisms to mitigate the effects of drought stress and some studies have reported on how deficit irrigation techniques impact on this. At mild stress, alternate partial rootzone drying reduced shoot, root and total dry mass by 10.4%, 41.1% and 18.8% respectively, followed by conventional deficit irrigation by 16.9%, 52.1% and 26.5%, and fixed partial rootzone drying by 25.2%, 58.1% and 34.2%. Previous studies have reported that APRD performs better than CDI with respect to biomass yield in corn, attributing it to the reduced stomatal conductance due to ABA root synthetic mechanism (Fengbei *et al*., 2017; Cheng *et al*., 2021). Conversely, some findings have found CDI to be more beneficial to APRD to biomass yield, but FPRD greatly reduce yield (Liang *et al.,* 2013; Barideh *et al.,* 2018).

Shoot, root and total dry mass increased by 11.6%, 13%, and 18.9% respectively with N2 fertilizer rate over N1, but they remained statistically similar. This could be attributed to the high rate of fertilizer used for both nitrogen treatment levels. Plant biomass has been reported to increase with nitrogen fertilizer in maize (Wang *et al*., 2017). However, increasing nitrogen fertilizer can increase plant biomass up to a certain limit, beyond which further addition do not significantly increase the shoot dry mass (Fengbei *et al.,* 2017).

Enhancing water productivity (WP) involves either increasing yield or reducing water usage in irrigation. Water productivity remained statistically similar across all irrigation treatments, indicating that water savings did not significantly compensate for yield reductions. Specifically, under mild stress conditions (21.6% water saved) compared to full irrigation, CDI80 increased WP by 5.4%, while APRD and FPRD reduced WP by 10.8% and 24.32%, respectively. Our study aligns with previous research that reported an increase in maize WP with DI (Eshete *et al.,* 2022; Singh *et al.,* 2023). However, when compared with the PRD method, similar or significantly higher WP with APRD has been reported (Wang *et al.* 2017; *Chandra et al.,* 2018; Gebreigziabher, 2020). These studies attribute the higher WP with APRD plants to partial stomatal closure and the ability to enhance soil water utilization by promoting root growth. WP was lowest with FPRD60, with a 40.3% water savings. According to Al-Ghobari and Dewidar, (2018), when crop water requirements are drastically reduced, WP decreases due to a decline in productivity. The least beneficial effect with the FPRD method can be attributed to compromised root metabolism and the production of chemical signals, particularly abscisic acid (ABA), when experiencing reduced water absorption from the dry section of the root system. Nitrogen application levels had no significant influence on WP. Water productivity with the N1 fertilizer rate was 3.3 kg/m^3, while it reduced by 15.2% to 2.8 kg/m^3 for the N2 fertilizer rate. This observation could be attributed to the rate of fertilizer used, as significant effects on WP between high N fertilizer levels and low/zero N application have been reported for corn (Fengbei *et al.,* 2017).

Nitrogen Uptake and Use Efficiency

Significant impacts on nitrogen uptake were observed across irrigation treatments, and the treatment interactions (Table 3). Shoot, root and total nitrogen uptake was highest ($p < 0.05$) under FI compared to other deficit irrigation treatments, while lowest nitrogen uptake was observed with fixed partial rootzone drying at severe deficit. Additional urea application did not significantly increased shoot, root and total nitrogen uptake over the standard rate. Nitrogen use efficiency (NUE) was highest for APRD60 and FPRD60 treatments, while the lowest NUE was observed with the FI treatment. Nitrogen use efficiency remained the same for N1 and N2 fertilizer rates.

Table 3. Analysis of variance on the effect of irrigation treatments and N fertilization rates and their interaction on Nitrogen uptake and use efficiency

Irrigation Regime	Shoot N uptake (mg plant $^{-1}$)	Root N uptake (mg plant $^{-1}$)	Total N uptake (mg plant $^{-1}$)	NUE (g mg $^{-1}$)
FI	1550.9 a	249.9 a	1801 a	0.061 d
CDI80	1025.1 bc	101.1 bc	1126 b	0.073 bc
APRD80	1132 b	135.3 b	1267 b	0.072 c
FPRD80	952.8 bc	88.9 c	1042 bc	0.076 bc
C-DI60	858.3 cd	76.04 bc	984 bc	0.077 b
APRD60	672.8 de	97.6 bc	770 cd	0.092 a
FPRD60	539.1 e	101.4 bc	640 d	0.093 a
p-value	<.001	<.001	<.001	<.001
N rate				
N1	1080.15	115.11	1052.41	0.08
N2	1271.57	142.09	1127.95	0.08
p-value	0.466	0.012	0.31	0.123
Irrigation x N rate p-value	0.002	0.03	0.008	<.001

Alphabetic differentiators within each column for each experimental factor denote statistically significant distinctions at $P < 0.05$ by Duncan's multiple range tests.

The significantly high N uptake in the shoot and roots of plants under full irrigation suggests a substantial accumulation of nitrogen with adequate water supply. This observation is consistent with previous studies that have reported increased N uptake with higher water regimes in crops such as sunflower (Eltarabily *et al.,* 2019), maize (Hammad *et al.,* 2017; Wang *et al.,* 2017). Among the deficit irrigation treatments, the highest total N uptake was observed with APRD80, followed by CDI80 and FPRD80, while further deficit resulted in lower N uptake with FPRD60, leading to an 81.9% reduction compared to full irrigation. In line with our findings, Barideh *et al.* (2018), also reported significant differences in shoot nitrogen uptake among different irrigation techniques in corn. Their study revealed that the highest uptake occurred under conventional irrigation and alternate rootzone irrigation, methodologies, both of which exhibited a marked contrast to fixed partial rootzone irrigation. Conversely, Fengbei *et al.* (2017) on sweet corn and found no significant variation among CDI, APRD, and FPRD methods when receiving the same amount of water, although shoot N uptake was highest with APRD.

Nitrogen fertilizer plays a crucial role in increasing the total nitrogen uptake of corn, which can have a positive impact on crop yield and productivity. The total nitrogen uptake was the same for the two nitrogen fertilizer levels and this could be attributed to the adequate nitrogen fertilizer level for both treatments. Previous studies have reported an increase in N uptake in corn with increasing fertilizer application (Hammad *et al.* 2017; Wang *et al.* 2017). However, these significant effects were observed between high and low, or zero nitrogen application. The findings from our study suggest that providing additional urea fertilizer beyond the standard requirement did not have a significant impact on plant nitrogen uptake.

Nitrogen use efficiency (NUE) was lowest under full irrigation, and among the deficit treatments, NUE was highest with APRD60 and FPRD60. NUE for the different irrigation methods decreased with increasing water deficit. This finding aligns with the results of Gheysari *et al.* (2009), who reported higher NUE at deficit irrigation levels compared to full and over irrigation levels. When receiving the same amount of water, NUE was highest with F-PRD, followed by APRD and CDI. Previous reports have yielded varying conclusions on the effect of irrigation technique on NUE. Hu *et al.* (2009) reported a significant difference among irrigation techniques for the NUE of maize, with FPRD and APRD outperforming CI technique. Conversely, (Fengbei *et al.* (2017) found a non-significant difference in NUE for CDI, APRD, and FPRD in sweet corn. However, NUE was highest with FPRD, followed by CDI and, lastly, APRD. In another study by Barideh *et al.* (2018) on maize, the conventional irrigation method had the greatest NUE, while alternate partial rootzone drying also had relatively good impact, but the fixed partial rootzone drying treatment, due to the lack of water content in half of the pot, failed to take advantage of the sources of nitrates in the soil. Overall, the effect of deficit irrigation on NUE depends on the crop and the specific conditions of the study.

Additionally, the influence of the two nitrogen levels on NUE was similar. This suggests that both N1 and N2 rates had same effect on the conversion of absorbed nitrogen into plant biomass. However, it is worth noting that in a study by (Hartmann *et al.,* 2015) on a maize-wheat cropping system, NUE declined with increasing N rates. As observed for all irrigation treatments, higher nitrogen use efficiency did not necessarily result in higher productivity. Nevertheless, improving nitrogen use efficiency can contribute to higher yields.

CONCLUSION

Plant growth, dry biomass, and nitrogen uptake were significantly reduced across all irrigation treatments when water deficit conditions were imposed, while water productivity (WP) was statistically similar when compared to full irrigation. The nitrogen use efficiency (NUE) showed a clear upward trend as the water deficit in the irrigation treatments increased, suggesting that nitrogen was better utilized when water was scarce. Moreover, the introduction of additional nitrogen fertilizer, exceeding the standard rate, yielded comparable outcomes in terms of plant growth, dry biomass, WP, nitrogen uptake, and NUE. This suggests the potential for optimizing nitrogen management strategies to mitigate the impact of water deficit on crop performance.

Both alternative partial rootzone drying (APRD) and conventional deficit irrigation (CDI) were equally effective in maintaining water productivity under mild stress conditions. This highlights the significance of choosing suitable irrigation methods to sustain agricultural output in the face of water scarcity.

Overall, it is advised to irrigate sweet corn with full crop water requirement in order to maximize its growth, water productivity, and nitrogen uptake. However, if deficit management is preferred or necessary due to water constraints, maintaining adequate soil moisture levels through the adoption of CDI or APRD, along with proper fertilization based on the optimal nitrogen requirement, is advisable for achieving satisfactory crop yields and resource use efficiency.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

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