Smart Agriculture; Optimizing Water Use Efficiency for Corn (*Zea mays* L.) Crop Cultivars through Responsive Drip Irrigation

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Abstract

Water scarcity poses a major challenge to sustainable maize production, necessitating irrigation strategies that improve water use efficiency without compromising yield. This study evaluated the performance of three sweet corn hybrids (Talar F1, MESSENGER, and SENTINEL) under standard drip irrigation (SDI) and six responsive drip irrigation (RDI) configurations differing in installation depth and lateral distance. The experiment was conducted during the 2025 growing season at Salahaddin University–Erbil using a (3×7) factorial randomized complete block design with three replicates. Implement Responsive Drip Irrigation (RDI) systems with axial pipes were installed at two depths (8 cm and 16 cm) and at varying distances (0 cm, 7.5 cm, and 15 cm) from the axial pipe. The irrigation systems assigned as follows: I1 Standard Drip Irrigation (SDI), I2: (RDI. 16 cm, 0 cm), I3: (RDI. 16 cm, 7.5 cm), I4: (RDI. 16 cm, 15 cm), I5: (RDI. 8 cm, 0 cm), I6: (RDI. 8 cm, 7.5 cm) and I7: (RDI. 8 cm, 15 cm). Growth traits, canopy characteristics, reproductive traits, yield components, total water use, water savings, and irrigation water use efficiency (IWUE) were assessed. Results showed that RDI treatments significantly influenced plant height, leaf area index, light interception, reproductive development, yield, and IWUE. Moderate RDI treatments, particularly RDI installed at 16 cm depth with 0–7.5 cm distance (I2 and I3), enhanced canopy development, improved reproductive traits, and produced the highest grain and forage yields compared with SDI. The SENTINEL hybrid (H3) exhibited superior yield components and biomass production, while MESSENGER (H2) and SENTINEL showed the highest IWUE. RDI systems reduced irrigation water use by approximately 40–53% relative to SDI, with corresponding increases in IWUE. Overall, the findings demonstrate that responsive drip irrigation, combined with suitable hybrid selection, can substantially reduce water use while maintaining or enhancing sweet corn productivity, offering a promising strategy for sustainable maize production in water-limited environments.

Keywords: Water Use, Corn Hybrids, Responsive Drip Irrigation, Crop Productivity.

Introduction

Corn (*Zea mays* L.) is one of the world's most important cereals. With global annual production reaching approximately 1.2 billion tonnes and an average productivity of about 5.8 tonnes per hectare [1]. Sweet corn hybrids (*Zea mays* L.) are developed by crossing inbred parent lines to exploit heterosis, resulting in enhanced yield, sugar content, and stress tolerance compared to open-pollinated varieties; these hybrids exhibit both additive and non-additive genetic control for key traits such as ear yield and carotenoid content, with general combining ability often serving as a reliable predictor of hybrid performance in breeding programs [2]. Modern breeding approaches integrate genomic selection and phenotyping tools to select hybrids with stable performance across environments, improving adaptability and quality traits such as kernel sweetness and nutrient composition under diverse agronomic conditions [3].

Irrigation is often known that plays a crucial role in maintaining food security [4]. It has been estimated that between 70% and 90% of the world's freshwater resources were used for agricultural production [5]. Global water scarcity has become a non-negligible problem that threatens the sustainable development of agriculture. In order to alleviate the contradiction between grain demand and water resource constraints, it is particularly important to explore appropriate irrigation strategy so as to synergistically increase grain yield and water use efficiency [6].

Irrigation efficiency is defined by irrigation scientists and engineers as "the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period to the water diverted from a river or other natural source into the farm or project canal or canals during the same period of time." It is used to describe how efficiently water is delivered to crops and to indicate the amount of water wasted at the plot, farm, command, or system level [7]. The implementation of innovative irrigation technology and the development of ideal irrigation plans have made simpler to use the water resources that are available sensibly, which has improved irrigation management overall [8]. Research indicates that employing techniques can enhance soil water retention and decrease wasteful water use in agricultural areas [9], straw covering [10], subsurface drip irrigation [11], deficit irrigation [12], and applying anti-transpirant agents. These techniques can therefore boost productivity and the effectiveness of agricultural water use [13].

The company that invented the revolutionary water distribution technique that has totally changed the norm for irrigation systems is called Responsive Drip Irrigation (RDI). In comparison to all other forms of forced irrigation, Grow Stream^{TM} tubing is the first and only plant-responsive irrigation and fertigation system in the world. It enables the plant to self-regulate its own water flow, leading to unparalleled water savings and plant performance. A smart subsurface watering tube called Grow Stream^{TM} interacts with and reacts to chemical cues given out by plant roots [14]. With operations in over 40 countries, RDI is expanding.

The objective of this study was to optimize water use efficiency for different sweet corn hybrids through responsive drip irrigation (RDI).

Material and Methods

Experimental Design Components, Plant Treatment, Cultivation Conditions

The study was carried out at Salahaddin University- Erbil, College of Agricultural Engineering Sciences, in the Grdarasha Field in Erbil, Kurdistan Region. The experiment was conducted with GPS coordinates at (Latitude: 36° 6' 45.054" N; Longitude: 44° 0' 44.2512" E, and an elevation of 400 m) between August 4 and October 20, 2025. Representative air- dried soil samples were taken from the field at a depth (0-30 cm), then sieved twice with mish (2 mm) and analyzed for some physical and chemical properties as shown in table (1). Soil tests were analyzed at the Directorate of Agriculture Research Centre, Erbil.

Table 1. Physical and chemical properties of experiment soil at a depth (0-30 cm).

Soil properties		**0-30 cm**
Physical properties	Sand %	36.23
	Silt %	32.94
	Clay %	30.83
	Soil texture	Clay Loam
Chemical properties	OM %	0.80
	N Total (%)	0.06
	P Available (ppm)	4.64
	K Available (ppm)	177.33
	EC $dS.m^{-1}$	0.23
	pH	7.70
	Total Boron (ppm)	1.90
	Boron (Hot water soluble) (ppm)	0.90

The location was divided into lines for three sweet corn hybrids (Talar F1 (Biotek) **H1**, MESSENGER (Semins) **H2** and SENTINEL (Talar type) EliSem (CLAUSE) **H3**, with seven irrigation systems. The experiment was applied with (3×7) Factorial randomized complete block design with three replicates. Beside Standard Drip Irrigation, implement Responsive Drip Irrigation (RDI) systems with axial pipes were installed at two depths (8 cm and 16 cm) and at varying distances (0 cm, 7.5 cm, and 15 cm) from the axial pipe (Figure 1). The treatments assigned as follows:

I1: Standard Drip Irrigation (SDI)

I2: Responsive Drip Irrigation (RDI), (Axial pipes embedded at (8 cm) and distances (0 cm direct) from the axial pipe)

I3: Responsive Drip Irrigation (RDI), (Axial pipes embedded at (8 cm) and distances (7.5 cm) from the axial pipe)

I4: Responsive Drip Irrigation (RDI), (Axial pipes embedded at (8 cm) and distances (15 cm) from the axial pipe)

I5: Responsive Drip Irrigation (RDI), (Axial pipes embedded at (16 cm) and distances (0 cm direct) from the axial pipe)

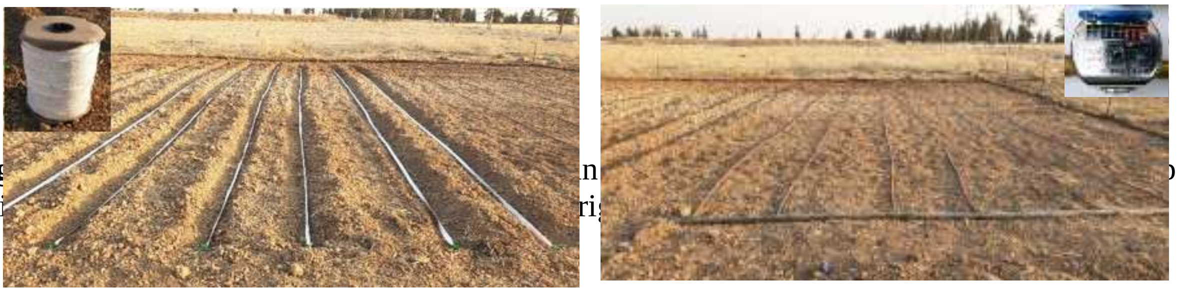
I6: Responsive Drip Irrigation (RDI), (Axial pipes embedded at (16 cm) and distances (7.5 cm) from the axial pipe)

I7: Responsive Drip Irrigation (RDI), (Axial pipes embedded at (16 cm) and distances (15 cm) from the axial pipe).

The length of each line was 15 m long. Each five-meter counted per replicates. The distance between lines in each treatment was 70 cm and the distance between plants was 20 cm on a line. A week prior to planting, the soil and irrigation systems were prepared, and one kernel was hand planted in each hole. The total volume of actual usage of water that had passed through the water meter (Flow meter) was measured for each treatment (Table 2). Average monthly air temperature and precipitation over the months of the year were collected at the experimental site in 2025 (Figure 2).

Table 2. Total Applied Water during the sweat corn growing seasons as affected by different irrigation systems.

Irrigation System	Total Volume of Applied Water (m^3)
I1	80.881
I2	43.245
I3	42.597
I4	48.894
I5	38.217
I6	39.024
I7	47.261



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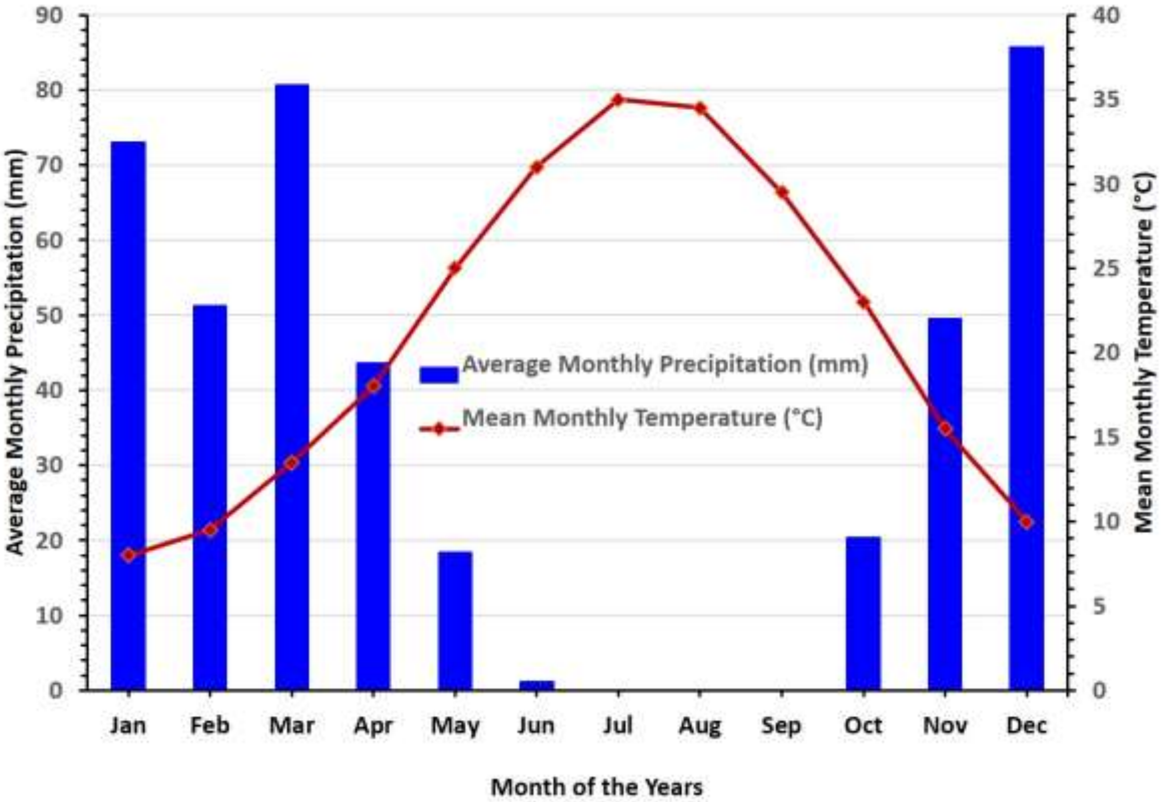

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Height of Plants (cm)

Plant height was monitored every two weeks after seedling emergence. After measuring the distance between the ground and the growing points of fifteen randomly selected plants in each replicate, the

Leaf area index and Light extinction coefficient (K)

At the end of the experiment, five plants from each replicate were destructively

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sampled to determine the leaf area. Image J software was used to compute the leaf area [15,16]. The leaf area index (LAI) was calculated using the determined leaf area. The LAI was calculated using the following equation [17].

$$\text{Leaf area index} = \text{Total leaf area of plant} / \text{Area per plant}$$

Light intensity was measured as light extinction coefficient with Photometer Luxomet 300 Model (M/S Research Instrumentation, New Delhi, India) at lower and upper of crop canopy [18].

$$\mathrm{I} = \mathrm{I}_0 \exp(-K_L\, L)$$

Whereas: I: Irradiance inside canopy, I_0: Irradiance above canopy, Exp: exponential k_L: Attenuation coefficient and L: leaf area index.

Tassel, Spike and Silky length (cm)

The silky length, spike, and tassel were measured using a ruler at 12 WAE. The spike length, including the husks was measured from the stalk to the tip, and the tassel length was measured from the flag leaf to the tip.

Yield and its Component Parameters

The measurements included the number of ears per plant, wet ear weight, cob length, row numbers per each cob, kernel numbers per each row, and mass of kernel per each cob, the length of ear, including the husks, was measured from the tip to the stalk, biological yield, harvest index and fresh forage yield (ton/ha).

Harvest Index (HI) %: was calculated from the following equation [19]:

$$\text{Harvest Index}\,\% = GY/BY * 100$$

GY: Grain Yield (ton/ha), BY: Biological Yield includes all parts of the plant above the soil surface (ton/ha).

Water Save and Irrigation Water Use Efficiency

Irrigation scheduling was applied according to SDI of readily available water and the irrigation interval was set such that the percent of available water depletion be 55%. The percent of depletion was checked by taking soil samples throughout the root zone by a small auger. The following equations were used to calculate the

depth and volume of soil moisture deficit and time of operation of the pump during SDI irrigation only, because for RDI the water was always opened depending on the plant and how much water needed to be used.

$$\mathrm{SMD} = \left[\frac{\theta\mathrm{FC} - \theta\mathrm{i}}{100}\right]\mathrm{Drz}$$

$$\theta\mathrm{i} = \mathrm{P} * \mathrm{TAW}(\%) + \theta_{\mathrm{pwp}}$$

$$\mathrm{TAW} = \theta\mathrm{Fc} - \theta_{\mathrm{pwp}}$$

where SMD = soil moisture deficit (mm), θ_{FC} and θ_{pwp} = Soil moisture content of the root zone at field capacity and permanent wilting point on mass basis, θ_i= Soil moisture content of the root zone prior to irrigation on mass basis. It was obtained from:

P = depletion fraction (0.55 for corn)

D_{rz}= root zone depth at the time of irrigation (mm)

TAW = Total available water (%)

The water use was determined for each separate treatment. The irrigation water use efficiency (IWUE, kg/m^3) was determined using the following equation [20,21]:

$$\mathrm{IWUE} = Ya/I$$

where: Ya: actual yield (kg/ha), and I: is the total irrigation water applied (m^3/ha).

Statistical Analysis

The data was analyzed using the SPSS software, which employed a Factorial Randomized Complete Block design and a general linear model [22]. Descriptive statistics were used to examine the data results, such as means at the 0.05 level, Duncan's multiple range test was used to identify significant differences among the various results [23].

Results and Discussion

The results presented in **Table 3** indicate that sweet corn plant height was significantly influenced by hybrid type, irrigation system, and their interaction at all growth stages (2, 4, 6, and 8 weeks after emergence, WAE). Among the hybrids, H1 (Talar F1) consistently produced the tallest plants throughout the growing period, recording heights of 29.19, 76.99, 154.75, and 185.52 cm at 2, 4, 6, and 8 WAE, respectively, and differing significantly ($P<0.05$) from H2 and H3. Hybrid H2 showed intermediate performance, while H3 generally exhibited the lowest plant height, particularly at the early (2 WAE) and final (8 WAE) growth stages. Irrigation systems also had a significant effect on plant height, with I2, I3, and I4 generally promoting greater vegetative growth compared with other treatments, especially at 4 and 8 WAE. The tallest plants at 8 WAE were observed under I3 (189.80 cm), followed closely by I1 and I2, whereas I6 and I5 resulted in significantly reduced plant height at later stages. The interaction between hybrids and irrigation systems further revealed pronounced variability, indicating differential hybrid responses to irrigation regimes. The maximum plant height across all treatments was recorded in H1 × I3 (197.40 cm) at 8 WAE, followed by H1 × I2 (194.73 cm), highlighting the superior adaptability of H1 under regulated deficit irrigation. In contrast, the lowest plant height was observed in H3 × I6 (154.20 cm) at 8 WAE. Overall, these findings demonstrate that optimal plant height in sweet corn is achieved through the appropriate combination of hybrid selection and irrigation management, with H1 under I2 or I3 showing the most favourable growth performance. The results in Table 3 demonstrate that plant height of sweet corn was significantly influenced by hybrid, irrigation system, and their interaction at all growth stages, indicating strong genotypic and management effects on vegetative growth. Among hybrids, H1 (Talar F1) consistently produced the tallest plants from 2 to 8 weeks after emergence (WAE), suggesting superior genetic vigour and a higher capacity for cell elongation and biomass accumulation compared with H2 and H3, which agrees with previous reports that hybrid differences in maize growth are largely attributed to genetic variability in water-use efficiency and growth rate [1,24]. Regarding irrigation systems, regulated deficit irrigation (RDI) treatments, particularly I2 and I3, resulted in comparable or even greater plant height than standard drip irrigation (I1), especially at later stages, indicating that moderate deficit irrigation can enhance root activity and improve water-use efficiency without severely restricting vegetative growth [25, 26]. In contrast, severe deficit treatments such as I6 significantly reduced plant height at 6 and 8 WAE, reflecting the sensitivity of sweet corn growth to excessive water stress during critical vegetative stages. The significant hybrid × irrigation interactions further reveal that H1 showed greater adaptability to RDI conditions, achieving the maximum plant height under I3 and I2 at 8 WAE, whereas H3 exhibited marked growth reductions under severe deficit irrigation, highlighting differential tolerance among hybrids. These findings confirm that optimizing irrigation strategies according to hybrid-specific responses can maintain or even enhance sweet corn growth while saving water, supporting earlier studies that advocate regulated deficit irrigation as a sustainable approach in maize production under water-limited environments [27,28].

The results in **Table 4** show that leaf area (LA), leaf area index (LAI), and light extinction coefficient (K) at maturity were significantly affected by irrigation systems and by the interaction between sweet corn hybrids and irrigation systems, while the main effect of hybrid alone was not significant ($P>0.05$) for any of the studied traits. Among hybrids, H3 numerically recorded the highest LA (1806.42 cm^2) and LAI (4.51) with the lowest K value (0.276), followed by H1 and H2; however, these differences were not statistically significant. In contrast, irrigation systems exerted a pronounced influence, where I2 and I3 resulted in the greatest canopy development, producing significantly higher LA (2337.89 and 2395.64 cm^2, respectively) and LAI (5.84 and 5.98), accompanied by the lowest K values (0.218 and 0.202), indicating improved light interception efficiency. The lowest LA and LAI were observed under I6 (1256.26 cm^2 and 3.14), which also recorded the highest K value (0.364), reflecting a more open canopy structure. The interaction effects further highlighted distinct hybrid responses to irrigation regimes, with H3 × I3 and H3 × I2 achieving the maximum LA (2812.68 and 2735.61 cm^2) and LAI (7.03 and 6.83), along with the minimum K values (0.169 and 0.166), whereas H3 × I6 exhibited the poorest performance, showing the lowest LA and LAI and the highest K value (0.393). Overall, these findings indicate that optimized regulated deficit irrigation, particularly I2 and I3, markedly enhanced canopy development and light-use efficiency at maturity, especially when combined with hybrid H3. Regulated deficit irrigation treatments I2 and I3 produced the highest LA and LAI values, markedly exceeding standard drip irrigation (I1), which indicates that moderate deficit irrigation enhanced canopy expansion and leaf persistence, likely through improved soil aeration and stimulation of root growth, resulting in more efficient water uptake and assimilate partitioning [26]. In contrast, severe deficit irrigation (I6) significantly reduced LA and LAI while increasing K, reflecting a more open canopy structure with reduced light interception, a common adaptive response of maize to water stress that limits transpirational water loss but compromises photosynthetic capacity [27]. The lowest K values observed under I2 and I3 indicate improved canopy architecture and more effective light distribution within the crop stand, which is closely associated with higher radiation use efficiency and biomass production. The significant hybrid × irrigation interaction further showed that H3 exhibited the greatest LA and LAI under I2 and I3, accompanied by the lowest K values, highlighting its superior plasticity and adaptability to moderate water deficit conditions, whereas all hybrids showed marked reductions in canopy traits under severe deficit irrigation. These findings support the concept that optimized regulated deficit irrigation can improve canopy structure and light interception efficiency in sweet corn, particularly when matched with responsive hybrids, thereby enhancing crop performance under limited water resources [24,28]. According to earlier studies on corn crops, for certain varieties, a LAI of 3 - 4 would be appropriate for optimizing grain yields [29]. Research indicates that the higher value of LAIs might be due to the necessity for effectively preventing sunlight at low lightning intensity ranges [30]. Increased K values indicate better light interception, which could contribute to higher biomass accumulation. Interestingly, H3 performed well in LA and LAI under I2 and I3, suggesting that while it lagged in height, it may have optimized leaf canopy characteristics under favourable irrigation.

The results in **Table 5** show that tassel length, spike length, and silky length of sweet corn were differentially influenced by irrigation systems and hybrid × irrigation interactions, whereas hybrid effects alone were not significant for tassel and spike length, indicating that reproductive organ development was more sensitive to water management than to genetic background under the conditions of this study. Regulated deficit irrigation, particularly I2 and I3, produced longer tassels and spikes and significantly increased silky length compared with standard drip irrigation, suggesting that moderate water supply during reproductive stages enhances assimilate availability, floral differentiation, and silk elongation, which are critical for successful pollination and kernel set [26, 31]. In contrast, more severe deficit treatments (I5 and I6) resulted in reduced silky length and, in some cases, shorter tassels, reflecting the high sensitivity of silk growth to water stress due to its dependence on turgor-driven cell expansion; shortened silks can lead to poor pollen–silk synchrony and reduced fertilization efficiency [32]. The significant hybrid × irrigation interaction for tassel and silky length further indicates differential adaptive responses among hybrids, with H1 under I2 exhibiting the longest tassel and silk, highlighting its superior responsiveness to moderate deficit irrigation, while all hybrids showed compromised silky development under severe water stress. These findings are consistent with previous reports that optimized irrigation strategies can mitigate reproductive stress in maize, improve floral development, and enhance yield potential, particularly when irrigation regimes are tailored to hybrid-specific sensitivities [33].

The results presented in **Table 6** indicate that grain yield components of sweet corn were significantly affected by hybrid, irrigation system, and their interaction, reflecting strong genetic and water-management influences on reproductive performance. Among hybrids, H3 consistently outperformed H1 and H2 by producing the greatest ear length (43.00 cm), wet ear weight (437.91 g), cob length (21.74 cm), wet cob weight (330.43 g), kernels per row (17.52), and kernels per cob (702.66), highlighting its superior sink capacity and kernel set efficiency, whereas H1 generally recorded the lowest values for most yield traits. Irrigation systems exerted a pronounced effect on all yield parameters, with I2 (RDI 16 cm, 0 cm) producing the highest number of ears per plant (2.16), longest ears (43.71 cm), greatest cob and ear weights, and maximum kernels per cob (781.11), followed closely by I3, indicating that moderate regulated deficit irrigation enhanced water-use efficiency without limiting yield formation. In contrast, severe deficit treatments (I6 and I7) significantly reduced ear number, ear size, and kernel traits, likely due to water stress during critical flowering and grain-filling stages, which is known to impair pollination and kernel development in maize [33,34]. The interaction effects further emphasized that the highest overall yield performance was achieved by H3 × I2, which recorded the maximum kernels per cob (828.00) and superior ear and cob characteristics, demonstrating that hybrid H3 responded most positively to optimized irrigation. These findings collectively suggest that selecting high-yielding hybrids such as H3 and applying appropriate regulated deficit irrigation strategies can substantially improve sweet corn productivity by maintaining reproductive growth and kernel set under limited water conditions, in agreement with earlier studies on maize yield response to irrigation management [26,35].

The results in **Table 7** reveal that grain yield and forage yield traits of sweet corn were significantly influenced by irrigation systems and by the interaction between hybrids and irrigation systems, while the main effect of hybrids was significant only for wet kernel weight per cob and biological yield. Among hybrids, H3 produced the highest wet kernel weight per cob (214.16 g) and biological yield (467.47 g plant^{-1}), indicating greater biomass accumulation and assimilate translocation capacity, whereas kernel yield (8.84–8.96 t ha^{-1}) and fresh forage yield (56.05–60.31 t ha^{-1}) did not differ significantly among hybrids, suggesting comparable overall productivity under averaged irrigation conditions. Irrigation systems had a pronounced effect on all parameters, with I2 (RDI 16 cm, 0 cm) producing the maximum kernel yield (11.12 t ha^{-1}), biological yield (512.02 g plant^{-1}), harvest index (2.21%), and fresh forage yield (70.72 t ha^{-1}), followed closely by I3, demonstrating that moderate regulated deficit irrigation enhanced both grain filling and vegetative biomass. In contrast, severe water stress treatments (I6 and I7) significantly reduced kernel yield, biological yield, and forage yield, reflecting the sensitivity of maize reproductive and vegetative growth to water limitation, particularly during silking and grain-filling stages. The interaction effects further emphasized differential hybrid responses, with H2 × I2 recording the highest kernel yield (12.15 t ha^{-1}) and H3 × I2 producing the greatest biological yield (596.66 g plant^{-1}) and fresh forage yield (90.48 t ha^{-1}), indicating that H3 is particularly suitable for dual-purpose production (grain and forage) under optimized irrigation.

The results presented in **Table 8** demonstrate that irrigation water use efficiency (IWUE) of sweet corn was significantly affected by hybrid type, irrigation system, and their interaction ($P<0.01$). Among hybrids, H2 and H3 exhibited significantly higher IWUE values (0.269 and 0.266 kg m^{-3}, respectively) compared with H1 (0.243 kg m^{-3}), indicating superior capacity of these hybrids to convert applied irrigation water into economic yield. This genotypic variation in IWUE is commonly attributed to differences in root architecture, photosynthetic efficiency, and assimilate partitioning among maize hybrids. Irrigation systems exerted a pronounced influence on IWUE, with I2 (RDI 16 cm, 0 cm) achieving the highest IWUE (0.372 kg m^{-3}), followed by I5 and I3, whereas standard drip irrigation (I1) resulted in the lowest IWUE (0.116 kg m^{-3}). This finding suggests that regulated deficit irrigation improved water productivity by reducing excessive water application while maintaining high yield levels. The interaction effects further highlighted differential hybrid responses, with H2 × I2 and H1 × I2 recording the maximum IWUE values (0.389 and 0.379 kg m^{-3}, respectively), followed closely by H2 × I5 and H3 × I2, whereas all hybrids under I1 consistently showed the lowest IWUE. These results indicate that moderate water deficit strategies enhanced crop physiological efficiency and reduced non-productive water losses, a response widely reported in maize under optimized irrigation scheduling. Similar improvements in IWUE under deficit irrigation have been attributed to enhanced stomatal regulation, improved biomass allocation to reproductive organs, and reduced evaporation losses [36,38]. Overall, the findings confirm that combining responsive hybrids, particularly H2 and H3, with regulated deficit irrigation systems such as I2 represents an effective strategy to maximize water productivity of sweet corn under water-limited conditions, in agreement with previous studies on maize water-use optimization [26,36].

The results illustrated in **Figure 3** demonstrate that all responsive drip irrigation (RDI) systems substantially reduced irrigation water use compared with the standard drip irrigation system (SDI), with water savings ranging from 39.54% to 52.74%. Among the treatments, I5 (RDI 8 cm, 0 cm) achieved the highest water saving (52.74%), followed closely by I6 (51.75%), indicating that reducing lateral spacing combined with controlled deficit scheduling was highly effective in minimizing water application without relying on full irrigation. Moderate water savings were recorded under I3 (47.33%) and I2 (46.53%), while I7 (41.56%) and I4 (39.54%) showed comparatively lower but still substantial reductions in water use. These findings confirm that responsive deficit irrigation strategies can markedly improve irrigation efficiency by supplying water more precisely according to crop demand and root-zone moisture conditions, thereby reducing deep percolation and evaporation losses. Similar trends have been reported in maize and sweet corn, where regulated deficit irrigation significantly decreased applied water while maintaining acceptable yield levels, leading to higher water productivity [33,34]. The data in (Figure 3) confirm that RDI treatments achieved significant water savings about 60% compared to SDI. The researchers showed that in their result RDI can reduce water use by up to 30% without sacrificing yield [37]. Responsive drip Irrigation, enable precise water delivery that aligns with crop evapotranspiration needs, improving both water productivity and environmental sustainability [38].

Differences in WUE among hybrids are likely attributable to genetic variations in root architecture, transpiration efficiency, and biomass partitioning [39]. Hybrids with more efficient stomatal regulation and greater capacity to maintain photosynthetic rates under mild water stress often achieve higher WUE [40]. The superior performance of SENTINEL and MESSENGER suggests that these cultivars may possess drought-adaptive traits, making them suitable for water-limited conditions.

Conclusion

In conclusions, responsive drip irrigation markedly improved sweet corn productivity and irrigation water use efficiency while substantially reducing water consumption compared with standard drip irrigation. Comparatively, standard drip irrigation (SDI) practices may lack these efficiencies, leading to higher water consumption and potentially less sustainable agricultural products. Moving towards RDI not only preserves water but might also enhance the resilience of crop yields.

Conflict of interests

A conflict of interest does not exist.

Author contribution

The manuscript has been written, drafted, data-analyzed, and finished by the author.

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Table 3. Response of three sweet corn hybrids to different irrigation systems and their interaction on plant height.

Treatment	**Plant Height (cm) WAE**			
	2 weeks	**4 weeks**	**6 weeks**	**8 weeks**
Sweet Corn Hybrids				
H1	29.19^{a}	76.99^{a}	154.75^{a}	185.52^{a}
H2	26.69^{b}	67.78^{c}	147.33^{b}	181.51^{b}
H3	21.50^{c}	72.62^{b}	147.53^{b}	176.63^{c}
P. value	<0.001	<0.001	0.002	<0.001
Irrigation Systems				
I1	26.47^{ab}	61.73^{b}	148.27^{a}	187.77^{ab}
I2	28.18^{a}	73.97^{a}	155.03^{a}	187.32^{ab}
I3	24.43^{cd}	75.82^{a}	154.06^{a}	189.80^{a}
I4	26.78^{ab}	74.04^{a}	150.31^{a}	183.45^{bc}
I5	25.04^{bcd}	74.67^{a}	148.78^{a}	173.88^{d}
I6	25.80^{bc}	74.37^{a}	141.23^{b}	166.63^{e}
I7	23.83^{d}	72.64^{a}	151.43^{a}	179.70^{c}
P. Value	<0.001	<0.001	0.005	<0.001
Interaction between Hybrids and Irrigation systems				
H1 × I1	29.93^{ab}	64.43^{hij}	156.90^{abc}	184.50^{c-g}
H1 × I2	32.00^{a}	76.86^{a-d}	162.83^{a}	194.73^{ab}
H1 × I3	24.76^{b-e}	76.33^{a-e}	158.20^{ab}	197.40^{a}
H1 × I4	31.90^{a}	82.83^{a}	153.93^{a-d}	186.00^{b-f}
H1 × I5	28.53^{abc}	80.40^{ab}	153.40^{a-d}	179.66^{d-i}
H1 × I6	30.46^{ab}	79.56^{ab}	145.90^{b-e}	174.90
H1 × I7	26.73^{a-e}	78.53^{abc}	152.13^{a-d}	181.50^{d-h}
H2 × I1	26.66^{a-e}	58.73^{j}	144.76^{b-e}	186.90^{b-e}
H2 × I2	29.66^{abc}	71.13^{c-h}	150.86^{a-d}	183.16^{c-h}
H2 × I3	27.70^{a-d}	70.96^{c-h}	149.33^{a-d}	187.83^{a-d}
H2 × I4	27.03^{a-e}	66.76^{ghi}	153.53^{a-d}	188.26^{a-d}
H2 × I5	26.40^{a-e}	70.16^{d-h}	144.76^{b-e}	173.50^{hij}
H2 × I6	25.86^{a-e}	68.56^{e-i}	142.66^{de}	170.80^{ij}
H2 × I7	23.53^{b-e}	68.13^{f-i}	145.43^{b-e}	180.10^{d-i}
H3 × I1	22.83^{c-e}	62.03^{ij}	143.16^{cde}	191.93^{abc}
H3 × I2	22.90^{c-e}	73.93^{b-g}	151.40^{a-d}	184.06^{c-g}
H3 × I3	20.83^{de}	80.16^{ab}	154.66^{a-d}	184.16^{c-g}
H3 × I4	21.43^{de}	72.53^{b-g}	143.46^{cde}	176.10^{f-j}
H3 × I5	20.20^{e}	73.46^{b-g}	148.20^{b-e}	168.50^{j}
H3 × I6	21.06^{de}	75.00^{a-f}	135.13^{e}	154.20^{k}
H3 × I7	21.23^{de}	71.26^{c-h}	156.73^{abc}	177.50^{e-j}
P. value	<0.001	<0.001	0.005	<0.001

H1: Talar F1 (Biotek), **H2:** MESSENGER (Semins) and **H3:** SENTINEL (Talar type) EliSem (CLAUSE).

I1 (SDI, standard drip irrigation), **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).

$^{a-i}$ Means within each column had the different subscript differing significantly (P<0.05).

Table 4. Response of three sweet corn hybrids to different irrigation systems and their interaction on LA, LAI and K at maturity growth stages.

Treatment	**LA (cm^2)**	**LAI**	**K**
Sweet Corn Hybrids			
H1	1706.87 ^{a}	4.26 ^{a}	0.282 ^{a}
H2	1625.50 ^{a}	4.06 ^{a}	0.285 ^{a}
H3	1806.42 ^{a}	4.51 ^{a}	0.276 ^{a}
P. value	0.189	0.189	0.800
Irrigation Systems			
I1	1609.24 ^{b}	4.02 ^{b}	0.277 ^{b}
I2	2337.89 ^{a}	5.84 ^{a}	0.218 ^{c}
I3	2395.64 ^{a}	5.98 ^{a}	0.202 ^{c}
I4	1568.88 ^{bc}	3.92 ^{bc}	0.307 ^{b}
I5	1490.53 ^{bc}	3.72 ^{bc}	0.301 ^{b}
I6	1256.26 ^{c}	3.14 ^{c}	0.364 ^{a}
I7	1332.08 ^{bc}	3.33 ^{bc}	0.299 ^{b}
P. Value	<0.001	<0.001	<0.001
Interaction between Hybrids and Irrigation systems			
H1 × I1	1563.75 $^{e-h}$	3.90 $^{e-h}$	0.267 ^{cde}
H1 × I2	2203.06 ^{bcd}	5.50 ^{bcd}	0.236 ^{def}
H1 × I3	2252.94 ^{bc}	5.63 ^{bc}	0.219 ^{ef}
H1 × I4	1893.80 $^{c-g}$	4.73 $^{c-g}$	0.275 ^{cde}
H1 × I5	1439.34 ^{gh}	3.59 ^{gh}	0.308 ^{bcd}
H1 × I6	1333.04 ^{gh}	3.33 ^{gh}	0.351 ^{abc}
H1 × I7	1262.16 ^{h}	3.15 ^{h}	0.316 $^{a-d}$
H2 × I1	1744.09 $^{c-h}$	4.36 $^{c-h}$	0.272 ^{cde}
H2 × I2	2075.00 $^{c-f}$	5.18 $^{c-f}$	0.252 ^{de}
H2 × I3	2121.31 ^{cde}	5.30 ^{cde}	0.219 ^{ef}
H2 × I4	1482.70 ^{fgh}	3.70 ^{fgh}	0.286 $^{b-e}$
H2 × I5	1391.60 ^{gh}	3.47 ^{gh}	0.315 $^{a-d}$
H2 × I6	1230.66 ^{h}	3.07 ^{h}	0.348 ^{abc}
H2 × I7	1333.14 ^{gh}	3.33 ^{gh}	0.305 ^{bcd}
H3 × I1	1519.87 ^{fgh}	3.80 ^{fgh}	0.292 $^{b-e}$
H3 × I2	2735.61 ^{ab}	6.83 ^{ab}	0.166 ^{f}
H3 × I3	2812.68 ^{a}	7.03 ^{a}	0.169 ^{f}
H3 × I4	1330.13 ^{gh}	3.32 ^{gh}	0.359 ^{ab}
H3 × I5	1640.67 $^{d-h}$	4.10 $^{d-h}$	0.280 $^{b-e}$
H3 × I6	1205.08 ^{h}	3.01 ^{h}	0.393 ^{a}
H3 × I7	1400.92 ^{gh}	3.50 ^{gh}	0.276 ^{cde}
P. value	<0.001	<0.001	<0.001

H1: Talar F1 (Biotek), **H2:** MESSENGER (Semins) and **H3:** SENTINEL (Talar type) EliSem(CLAUSE).

I1 (SDI, standard drip irrigation), **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).

$^{a-i}$ Means within each column had the different subscript differing significantly (P<0.05).

Table 5. Response of three sweet corn hybrids to different irrigation systems and their interaction on tassel length, spike length and silky length.

Treatments	**Tassel Length (cm)**	**Spike Length (cm)**	**Silky Length (cm)**
Sweet Corn Hybrids			
H1	40.74^{a}	23.43^{a}	8.57^{a}
H2	41.05^{a}	25.64^{a}	8.09^{b}
H3	41.51^{a}	25.58^{a}	7.58^{c}
P. value	0.407	0.092	<0.001
Irrigation Systems			
I1	40.61^{bc}	25.77^{a}	8.25^{bc}
I2	42.76^{a}	27.44^{a}	9.30^{a}
I3	41.82^{ab}	25.64^{a}	8.71^{b}
I4	41.57^{ab}	21.44^{b}	8.07^{c}
I5	39.55^{c}	25.22^{a}	7.22^{d}
I6	41.02^{abc}	24.67^{ab}	7.31^{d}
I7	40.37^{bc}	24.01^{ab}	7.71^{cd}
P. Value	0.019	0.047	<0.001
Interaction between Hybrids and Irrigation systems			
H1 × I1	37.56^{d}	24.10^{a}	9.20^{abc}
H1 × I2	46.10^{a}	27.76^{a}	9.70^{a}
H1 × I3	41.32^{bc}	25.46^{a}	9.53^{ab}
H1 × I4	41.06^{bcd}	28.50^{a}	9.06^{a-d}
H1 × I5	39.46^{bcd}	26.80^{a}	8.16^{c-f}
H1 × I6	39.30^{bcd}	27.03^{a}	7.83^{e-i}
H1 × I7	40.36^{bcd}	24.20^{a}	6.53^{j}
H2 × I1	42.33^{b}	25.33^{a}	7.70^{e-i}
H2 × I2	40.93^{bcd}	27.40^{a}	9.70^{a}
H2 × I3	42.23^{bc}	21.16^{a}	8.73^{a-e}
H2 × I4	41.56^{bc}	24.33^{a}	8.10^{c-g}
H2 × I5	38.56^{cd}	18.83^{a}	6.76^{hij}
H2 × I6	41.60^{bc}	23.30^{a}	7.03^{g-j}
H2 × I7	40.16^{bcd}	25.66^{a}	8.63^{a-e}
H3 × I1	41.93^{bc}	26.70^{a}	7.86^{e-h}
H3 × I2	41.26^{bc}	21.53^{a}	8.50^{b-e}
H3 × I3	41.90^{bc}	25.30^{a}	7.86^{e-h}
H3 × I4	42.10^{bc}	27.20^{a}	7.06^{f-j}
H3 × I5	40.63^{bcd}	21.26^{a}	6.73^{ij}
H3 × I6	42.16^{bc}	24.30^{a}	7.06^{f-j}
H3 × I7	40.60^{bcd}	26.46^{a}	7.96^{d-g}
P. value	0.010	0.152	<0.001

H1: Talar F1 (Biotek), **H2:** MESSENGER (Semins) and **H3:** SENTINEL (Talar type) EliSem(CLAUSE).

I1 (SDI, standard drip irrigation), **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).

each column had the different subscript differing significantly ($P<0.05$).

Table 6. Response of three sweet corn hybrids to different irrigation systems and their interaction on grain yield parameters.

Treatment	**Parameters**							
	No. Ear/Plant	**Ear Length (cm)**	**Wet Ear Weight (g)**	**Cob Length (cm)**	**Wet cob weight (g)**	**Row/Cob**	**Kerels/ Row**	**Kerels/ Cob**
Hybrids								
H1	1.83^{b}	36.80^{c}	352.62^{c}	20.21^{b}	283.25^{b}	41.42^{a}	15.71^{b}	652.76^{b}
H2	1.81^{a}	40.08^{b}	407.91^{b}	21.34^{a}	315.73^{a}	39.19^{b}	16.04^{b}	632.57^{b}
H3	1.73^{a}	43.00^{a}	437.91^{a}	21.74^{a}	330.43^{a}	40.09^{ab}	17.52^{a}	702.66^{a}
P. value	0.002	<0.001	<0.001	0.001	<0.001	0.040	<0.001	0.002
Irrigation S.								
I1	1.51^{d}	39.56^{bcd}	382.27^{cd}	21.75^{a}	295.37^{b}	40.66^{b}	16.77^{ab}	683.33^{bc}
I2	2.17^{a}	43.71^{a}	419.15^{b}	22.10^{a}	353.24^{a}	43.88^{a}	17.77^{a}	781.11^{a}
I3	1.89^{b}	41.46^{b}	448.42^{a}	21.15^{ab}	346.38^{a}	40.88^{b}	17.55^{a}	715.11^{b}
I4	1.83^{b}	38.06^{de}	394.05^{c}	20.28^{bc}	287.98^{b}	39.66^{b}	16.22^{bc}	643.77^{c}
I5	1.71^{c}	41.14^{bc}	435.80^{ab}	21.64^{a}	346.53^{a}	40.22^{b}	16.88^{ab}	680.00^{bc}
I6	1.70^{c}	36.77^{e}	356.14^{e}	19.86^{c}	261.14^{c}	36.88^{c}	15.33^{cd}	564.44^{d}
I7	1.73^{c}	39.00^{cde}	360.51^{de}	20.92^{abc}	277.96^{bc}	39.44^{bc}	14.44^{d}	570.88^{d}
P. Value	<0.001	<0.001	<0.001	0.003	<0.001	0.001	<0.001	<0.001
Hybrids × Irrigation S.								
H1 × I1	1.51^{gh}	37.63^{f-i}	357.40^{ghi}	19.73^{fg}	284.80^{e-h}	42.00^{abc}	16.66^{bcd}	701.33^{bcd}
H1 × I2	2.18^{b}	41.40^{c-f}	401.40^{efg}	20.43^{d-g}	356.76^{abc}	43.66^{ab}	18.00^{b}	786.00^{ab}
H1 × I3	2.00^{c}	38.56^{e-h}	371.56^{fgh}	20.36^{d-g}	304.93^{def}	44.00^{ab}	16.00^{cde}	704.00^{bcd}
H1 × I4	1.86^{cd}	34.96^{hi}	376.50^{fg}	20.16^{efg}	244.70^{h}	42.00^{abc}	16.66^{bcd}	697.33^{bcd}
H1 × I5	1.80^{de}	34.90^{hi}	314.00^{i}	20.00^{efg}	257.33^{gh}	38.66^{b-e}	15.33^{def}	593.33^{d-i}
H1 × I6	1.72^{def}	34.23^{i}	330.56^{hi}	20.60^{c-g}	283.33^{e-h}	40.00^{b-e}	14.00^{fg}	560.00^{e-i}
H1 × I7	1.77^{de}	35.90^{ghi}	316.93^{i}	20.23^{efg}	250.90^{h}	39.66^{b-e}	13.33^{g}	527.33^{hi}
H2 × I1	1.57^{fgh}	42.40^{a-e}	409.06^{def}	23.63^{a}	300.20^{d-g}	39.00^{b-e}	16.33^{b-e}	640.00^{c-h}
H2 × I2	2.35^{a}	43.83^{a-d}	405.20^{ef}	22.80^{abc}	339.30^{bcd}	42.00^{abc}	17.33^{bc}	729.33^{abc}
H2 × I3	2.01^{c}	41.20^{c-f}	494.70^{a}	21.93^{a-f}	360.46^{abc}	39.33^{b-e}	16.66^{bcd}	654.66^{c-g}
H2 × I4	1.75^{def}	39.86^{d-g}	405.40^{ef}	20.10^{efg}	301.00^{d-g}	39.33^{b-e}	14.66^{efg}	581.33^{e-i}
H2 × I5	1.68^{efg}	42.10^{b-d}	483.10^{ab}	22.33^{a-e}	399.90^{a}	42.00^{abc}	18.00^{b}	756.00^{abc}
H2 × I6	1.70^{def}	35.00^{hi}	331.20^{hi}	19.66^{fg}	245.96^{h}	36.00^{de}	15.33^{def}	553.33^{ghi}

H2 × I7	1.63 $^{e-h}$	36.16 ^{ghi}	326.70 ^{i}	18.96 ^{g}	263.30 ^{fgh}	36.66 ^{cde}	14.00 ^{fg}	513.33 ^{i}
H3 × I1	1.46 ^{h}	38.66 $^{e-h}$	380.36 ^{fg}	21.90 $^{a-f}$	301.13 $^{d-g}$	41.00 $^{a-d}$	17.33 ^{bc}	708.66 ^{bcd}
H3 × I2	1.97 ^{c}	45.90 ^{ab}	450.86 ^{bcd}	23.06 ^{ab}	363.66 ^{abc}	46.00 ^{a}	18.00 ^{b}	828.00 ^{a}
H3 × I3	1.67 ^{efg}	44.63 ^{abc}	479.00 ^{abc}	21.16 $^{b-g}$	373.76 ^{ab}	39.33 $^{b-e}$	20.00 ^{a}	786.66 ^{ab}
H3 × I4	1.88 ^{cd}	39.36 ^{efg}	400.26 ^{efg}	20.60 $^{c-g}$	318.26 ^{cde}	37.66 ^{cde}	17.33 ^{bc}	652.66 $^{c-g}$
H3 × I5	1.66 ^{efg}	46.43 ^{a}	510.30 ^{a}	22.60 $^{a-d}$	382.36 ^{ab}	40.00 $^{b-e}$	17.33 ^{bc}	690.66 $^{b-e}$
H3 × I6	1.67 ^{efg}	41.10 $^{c-f}$	406.66 ^{ef}	19.33 ^{g}	254.13 ^{gh}	34.66 ^{e}	16.66 ^{bcd}	580.00 $^{d-i}$
H3 × I7	1.80 ^{de}	44.93 ^{abc}	437.90 ^{cde}	23.56 ^{a}	319.70 ^{cde}	42.00 ^{abc}	16.00 ^{cde}	672.00 $^{b-f}$
P. value	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.022

H1: Talar F1 (Biotek), **H2:** MESSENGER (Semins) and **H3:** SENTINEL (Talar type) EliSem (CLAUSE).
I1 (SDI, standard drip irrigation), **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).
$^{a-i}$ Means within each column had the different subscript differing significantly (P<0.05).

Table 7. Response of three sweet corn hybrids to different irrigation systems and their interaction on grain yield and forage yield parameters.

Treatment	**Parameters**				
	Wet Kernel weight/cob (g)	**Kernel Yield (**ton/ha**)**	**Biological Yield (g/plant)**	**Harvest index (%)**	**Fresh Forage Yield (**ton/ha**)**
Sweet Corn Hybrids					
H1	202.21 ^{b}	8.87 ^{a}	437.64 ^{b}	2.03 ^{a}	56.05 ^{a}
H2	205.75 ^{ab}	8.96 ^{a}	455.99 ^{a}	1.97 ^{ab}	59.58 ^{a}
H3	214.16 ^{a}	8.84 ^{a}	467.47 ^{ab}	1.90 ^{b}	60.31 ^{a}
P. value	0.020	0.865	0.016	0.095	0.086
Irrigation Systems					
I1	195.53 ^{b}	7.04 ^{f}	461.37 ^{b}	1.54 ^{c}	63.29 ^{b}
I2	214.97 ^{a}	11.12 ^{a}	512.02 ^{a}	2.21 ^{a}	70.72 ^{a}
I3	212.40 ^{a}	9.57 ^{b}	506.20 ^{a}	1.90 ^{b}	69.95 ^{a}
I4	217.15 ^{a}	9.49 ^{bc}	466.14 ^{b}	2.04 ^{ab}	59.28 ^{b}
I5	215.12 ^{a}	8.76 ^{cd}	436.75 ^{a}	2.01 ^{b}	52.76 ^{c}
I6	191.53 ^{b}	7.76 ^{ef}	388.27 ^{c}	1.99 ^{b}	46.84 ^{c}
I7	204.91 ^{ab}	8.46 ^{de}	405.13 ^{c}	2.08 ^{ab}	47.67 ^{c}
P. Value	0.001	<0.001	<0.001	<0.001	<0.001
Interaction between Hybrids and Irrigation Systems					
H1 × I1	195.73 ^{bc}	7.05 ^{jkl}	474.16 $^{c-f}$	1.49 ^{gh}	66.29 ^{bcd}

H1 × I2	211.83^{abc}	11.08^{ab}	444.46^{d-h}	2.49^{a}	55.38^{d-g}
H1 × I3	195.80^{d}	9.31^{c-h}	466.06^{c-g}	2.00^{b-e}	64.35^{bcd}
H1 × I4	230.20$^{a\ bc}$	10.21^{bcd}	465.96^{c-g}	2.20^{abc}	56.13^{d-g}
H1 × I5	195.80^{bc}	8.39^{g-j}	412.36^{f-j}	2.04^{b-e}	51.56^{efg}
H1 × I6	215.20^{abc}	8.82^{d-h}	419.70^{f-j}	2.10^{bcd}	48.68^{fg}
H1 × I7	170.90^{d}	7.22^{i-k}	380.76^{ij}	1.89^{c-f}	49.97^{efg}
H2 × I1	166.76	6.26^{l}	486.06^{b-e}	1.28^{h}	76.02^{b}
H2 × I2	216.46^{abc}	12.15^{a}	494.93^{bcd}	2.46^{a}	66.30^{bcd}
H2 × I3	222.46^{a}	10.69^{bc}	517.70^{bc}	2.06^{bcd}	70.29^{bc}
H2 × I4	206.36^{abc}	8.60^{f-i}	466.06^{c-g}	1.86^{c-f}	61.83^{cde}
H2 × I5	221.93^{ab}	8.90^{d-h}	437.10^{d-i}	2.03^{b-e}	51.22^{efg}
H2 × I6	193.50^{c}	7.86^{h-k}	384.50^{hij}	2.04^{b-e}	45.47^{g}
H2 × I7	212.76^{abc}	8.27^{g-j}	405.56^{g-j}	2.03^{b-e}	45.90^{g}
H3 × I1	224.10^{a}	7.81^{h-k}	423.90^{e-i}	1.84^{def}	47.57^{fg}
H3 × I2	216.63^{abc}	10.15^{b-e}	596.66^{a}	1.70^{efg}	90.48^{a}
H3 × I3	218.93^{abc}	8.72^{e-h}	534.83^{b}	1.64^{fg}	75.21^{b}
H3 × I4	214.90^{abc}	9.67^{b-g}	466.40^{c-g}	2.07^{bcd}	59.88^{c-f}
H3 × I5	227.63^{a}	9.00^{d-h}	460.80^{c-g}	1.95^{c-f}	55.51^{d-g}
H3 × I6	165.90^{d}	6.61^{kl}	360.63^{j}	1.83^{def}	46.36^{g}
H3 × I7	231.06^{a}	9.90^{b-f}	429.06^{e-i}	2.31^{ab}	47.14^{g}
P. value	<0.001	<0.001	<0.001	<0.001	<0.001

H1: Talar F1 (Biotek), **H2:** MESSENGER (Semins) and **H3:** SENTINEL (Talar type) EliSem (CLAUSE).
I1 (SDI, standard drip irrigation), **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).
$^{a-i}$ Means within each column had the different subscript differing significantly (P<0.05).

Table 8. Effect of three sweet corn hybrids to different irrigation systems and their interaction on water use efficiency.

Treatment	**IWUE (**kg/m^3)
Sweet Corn Hybrids	
H1	0.243^{b}
H2	0.269^{a}
H3	0.266^{a}
P. value	0.006
Irrigation Systems	
I1	0.116^{d}
I2	0.372^{a}
I3	0.323^{b}
I4	0.227^{c}
I5	0.324^{b}
I6	0.239^{c}
I7	0.215^{c}
P. Value	<0.001
Interaction between Hybrids and Irrigation	

Systems	
H1 × I1	0.111 ^{g}
H1 × I2	0.379 ^{a}
H1 × I3	0.301 ^{bcd}
H1 × I4	0.196 ^{f}
H1 × I5	0.255 ^{de}
H1 × I6	0.263 ^{cde}
H1 × I7	0.198 ^{f}
H2 × I1	0.123 ^{g}
H2 × I2	0.389 ^{a}
H2 × I3	0.359 ^{a}
H2 × I4	0.227 ^{ef}
H2 × I5	0.369 ^{a}
H2 × I6	0.226 ^{ef}
H2 × I7	0.191 ^{f}
H3 × I1	0.114 ^{g}
H3 × I2	0.349 ^{ab}
H3 × I3	0.308 ^{bc}
H3 × I4	0.258 ^{de}
H3 × I5	0.348 ^{ab}
H3 × I6	0.229 ^{ef}
H3 × I7	0.257 ^{de}
P. value	<0.001

H1: Talar F1 (Biotek), **H2:** MESSENGER (Semins) and **H3:** SENTINEL (Talar type) EliSem (CLAUSE).

I1 (SDI, standard drip irrigation), **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).

$^{a-i}$ Means within each column had the different subscript differing significantly ($P<0.05$).

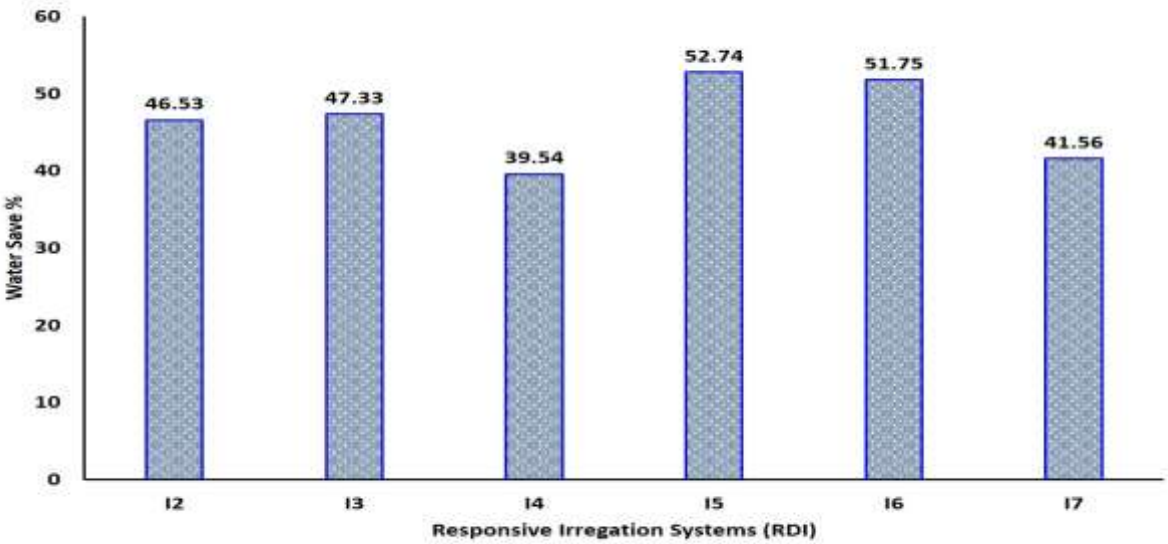

Figure 3: Water saved with installed responsive irrigation system RDI over standard irrigation system (SDI). **I2**: (RDI. 16 cm ,0 cm), **I3**: (RDI. 16, 7,5 cm), **I4**: (RDI. 16, 15 cm), **I5**: (RDI. 8, 0 cm), **I6**: (RDI. 8, 7.5 cm) and **I7**: (RDI. 8, 15 cm).

References

[1] **FAO, (2021).** The State of Food Security and Nutrition in the World 2021: Transforming food systems for food security, improved nutrition and affordable healthy diets for all. FAO, Rome. https://doi.org/10.4060/cb4474en.

[2] **Kanyarat, Yaowapha J., Khundej S. and Bhornchai H. (2024).** The Combining Ability and Heterosis Analysis of Sweet-Waxy Corn Hybrids for Yield-Related Traits and Carotenoids. Plants (Basel). 18;13(2):296.

[3] **Hajer S., Attila V. and Janos N. (2025).** Advances in Sweet Corn (Zea mays L. saccharata) Research from 2010 to 2025: Genetics, Agronomy, and Sustainable Production. 15(5), 1260.

[4] **Wang, X.H.; Müller, C.; Elliot, J.; Mueller, N.D.; Ciais, P.; Jägermeyr, J.; Gerber, J.; Dumas, P.; Wang, C.Z. and Yang, H. (2021)** 'Global irrigation contribution to wheat and maize yield', *Nature Communications*. Springer US, 12(1), pp. 1–8. doi: 10.1038/s41467-021-21498-5.

[5] **Wu, B.F.; Tian, F.Y.; Zhang, M.; Piao, S.L.; Zeng, H.W.; Zhu, W.W.; Liu, J.G.; Elnashar, A. and Lu, Y.M. (2022).** Quantifying global agricultural water appropriation with data derived from earth observations. *Journal of Cleaner Production*. 358, 131891.

[6] **Bian, Q., Zhiduo D., Yanbo F., Yupeng Z., Yaozu F., Zhiguo W. and Jingquan Z. (2024)** 'Optimizing Irrigation Strategies to Improve Yield and Water Use Efficiency of Drip-Irrigated Maize in Southern Xinjiang', *Plants*, 13(24). doi: 10.3390/plants13243492.

[7] **Fereres, E. and Maria, A. S. (2007).** Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany*. 58(2):147-159.

[8] **Li, F.W.; Yu, D. and Zhao, Y. (2019).** Irrigation scheduling optimization for cotton based on the AquaCrop model. *Water Resource Management*. 33, 39-55.

[9] **Wang, Z.; Chen, R.; Li, W.; Zhang, J.; Zhang, J.; Song, L. and Guo, L. (2024)**. 'Mulched drip irrigation: a promising practice for sustainable agriculture in China ' s arid region', *npj Sustainable Agriculture*. Springer US. doi: 10.1038/s44264-024-00024-2.

[10] **Zhao, H.; Liu, G.; Dou, Y.; Yang, H.; Wang, T.; Wang, Z. and Khan, A.A. (2024)**. 'Plastic mulch increases dryland wheat yield and water-use productivity, while straw mulch increases soil water storage', *Journal of Integrative Agriculture*. CAAS. Published by Elsevier B.V, 23(9), pp. 3174–3185. doi: 10.1016/j.jia.2024.01.008.

[11] **Namdarian, D.; Boroomand-Nasab, S.; Gorooei, A.; Gaiser, T.; Solymani, A.; Naseri, A.; Dos Santos Vianna, M. (2024)**. 'Determination of the optimum depth for subsurface dripping irrigation of sugarcane under crop residue management', *Agricultural Water Management*. Elsevier, 303, p. 109026. doi: 10.1016/J.AGWAT.2024.109026.

[12] **Comas, L.H.; Trout, T.J.; Dejonge, K.C.; Zhang, H. And Gleason, S.M. (2019)**. 'Water productivity under

strategic growth stage-based deficit irrigation in maize', *Agricultural Water Management*. Elsevier, 212, pp. 433-440. doi: 10.1016/J.AGWAT.2018.07.015.

[13] Alvar-Beltrán, J.; Heureux, A.; Soldan, R.; Manzanas, R.; Khan, B.; Dalla And Marta, A. (2021) 'Assessing the impact of climate change on wheat and sugarcane with the AquaCrop model along the Indus River Basin, Pakistan', *Agricultural Water Management*. Elsevier, 253, p. 106909. doi: 10.1016/j.agwat.2021.106909.

[14] Gültekin, R. (2023). Future Agricultural Irrigation Technologies and Water Management. Advances in Agriculture, *Forestry and Aquaculture Sciences*, p.182.

[15] Easlon, H. M. and Bloom, A. J. (2014) 'Easy Leaf Area: Automated digital image analysis for rapid and accurate measurement of leaf area', *Applications in Plant Sciences*, 2(7), pp. 2–5. doi: 10.3732/apps.1400033.

[16] Marofi, L. D. and Amin, S. M. A. M. (2019) 'Response of some wheat cultivars to plot orientation and foliar boron levels', *Kurdistan Journal of Applied Research*, 4(2), pp. 1–14. doi: 10.24017/science.2019.2.1.

[17] Bocanski, J., Sreckov, Z. and Nastasic, A. (2009) 'Genetic and phenotypic relationship between grain yield and components of grain yield of maize (Zea mays L.)', *Genetika*, 41(2), pp. 145–154. doi: 10.2298/gensr0902145b.

[18] Sarlikioti, V. (2011). Modelling and remote sensing of canopy light interception and plant stress in greenhouses. Wageningen University and Research.

[19] Donald, C. M. and Hamblin, J. (1976) **'**The Biological Yield and Harvest Index of Cereals as Agronomic and Plant Breeding Criteria', *Advances in Agronomy*. Academic Press, 28(C), pp. 361–405. doi: 10.1016/S0065-2113(08)60559-3.

[20] Stanhill, G. (1986). Water Use Efficiency. *Advances in Agronomy*, 39, 53-85.

[21] Howell, T.A., Cuenca, R.H. and Solomon, K.H. (1990). Crop Yield Response. In: Hoffman, G.J., Howell, T.A. and Solomon, K.H., Eds., Management of Farm Irrigation Systems, *American Society of Agricultural Engineers*, St. Joseph, 93-122.

[22] SPSS, IBM CORP. (2020). IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.

[23] DUNCAN, D. B. (1955). Multiple range and multiple F tests', Biometrics, 11(1), pp. 1-42.

[24] Gheysari, M., *et al*. (2017). Growth and yield response of maize to deficit irrigation. *Agricultural Water Management*, 179, 1–10.

[25] Fereres, E., & Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany*, 58, 147–159.

[26] Kang, S., Zhuang, Y., And Zhang, L. (2017). Improving agricultural water productivity to ensure food security in China under changing environment. *Journal of Experimental Botany*, 68(13), 3523–3530.

[27] Zhang, H., et al. (2019). Effects of regulated deficit irrigation on maize growth and water use efficiency. *Field Crops Research*, 235, 11–20.

[28] Pereira, L. S., et al. (2020). Water saving in irrigation systems. *Water*, 12, 324.

[29] Lindquist, J. L., Arkebauer, T. J., Walters, D. T., Cassman, K. G., and Dobermann, A. (1998). Maize radiation use efficiency under optimal growth conditions. *Agronomy Journal*, 90, 190–199.

[30] Maddonni, G. A. and Otegui, M. E. (1996) 'Leaf area, light interception, and crop development in maize', *Field Crops Research*. Elsevier, 48(1), pp. 81–87. doi: 10.1016/0378-4290(96)00035-4.

[31] Otegui, M. E., Andrade, F. H., and Suero, E. E. (1995). Growth, water use, and kernel abortion in maize. *Field Crops Research*, 40, 81–94.

[32] Edmeades, G. O., Bolanos, J., Chapman, S. C., Lafitte, H. R., and Banziger, M. (2000). Selection improves drought tolerance in tropical maize populations. *Crop Science*, 40, 1315–1324.

[33] Cakir, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of maize. *Field Crops Research*, 89, 1–16.

[34] Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., and Basra, S. M. A. (2009). Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development*, 29, 185–212.

[35] Kirda, C., Topcu, S., Kaman, H., Ulger, A. C., Yazici, A., Cetin, M., and Derici, M. R. (2005). Grain yield response and N-fertiliser recovery of maize under deficit irrigation. *Field Crops Research*, 93, 132–141.

[36] Kresović, B., Tapanarova, A., Tomić, Z., Životić, L., Vujović, D., and Sredojević, Z. (2016). Grain yield and water use efficiency of maize as influenced by different irrigation regimes. *Agricultural Water Management*, 178, 93–101.

[37] Pereira, L. S., Oweis, T., and Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, 57(3), 175-206.

[38] Cotera, R.V.; Egerer, S.; Nam, C.; Lierhammer, L.; Moors, L. And Costa, M.M. (2024) 'Resilient agriculture: water management for climate change adaptation in Lower Saxony', *Journal of Water and Climate Change*, 15(3), pp. 1034–1053. doi: 10.2166/wcc.2024.455.

[39] Condon, A. G., Richards, R. A., Rebetzke, G. J., and Farquhar, G. D. (2004). Breeding for high water-use efficiency. *Journal of Experimental Botany*, 55(407), 2447-2460.

[40] Gleason, M., , Lauren N., Cameron H., Robert B., Satya C., and Louise H C. (2021). Growth and grain yield of eight maize hybrids are aligned with water transport, stomatal conductance, and photosynthesis in a semi-arid irrigated system. *Physiologia Plantarum*. 172(4):1941-1949.