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Impact of deficit sprinkler irrigation scheduling on maize (*Zea mays* L.) crop coefficient and vegetative growth in coastal Syria

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Abstract

This study was conducted in the Jableh District, Latakia Governorate in northwestern Syria during the 2023-2024 irrigation seasons to evaluate the effect of deficit irrigation on the vegetative growth of maize (*Zea mays* L.) cultivar "Casper". A randomized complete block design (RCBD) was employed with four irrigation treatments representing 70%, 80%, 90%, and 100% of crop water requirement. The results revealed significant differences among irrigation treatments ($p \leq 0.05$). The 80% irrigation level showed the most favorable effect on vegetative growth parameters. Significant increases were observed in leaf area (21.7%), leaf surface area (29.9%), and leaf area index (32.6%) compared to the control treatment (100%). These findings suggest that moderate deficit irrigation can improve water use efficiency while maintaining optimal plant growth under coastal Syrian conditions. These results demonstrate that moderate deficit irrigation (80%) enhances vegetative growth parameters while improving water use efficiency, indicating its potential as a sustainable irrigation strategy for maize cultivation under similar environmental conditions.

Keywords: Irrigation scheduling, *Zea mays L.*, Deficit irrigation, Physiological characteristics.

1. Introduction

Maize (*Zea mays L.*) is an important cereal crop in Syria due to its high nutritional value as a primary source of energy and protein for humans' consumption. In addition, maize is widely used in biofuel production, particularly ethanol. The cultivated area of maize in Syria is estimated at approximately 30,000 hectares, with an average grain yield of about 3,500 kg ha^{-1} (Ministry of Agriculture and Agrarian Reform [MAAR], 2013). Despite its economic importance, maize production remains insufficient to meet local demand, resulting in a significant reliance on imports, which account for nearly 80% of national consumption (General Organization for Grains, 2014).

Water scarcity, recurrent drought, and noticeable changes in rainfall patterns are some of the main factors limiting agricultural productivity, particularly in arid and semi-arid regions (Skaff and Saqr, 2015; Hamid and Mansoor, 2019). Improving water use efficiency has therefore become a critical priority for ensuring agricultural sustainability under changing climatic conditions (FAO, 2021). In addition, the use of traditional irrigation methods (flooding, furrows, lines) leads to significant water waste and uneven distribution. This inefficient distribution of water hinders optimal water absorption by the roots, leading to reduced crop productivity (Chen *et al.*, 2023). Consequently, rationalizing water use for irrigation purposes has become a priority due to population growth and increasing demand for water from the agricultural, industrial, and urban sectors of society. The importance of this trend stems from the fact that agriculture is the main consumer of water, which has prompted consideration of ways and means to contribute to rationalizing water consumption. Controlling the amount of water given in each irrigation and the number of irrigations (irrigation scheduling), knowing the soil's water absorption capacity and the plant's needs at different stages of growth, to achieve the highest productivity, is an effective means of optimizing water investment.

Irrigation scheduling depends on soil properties, crop type, atmospheric conditions, the irrigation system, and operational factors. Good irrigation scheduling is essential for increasing water-use efficiency, improving crop productivity, and reducing production costs. One of the most effective ways to optimize water use is to control the amount of water applied in each irrigation and to determine the number of irrigations according to the stages of plant growth, that is, scheduling irrigation according to the soil's water-holding capacity in order to achieve the highest possible yield. One of the concepts adopted in scheduling and repeating irrigation is to use the ratio of the amount of water added (Irrigation water, IW) to the cumulative evaporation from the evaporation pan (Cumulative pan evaporation, CPE) (Schulthess *et. al.*, 2019). This method allows for better synchronization between water application and plant requirements (Kaur and Brar, 2016; Kumawat *et. al.*, 2016; Datta *et. al.*, 2022). In this context, However, crop response to deficit irrigation varies depending on the growth stage and environmental conditions (FAO, 2002).

Previous studies have reported mixed results regarding the impact of deficit irrigation on maize growth and yield. For example, moderate deficit irrigation (e.g., 80% of evapotranspiration) has been associated with improved water use efficiency and acceptable yield levels, whereas severe water stress may reduce leaf area development and limit growth, particularly during sensitive stages such as flowering (Al-Kaisi and Yin, 2003; Elsayed *et al.*, 2023). In contrast, other studies have shown that full irrigation (100%) may result in higher leaf area index and biomass accumulation under certain conditions (Zeno and Issam, 2007). These variations highlight the importance of considering local environmental conditions when evaluating irrigation strategies.

Previous studies have shown that corn yield is affected by insufficient irrigation, which is reflected in field characteristics and, consequently, in the yield and its components, as corn water consumption depends on leaf width, leaf angle, plant height, soil moisture content, and vegetative density (Petrík et al., 2023). Therefore, it is important to study the morphological characteristics of the crop and their effect on increasing grain yield, which depends mainly on the size and efficiency of carbon fixation and dry matter accumulation, which is the result of the effectiveness of the green area. In a unit of land area capable of intercepting the largest amount of light, carbon fixation increases and thus growth (Elsahookie, 2013). In other words, morphological traits are influenced by environmental factors and accompanying field operations in crop production (Wuhaib, 2013), including irrigation, where several studies have found that exposure of plants to water shortage leads to a decrease in height and a reduction in leaf area (Zou et. al., 2021). The leaf area decreases when irrigation duration is prolonged, as low soil moisture negatively affects plant physiological processes, as evidenced by the decrease in leaf area. The stalk of the corn crop stores solid nutrients dissolved in the flowering stage, which mainly consist of sucrose, contributing to increased grain yield (Altaf et. al., 2023). The carbohydrates stored in the stalk and leaf sheaths are transferred to the ears when corn plants are exposed to unfavorable environmental conditions (stress). These nutrients, accumulated (stored) in the stem and leaf sheaths and transferable to the ears during the grain filling period, are determining factors for the productivity of yellow corn plants (Srivastava et. al., 2017). On the other hand, the exposure of yellow corn to water shortage during specific growth stages does not cause a significant reduction in grain yield. Therefore, a quantity of water can be saved for agricultural expansion purposes (Zhang et. al., 2021).

This study aims to optimize water use efficiency by controlling the amount of water given in each irrigation, i.e., scheduling irrigation according to plant needs and soil water absorption capacity to achieve optimal plant growth and maximum yield. The increase in the areas planted with yellow corn in the Syrian Arab Republic, the decline in rainfall, its poor distribution during the growing season, its fluctuation from one agricultural season to another, and the low level of agricultural services provided to the crop have all contributed to lower productivity. Therefore, serious consideration must be given to regulating and rationalizing water consumption in yellow corn cultivation and to seeking modern irrigation techniques and good water management. Although deficit irrigation strategies for maize have been extensively studied, their application in specific agro-ecological contexts, such as the coastal region of Syria, remains insufficiently explored. This study evaluates the physiological and vegetative responses of maize (*Zea mays* L. (cv. Casper)) under a localized sprinkler irrigation system, which has not been previously investigated in this region. In addition, irrigation scheduling based on crop coefficients (Kc) and climatic data is applied to manage water stress at 70%, 80%, and 90% of crop water requirements over two consecutive growing seasons (2023–2024). The findings provide region-specific insights into optimizing irrigation practices and improving sustainable maize production under water-limited Mediterranean conditions.

2. Materials and Methods

Location

The experiment was conducted during the 2023 - 2024 irrigation seasons in the Jableh area of Latakia Governorate, 35°22′6″N, 35°55′26″E. Table 1 presents the monthly averages of climate data for the study period (May -September) for the irrigation seasons (2023-2024). The study area is characterized by a Mediterranean climate with hot, dry summers and mild, wet winters.

Table 1. Changes in climate data in the study area were calculated as monthly averages (2023-2024)

Atmospheric Elements / Month	Sunshine duration (hours/day)		Minimum humidity %		Maximum humidity %		Minimum °C temperature		Maximum °C temperature	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
May	7.4	10.3	45.6	33.1	95.8	94.6	18.5	16.7	25.1	28.3
June	7.5	10.6	53.4	45.2	97.1	93.1	22.9	22.6	29.5	29.3
July	10.5	11.9	59.6	50.5	95.7	92.7	25	24.7	30	30.5
August	10.3	11	56.4	53.7	94.3	93.9	24.5	24.6	31.5	31.3
September	9.7	9.5	49.9	36.8	97	93.8	21.8	21.9	27.5	29.2

Plant material

The research used *Zea mays* L. (Casper variety), an imported variety sourced from the General Authority for Agricultural Scientific Research and grown in agricultural research stations. It is a hybrid variety with high productivity and tolerance to the environmental conditions of the coastal region, and its total water consumption is high, reaching up to 3000 $m^3.h^{-1}$.

Preparation for cultivation

The soil was deeply plowed to a depth of 27-30 cm, followed by shallow plowing to a depth of 15 cm. The soil was then leveled manually with rakes.

Fertilization

Mineral fertilizers were added after analyzing the soil and determining its nutrient content as follows ;Potassium fertilizer (K_2O) was added at a rate of 100 $kg.ha^{-1}$, nitrogen (N) was added in three batches at a rate of 400 $kg.ha^{-1}$, and phosphorus (P_2O_5) was added at a rate of 180 $kg.ha^{-1}$ (Bouaisa and Nadim, 1997).Weeds were removed manually, and thinning and singling operations were carried out (only one plant was left to achieve a plant density of 35,714.285 $plants.ha^{-1}$). Weeding and pest control were carried out at the appropriate times, and irrigation was conducted according to the experiment plan.

Experimental design

Planting was carried out on May 26, 2023, and June 10, 2024, using Randomized Complete Block Design (RCBD) with three replicates and four plots per replicate. The dimensions of the experimental plot (4 x 2 m) and contained of three rows, with 70 cm between rows and 40 cm between plants within each row. Two to three seeds were planted in each hole, and after germination, only one plant was left in each hole. Crop water requirements were calculated based on crop coefficients (Kc) and reference evapotranspiration (ET_0).

The plots were assigned to four irrigation treatments to evaluate the effect of deficit irrigation: 70% (T1), 80% (T2), and 90% (T3) of crop water requirements, in addition to the control treatment at 100% (T4). The harvest was on September 1, 2023, for the first season, and on September 16, 2024, for the second season.

Specifications of the micro-sprinkler irrigation network

Two sprinklers were installed for each experimental plot, with a wetted diameter of 2 m and a theoretical sprinkler discharge of 57 $L\ h^{-1}$, operating at a pressure of 1.5 bar. The water distribution uniformity of the sprinkler system was almost identical in all experimental plots.

Soil characteristics

Soil samples were collected from depths of 0–30 cm and 30–60 cm to determine selected physical soil properties using standard laboratory methods. The soil texture was classified as clay loam.

Characteristics studied of the Crop

Ten plants were selected from each experimental plot, and the following field measurements were recorded:

Morphological characteristics

Plant height was measured from the soil surface to the base of the inflorescence, the number of leaves per plant was recorded, and the height of the first ear was determined.

Physiological characteristics

Leaf area was calculated as leaf length × maximum leaf width × 0.75 (Carleton and Foote, 1965). Total leaf area per plant was determined by multiplying the number of leaves by the leaf area, and leaf area index (LAI) was calculated as the ratio of total leaf area to the ground area per plant.

Table 2. Physical properties of the experimental soil at different depths (0–30 and 30–60 cm)

Analysis	Depth (cm)	
	0-30	30-60
Sand %	3.5	5.29
Silt %	50.65	47.35
Clay %	45.89	47.36
True Density g.cm^3	2.6	2.61
Bulk Density g.cm^3	1.22	1.41
Field capacity %	36.89	36.89
Permanent wilting point %	24.6	24.6

Calculating the rate of watering per irrigation

The amounts of irrigation water were calculated based on soil moisture depletion within the root zone, which increased from 0-20 cm at early growth stages to 0-50 cm at maturity. The irrigation water volume (Q) was calculated using the following equation:
$Q = W \times F \times 10$ (Ibrahim and Mona, 2013)

Where Q is the irrigation water volume (m^3), W is the irrigation water depth (mm), F is the field area (ha), and 10 is a conversion factor to express the volume in cubic meters.

Water depth (W) was determined using the following relationship:

$W = (\theta FC - \theta WP) \times D$
Where ($\theta FC - \theta WP$) represents the difference between soil moisture content at field capacity and wilting point, and D is the effective root zone depth (cm). Soil moisture content was determined using the standard gravimetric method for all treatments.

Water requirements for experimental treatments

According to the relationship: ETc = ETo. Kc (FAO, 1977)
ETc: Total water requirement mm
ETo: Maximum latent evaporation (reference) mm. Calculated using the ETo calculator program according to the modified Penman-Monteith equation (FAO Penman-Monteith) (Allen *et al.*, 1998).
Kc: Crop coefficient. The coefficient values were adopted according to the phenological stages of the plant (FAO, 2010).

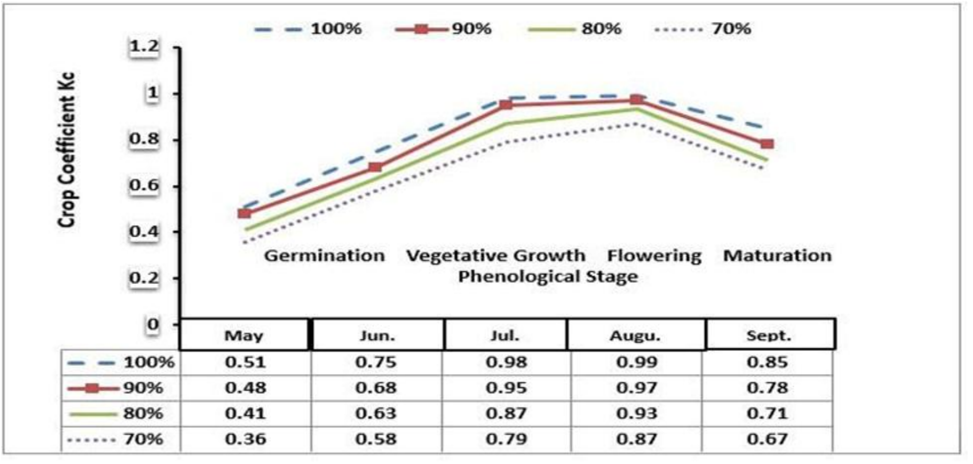
Statistical analysis

The experimental design was a randomized complete block design (RCBD) with three replicates. The experimental unit was the individual plot (4 m × 2 m), from which ten plants were randomly selected for measurement to account for within-plot variability. Data were subjected to analysis of variance (ANOVA) using Genstat 12 software. The statistical model included year (Y), treatment (T), and their interaction (Y × T) as fixed factors, while blocks (replicates) nested within years were considered random effects. This model allowed the assessment of treatment consistency across the two growing seasons. Mean comparisons were performed using Fisher's least significant difference at a 5% probability level ($P \leq 0.05$) to identify significant differences among treatment means. Tables present the LSD values to facilitate the interpretation of treatment effects and their interactions.

3. Results

Yield coefficient Kc and irrigation scheduling

The crop coefficient (Kc) values followed the expected pattern for maize, increasing from low values during germination to a peak during the flowering and milk stages, and then declining as the crop approached maturity (Figure 1). This trend is consistent with previous findings (Auda *et. al.*, 2016; Kumar *et al.*, 2019; Zou et al., 2021) and reflects the variation in water demand across different phenological stages. The highest Kc values were observed under the control treatment (100% ETc), which can be attributed to greater water availability, maintaining soil moisture near field capacity throughout the growing season.



	May	Jun.	Jul.	Augu.	Sept.
100%	0.51	0.75	0.98	0.99	0.85
90%	0.48	0.68	0.95	0.97	0.78
80%	0.41	0.63	0.87	0.93	0.71
70%	0.36	0.58	0.79	0.87	0.67

Figure 1. Crop coefficient Kc curves for maize under deficit sprinkler irrigation treatments during the 2023–2024 growing seasons.

The irrigation scheduling analysis revealed that the flowering stage represented the peak water consumption period, making it the most sensitive to water deficits. During this critical phase, any shortage can impair reproductive organ function and reduce grain filling (Otegui and Andrade, 2020; Yan et. al., 2021). Notably, the 80% irrigation treatment maintained adequate soil moisture during flowering while achieving a 20% reduction in total water applied compared with the control. This water saving did not compromise vegetative growth; in fact, the 80% treatment often outperformed the control in key physiological traits such as leaf area and leaf area index (Tables 5 and 6). These results indicate that the 80% irrigation level optimizes the balance between water conservation and crop performance by maintaining sufficient moisture during critical growth stages while avoiding the excessive vegetative growth associated with full irrigation.

Table 3. Net and total water requirements (m^3. ha^{-1}), number of irrigations, and mean daily consumption (m^3 ha^{-1}) for maize under different irrigation treatments during the 2023 growing season.

Growth Stage	Treatment	Net Water Requirement (m^3 ha^{-1})	Total Water Requirement (m^3 ha^{-1})	Number of Irrigations	Mean Daily Consumption (m^3 ha^{-1})
Germination	70%	103.3	119.7	1	11.4
	80%	118.1	136.7	1	13.1
	90%	132.8	153.7	1	14.7
	100%	147.6	170.8	1	16.4
Vegetative	70%	464.9	538.1	3	13.3
	80%	531.4	615.1	3	15.2
	90%	597.7	691.8	3	17.1
	100%	664.2	768.8	3	18.9
Flowering	70%	619.9	717.5	3	30.9
	80%	708.5	820	3	35.4
	90%	797	922.5	3	39.8
	100%	885.6	1025	3	44.3
Maturity	70%	774.9	896.9	3	25.8
	80%	885.6	1025	3	29.5
	90%	996.3	1153.1	3	33.2
	100%	1107	1281.3	3	36.9

Table 4. Net and total water requirements (m^3 ha^{-1}), number of irrigations, and mean daily consumption (m^3 ha^{-1}) for maize under different irrigation treatments during the 2024 growing season.

Growth Stage	Treatment	Net Water Requirement (m^3 ha^{-1})	Total Water Requirement (m^3 ha^{-1})	Number of Irrigations	Mean Daily Consumption (m^3 ha^{-1})
Germination	70%	206.6	239.1	2	20.7
	80%	236.2	273.4	2	23.6
	90%	265.6	307.4	2	26.6
	100%	295.2	341.7	2	29.5
Vegetative	70%	619.6	717.1	4	17.7
	80%	708.4	819.9	4	20.3
	90%	797.2	922.7	4	22.8
	100%	885.6	1025	4	25.3
Flowering	70%	619.6	717.1	3	30.9
	80%	708.4	819.9	3	35.4
	90%	797.2	922.7	3	39.9
	100%	885.6	1025	3	44.3
Maturity	70%	774.9	896.9	3	26.7
	80%	885.6	1025	3	30.5
	90%	996.3	1153.1	3	34.4
	100%	1107	1281.3	3	38.2

Table 5. Effect of irrigation treatments on plant height (cm), number of internodes and leaves, and height of the first maize pod (cm) for the two seasons (2023-2024).

Treatment		High of the First Maize Pod (cm)		Number of leaves		Number of internods		Plant height (cm)	
		First season	Second season	First season	Second season	First season	Second season	First season	Second season
70%		96.94	99.9	15.4	15.9	11.4	13.4	177.1	229.1
80%		107.8	110.8	15.5	15.9	13.1	15.1	206.2	248.8
90%		101.2	104.2	15.7	14.8	11.4	13.4	199.6	213
100% (control)		107.6	110.5	15.3	14.9	12.6	14.6	192.7	201.7
L.S.D 5%		4.8	4.9	1.4	0.66	0.32	0.32	24.7	6.96
C.V%		4.9	4.8	4.7	4.43	6.3	5.4	8.2	8.4
L.S.D 5%	Y	4.5		0.58		0.75		15.76	
	T	6.4		0.82		1.06		22.29	
	Y*T	9.1		1.2		1.5		31.53	

Table 6. Effect of irrigation treatments on leaf area and total leaf area (cm²). Leaf area index for the two seasons (2023-2024).

Treatment		High of the First Maize Pod (cm)		Number of leaves		Number of internods		Plant height (cm)	
		First season	Second season	First season	Second season	First season	Second season	First season	Second season
70%		96.94	99.9	15.4	15.9	11.4	13.4	177.1	229.1
80%		107.8	110.8	15.5	15.9	13.1	15.1	206.2	248.8
90%		101.2	104.2	15.7	14.8	11.4	13.4	199.6	213
100% (control)		107.6	110.5	15.3	14.9	12.6	14.6	192.7	201.7
L.S.D 5%		4.8	4.9	1.4	0.66	0.32	0.32	24.7	6.96
C.V%		4.9	4.8	4.7	4.43	6.3	5.4	8.2	8.4
L.S.D 5%	Y	4.5		0.58		0.75		15.76	
	T	6.4		0.82		1.06		22.29	
	Y*T	9.1		1.2		1.5		31.53	

Irrigation levels affect morphological characteristics

Plant height

In the first season, the 80% irrigation treatment resulted in significantly taller plants compared to the 70% treatment, with an increase of 14% (Table 5). No significant differences were observed among the other treatments, including the control (100%). In the second season, all deficit irrigation treatments (70%, 80%, and 90%) produced significantly greater plant heights than the control, with increases of

13.5%, 23.3%, and 5.6%, respectively. The tallest plants were recorded under the 80% treatment in the second season.

Number of internodes

In the first season, the 80% treatment had significantly more internodes than the 70%, 90%, and control treatments, representing a 3.9% increase over the control (Table 5). The control treatment also had significantly more internodes than the 70% and 90% treatments (9.5% increase for both). In the second season, the 80% treatment again produced the highest number of internodes, significantly exceeding all other treatments, with a 3.4% increase over the control. The control remained significantly higher than the 70% and 90% treatments (8.2% increase).

Height of the first maize pod

In the first season, the control treatment recorded a significantly higher first pod height compared to the 70% and 90% treatments, with increases of 9.9% and 5.9%, respectively (Table 5). The 80% treatment did not differ significantly from the control. Similar trends were observed in the second season: the control and 80% treatments were statistically comparable, and both significantly exceeded the 70% and 90% treatments, with the control showing increases of 9.5% and 5.7% over the 70% and 90% treatments, respectively.

Number of leaves

In the first season, no significant differences in leaf number were detected among treatments (Table 5). In the second season, the 70% and 80% treatments produced significantly more leaves than the 90% and control treatments, representing a 6.9% increase over the control.

The effect of irrigation levels on physiological characteristics

Leaf area

In the first season, leaf area did not differ significantly among treatments (Table 6). In the second season, the 70% and 80% treatments exhibited significantly greater leaf area than the control, with increases of 18.7% and 21.7%, respectively. The 90% treatment was statistically similar to the control.

Total Leaf area

In the first season, total leaf area showed no significant variation among treatments (Table 6). In the second season, the 70% and 80% treatments significantly outperformed both the 90% and control treatments, with increases of 26.5% and 29.9% over the control, respectively. The interaction between year and treatment revealed that the highest total leaf area was achieved under the 80% treatment in the second season, while the lowest was recorded under the 90% treatment in the same season.

Leaf area index

Consistent with leaf area and total leaf area, the leaf area index (LAI) in the first season did not differ significantly among treatments (Table 6). In the second season, the 70% and 80% treatments recorded significantly higher LAI values than the 90% and control treatments, corresponding to increases of 28.2% and 32.6% over the control, respectively.

4. Discussion

Yield coefficient Kc and irrigation scheduling

The crop coefficient (Kc) values followed the expected pattern for maize, increasing from low values during germination to a peak during the flowering and milk stages, then declining as the crop approached maturity (Figure 1). This trend, consistent with findings by Auda et al. (2016), Kumar et al. (2019), and Zhang et al. (2021), reflects the varying water demands across phenological stages. The highest Kc values were consistently observed under the control treatment (100% ETc), which can be attributed to greater water availability, maintaining soil moisture near field capacity throughout the season. This resulted in higher evapotranspiration rates and, consequently, greater water consumption, as also reported by Al-Kaisi and Yin (2003).

The irrigation scheduling analysis revealed that the flowering stage represented the peak water consumption period, making it the most sensitive to water deficits. During this critical phase, any shortage can impair reproductive organ function by reducing pollen viability and ovary formation, ultimately decreasing grain set and filling (Otegui and Andrade, 2020; Yan et al., 2021). Notably, the 80% irrigation treatment maintained adequate soil moisture during flowering while achieving a 20% reduction in total water applied compared with the control. This finding is particularly significant because it demonstrates that moderate deficit irrigation can sustain critical physiological processes during the most water-sensitive stage while conserving substantial amounts of water—a result consistent with Zhang et al. (2021), who reported similar water savings without yield penalties in maize under deficit irrigation.

Irrigation levels affect morphological characteristics.

Plant height

The superior performance of the 80% irrigation treatment in terms of plant height, particularly during the drier and hotter second season (23.3% increase over control), can be explained by several physiological mechanisms. First, moderate water stress (20% deficit) likely stimulated root development, enabling more efficient water uptake from deeper soil layers—a compensatory mechanism well documented by Zou et al. (2021). Second, the 80% treatment provided sufficient soil aeration and moisture in the root zone, avoiding the oxygen deficiency that can occur under full irrigation (100%) when soil pores remain water-saturated for extended periods. This balance between water availability and aeration is critical for optimal cell elongation and division, as noted by Zhang et al. (2021). The fact that all deficit treatments (70%, 80%, and 90%) outperformed the control in the second season suggests that under water-limited conditions, even mild water savings can trigger adaptive responses that enhance growth compared to plants accustomed to abundant water.

Number of internodes

The consistent superiority of the 80% treatment in internode number across both seasons (3.9% and 3.4% increases over control) indicates that this irrigation level optimized the conditions for node differentiation and elongation. Internode formation is particularly sensitive to water availability during the early vegetative stages, as each internode's development is linked to the expansion of the leaf at that node (Morsi, 1979). The 80% treatment likely maintained optimal turgor pressure in the meristematic tissues without inducing the stress responses observed in the 70% treatment, where a more severe deficit probably limited cell division. The intermediate performance of the 90% treatment suggests that near-full irrigation may not provide additional benefits for internode differentiation, supporting the concept of a threshold beyond which extra water does not translate into improved morphological traits.

Height of the first maize pod

The absence of significant differences between the 80% treatment and the control in the first pod height is agronomically important, as this trait is directly related to lodging resistance and harvest efficiency (Abd, 2012). While the control and 80% treatments were statistically comparable, both significantly exceeded the 70% and 90% treatments. The poor performance of the 70% treatment likely reflects severe water stress during the reproductive phase, when the plant allocates resources to pod formation. Conversely, the 90% treatment's intermediate values may indicate that slight water excess can delay reproductive development, as plants prioritize vegetative growth under non-stressed conditions—a phenomenon observed by Srivastava et al. (2017) in their study of carbohydrate remobilization in maize.

Number of leaves

The seasonal variation in leaf number response—no differences in the first season but significant superiority of 70% and 80% treatments in the second season—highlights the interaction between irrigation regime and environmental conditions. The second season's higher temperatures and lower humidity (Table 1) likely increased evaporative demand, making water availability more critical for leaf initiation and expansion. Under these stress conditions, the 70% and 80% treatments may have induced earlier leaf maturation and better stomatal regulation, as suggested by Elsayed et al. (2023), while the control plants, accustomed to ample water, may have experienced greater transient water deficits during peak demand hours.

The effect of irrigation levels on physiological characteristics

Leaf area, total leaf area, and leaf area index

The most striking results of this study are the substantial improvements in leaf area (21.7%), total leaf area (29.9%), and leaf area index (32.6%) under the 80% treatment during the second season. These findings merit detailed physiological interpretation.

Leaf expansion is one of the most sensitive processes to water deficit, as it depends on cell turgor pressure and continued cell division (Kenzhebaeva and Sarajevo, 2000). The 80% treatment likely maintained sufficient turgor for cell expansion while avoiding the excessive vegetative growth that can occur under full irrigation, which sometimes produces larger but less efficient leaves with higher transpiration rates per unit of carbon fixed. This interpretation aligns with Petrík et al. (2023), who reported that moderate water stress can improve water-use efficiency by optimizing leaf morphology.

The dramatic improvement in total leaf area under the 80% treatment during the second season (29.9% increase) reflects both increased individual leaf area and, in some cases, more leaves per plant. This synergistic effect suggests that the 80% treatment created conditions favorable for both leaf initiation and expansion simultaneously—a balance that neither severe deficit (70%) nor excess water (100%) could achieve. The 70% treatment likely limited cell division due to water shortage, while the 100% treatment may have promoted excessive vegetative growth that became vulnerable to the second season's higher evaporative demand, leading to midday wilting and reduced effective leaf area.

The leaf area index (LAI) results (32.6% increase under 80% treatment) are particularly important because LAI determines the crop's light interception capacity and, consequently, its photosynthetic potential (Abd et al., 2014). The 80% treatment's superior LAI indicates better canopy structure, with leaves optimally arranged to intercept light while minimizing mutual shading. This optimal canopy architecture, combined with adequate but not excessive water supply, likely explains why the 80% treatment outperformed the control despite using 20% less water.

The contrasting results between seasons—no significant differences in the first season but dramatic improvements in the second—underscore the importance of multi-year trials in deficit irrigation research. The first season's milder conditions (lower temperatures, higher humidity, more rainfall) may have masked treatment effects because even the control plants experienced minimal stress. The second season's harsher conditions revealed the true potential of deficit irrigation: under water-limited environments, moderate stress can trigger adaptive responses that actually improve growth compared to plants grown with unlimited water, which may lack these adaptive mechanisms.

Comparison with previous studies

Our finding that 80% irrigation optimizes vegetative growth aligns partially with Al-Kaisi and Yin (2003), who reported similar yields between 80% and 100% irrigation in sandy loam soil, but contrasts with Zeno and Issam (2007), who found decreasing leaf area index with decreasing irrigation levels in Syrian conditions. This discrepancy may reflect differences in varieties (Casper vs. local lines), irrigation methods (sprinkler vs. surface), or soil types. Our results support the emerging view that moderate deficit irrigation (80-85% of full requirements) can maintain or even enhance certain growth parameters while saving water, particularly in Mediterranean environments where crops experience periodic stress (Zou et al., 2021; Elsayed et. al., 2023).

The superior performance of deficit treatments under stress conditions (second season) compared to non-stress conditions (first season) suggests that deficit irrigation may "prime" plants for stress tolerance-a concept supported by Altaf et. al. (2023), who reviewed drought stress mechanisms in maize. Plants under moderate deficit likely develop deeper root systems, better osmotic adjustment, and more efficient stomatal control, enabling them to maintain growth when conditions deteriorate, whereas plants grown with full irrigation may lack these adaptive traits.

5. Conclusion

This study demonstrates that deficit sprinkler irrigation significantly influences the vegetative growth characteristics of maize (*Zea mays L.* cv. Casper) under the coastal conditions of Syria. Among the irrigation treatments evaluated (70%, 80%, 90%, and 100% of crop water requirements), the 80% treatment consistently resulted in superior vegetative growth performance, particularly in terms of leaf area, total leaf area, and leaf area index, with increases of up to 21.7%, 29.9%, and 32.6%, respectively, compared to the full irrigation control. These improvements were most pronounced during the second growing season, which experienced drier and hotter conditions, highlighting the potential of moderate deficit irrigation to enhance growth under water-limited environments. Importantly, the 80% treatment achieved a 20% reduction in total irrigation water applied without compromising key physiological traits, indicating its promise as a water-saving strategy. However, as this study focused solely on vegetative parameters, further research is needed to validate whether these positive growth responses translate into comparable or improved grain yields.

6. Recommendations

Based on the findings, an irrigation level of 80% is recommended to optimize vegetative growth and improve water-use efficiency in maize production under similar agro-ecological conditions, particularly in water-limited environments. Future studies should incorporate grain yield measurements to better establish the relationship between vegetative traits and productivity under deficit irrigation regimes. Furthermore, additional research across multiple seasons and locations is necessary to validate the consistency of these results and to refine irrigation scheduling strategies for maize cultivation in coastal regions of Syria.

Conflict of interests

The authors declare that they have no conflicts of interest that could have influenced the conduct, analysis, or presentation of the research.

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