Pak. J. Bot., 57(3): 839-846, 2025. DOI: http://dx.doi.org/10.30848/PJB2025-3(1)

EFFECTS OF IRRIGATION LEVEL, PLANT DENSITY, AND NITROGEN DOSES ON SWEET CORN YIELD AND WATER PRODUCTIVITY

HAYRETTIN KUŞÇU[1], HALIS SEÇME[2*] AND İPEK KARAKUŞ[1]

[1]*Faculty of Agriculture, Department of Biosystems Engineering, Bursa Uludağ University, Turkey*
[2]*Faculty of Agriculture, Department of Biosystems Engineering, Siirt University, Turkey*
[*]*Corresponding author email: halis.secme@siirt.edu.tr*

Abstract

Plant density, nitrogen and irrigation management are three important agricultural inputs that affect plant yield and quality. This study was undertaken to ascertain the impact of varying plant densities, irrigation water levels and nitrogen rates on the yield, some yield components and irrigation water productivity (IWP) of sweet corn (*Zea mays* L.) cultivated in an open-field environment. To this end, two-year field experiments were carried out using the Challenger F1 corn variety on clay-textured soil in the Bursa province located in the Southern Marmara Region of Turkey. In the first year of the experiment, plant density in the main plots and irrigation levels in split plots were randomized. Accordingly, two plant density levels (57000 and 95000 plants ha^{-1}) and three irrigation levels (100%, 67%, and 33% of crop evapotranspiration (ETc)) were applied. In the second year of the experiment, three irrigation levels in main plots (100%, 80%, and 60% of ETc) and three N fertility ratios (150, 300, and 450 kg ha^{-1}) in split plots were assigned. A combination of 95000 plants ha^{-1} population and 100%ETc irrigation ratio provided maximum fresh ear yield. The irrigation treatment 80%ETc, accompanied by 300 kg N ha^{-1}, and 76000 plants ha^{-1} population was determined as the optimal management system for maximum yield, yield components, and IWP. To preserve soil and water resources, the optimal management system at maximum yield and IWP should be implemented for sweet corn production in the Marmara region.

Key words: Corn, Deficit irrigation, Ear yield, Nitrogen fertilizer.

Introduction

The global corn cultivation is nearly 1.21 million tons. The United States of America ranks first in global corn cultivation, with 383 thousand tons, followed by China, Brazil, Argentina, and Ukraine, respectively. Within the last 5 years, Turkey has increased its production from 5900 tons to 6750 tons (Anon., 2024). Sweet corn has a considerably high protein content (Jafarikouhini *et al*., 2020a), low starch content (Altinel *et al*., 2019; Peng *et al*., 2014), and a high concentration of water-soluble polysaccharides. Farmers favor sweet corn as it ripens and reaches harvest early, and it holds a significant market value (Feng *et al*., 2007). Furthermore, it offers more benefits than other corn varieties as it has thin-shelled, is tasty, can be consumed fresh, has soft seeds, and contains high sugar content.

The factors that impact the seed quality and structure of corn include cultivation style, corn variety, and agricultural practices. During vegetative growth, plants require high levels of nitrogen for their photosynthetic capacities, leaf growth, and root-stem structure development. Nitrogen server as the main nutritional source impacting plant growth, seed quality, and mineral content (Oktem *et al*., 2010). With fertilizer prices continuously increasing, farmers should be encouraged to adopt efficient fertilizer use. It's worth noting that plants utilize less than 50% of the applied N fertilizer. Therefore, soil analysis should be conducted to guide appropriate nitrogen fertilizer application, aiming to avoid overuse and ensure effectiveness (Oktem *et al*., 2010).

Although some researchers suggest that yield increases with the amount of nitrogen (N) applied (Rafiullah *et al*., 2020), others claim that N fertilizer does not significantly impact plant growth or yield. Many researchers point out that the amount of nitrogen (N) required may vary depending on different climates, sowing times, and soil and seed types. The N amounts reported for application in sweet corn cultivation has been 240 kg ha^{-1}, 160 kg ha^{-1}, 150 kg ha^{-1}, and 112 kg ha^{-1}.

In corn, plant density is a cultural practice that affects yield. In sweet corn, different plant densities have significantly different effects on yield and yield parameters. It has been reported that as plant density increases, so do the seed yield, plant height, and ear yield per hectare (Akman, 2002; Moretti, 2012; Zhanbota *et al*., 2022), while ear height (Chowchong & Ngamprasitthi, 2003), ear diameter and seeds per ear decrease. In Turkey, the number of plants that can be applied per unit area ranges from 2000 to 6000 plants ha^{-1}. For instance, in France, this figure can extend to 11000 plants ha^{-1}. Depending on the irrigation conditions, plant density can be increased. Some studies have suggested that with increasing planting density, seed yield also increases (Burcu & Akgün, 2018) while other studies have concluded otherwise (Atasever *et al*., 2020).

In regions characterized by restricted water availability, the focus should be on efficient water usage, while in regions with restricted agricultural land, maximizing yield per unit area is essential. (Yetik & Candogan, 2022). Depending on climatic factors, corn plant requires 600-700 mm of water to growth (Reddy & Ramu, 2016). Since corn is highly sensitive to water stress, proper irrigation planning is essential to avoid yield losses. The lack of water at any growth period in corn is a significant factor that can adversely affect yield. Insufficient irrigation leads to reductions in leaf area and plant height (Soler *et al*., 2007). It was observed that as the irrigation interval was prolonged, there were decreases in plant height (14.6%), leaf area index (12.9%), seeds per ear (29.8%), thousand-kernel weight (6.9%), kernel yield (33.8%), and harvest index (23.2%) (Kazemeini *et al*., 2014).

However, knowledge regarding the response of sweet corn grown in open field conditions to different plant densities, nitrogen fertilization, and drip irrigation levels is limited, especially in regions with limited irrigation water. Hence, in our study was undertaken to assess the impacts of varying density of plant, drip irrigation, and nitrogen (N) fertilization rates on the yield, specific morphological characteristics, and water productivity of sweet corn cultivated in a sub-humid ecological setting.

Material and Methods

Experiment site: Field trials were performed on the Research Farm belonging to the Agricultural Application and Research Centre (40º11' N, 29º04' W; 100 m above mean sea level), located at Bursa Uludağ University in western Turkey, during the growing seasons of 2017 and 2018.

Moderate climatic conditions prevail in the research area, featuring temperate winters and scorching summers. Based on long-term climate data averages provided by the Bursa Meteorological Station, which operates under the Turkish State Meteorological Service and has a 90-year observation period, the annual mean precipitation is 707.5 mm, and the mean temperature is 14.6°C. Considering the monthly mean temperatures, January is the coldest month, with a mean temperature of 5.3ºC, while July is the month with the lowest temperature, with a mean of 24.5ºC. The long-term data was obtained from the Bursa Meteorological Station, and meteorological data for the cultivation season was collected from an automatic climate station (WatchDog. Spectrum Technologies, Inc., Plainfield, IL, USA) located approximately 200 m from the experiment location (Table 1).

The characteristics of the upper 30 cm soil layer at the research site were as follows: clay-textured, deep and, with low calcium carbonate content (1.3%), low organic matter content (0.72%), total nitrogen (N) content 0.1%, phosphorus (P) content available, measured at 22 mg kg^{-1}, and potassium (K) content exchangeable, measured at 109 mg kg^{-1}. Site soil was categorized as Eutric Vertisol according to the FAO/Unesco (1990 classification system) (Özsoy & Aksoy, 2007). Table 2 presents several physical and chemical attributes of the soil at the experimental location.

The irrigation water for the experiment site was sourced from a hydrant located approximately 350 m away and used a drip irrigation system for the the experimental plots. The electrical conductivity of the irrigation water was measured at 0.31 dS m^{-1}, and the sodium adsorption ratio was calculated to be 0.23, indicating no adverse effects on the sweet corn plants (El Osta *et al*., 2022). The characteristics of the irrigation water quality are presented in Table 3.

Experimental design and agricultural applications: A split-plot experimental design with three replications was utilized for field trials spanning two years (Abd El-Fattah *et al*., 2023). In the first year, plant density in the main plots and irrigation levels in the split plots were randomized. To this end, two different plant densities (low: 57000 plants ha^{-1} and high: 95000 plants ha^{-1}) (Bhatt, 2012; Karaşahin & Sade, 2011) and three different irrigation levels (100%, 67%, and 33 % of crop evapotranspiration (ETc) were applied. In the second year, three irrigation levels (100%, 80%, and 60% of ETc) in the main plots and three N fertility ratios (150 (N150), 300 (N300), and 450 (N450) kg N ha^{-1}) in split plots were assigned (Jafarikouhini *et al*., 2020a).

Table 1. Temperature, rainfall, evaporation, wind speed, and relative humidity values for 2017, 2018, and long-term cultivation periods in Bursa, Turkey.

Month	Average temperature (°C)	Rainfall (mm)	Evaporation (mm)	Wind speed (m s^{-1})	Relative humidity (%)
1928 to 2018					
May	17.7	46.0	119.0	2.0	68.1
June	22.1	36.7	146.0	2.0	62.3
July	24.5	15.8	163.0	2.3	59.6
2017 year					
May	18.0	33.3	106.5	2.1	73.0
June	23.1	56.4	138.2	2.2	71.2
July	26.0	18.9	199.7	2.1	62.0
2018 year					
May	19.4	72.7	95.7	2.1	76.5
June	22.9	29.2	149.2	2.3	70.1
July	25.5	14.3	190.5	2.2	63.2

Table 2. Some physical and chemical characteristics of experimental location soil.

Soil depth (cm)	Texture	Field capacity (%)	Permanenet wilting point (%)	Bulk density (g cm^{-3})	pH	Organic matter (%)	Electrical conductivity (dS m^{-1})
0-30	Clay	38.17	27.07	1.35	6.1	0.72	0.45
30-60	Clay	40.01	27.03	1.36	6.4	0.43	0.45
60-90	Clay	43.01	26.75	1.34	7.1	0.57	0.79
90-120	Clay	40.05	23.18	1.38	8.0	0.17	0.64

Table 3. The qualitative attributes of the irrigation water utilized in the experiment.

Electrical conductivity (dS m^{-1})	Sodium adsorption ratio	pH	B (ppm)	Total cations (Na, K, Ca, Mg) (meq/l)	Total anions (CO_3^{2-}, HCO_3-, Cl, SO_4^{2}-) (meq/l)
0.31	0.23	7.12	0.85	3.32	3.31

In the study, the Challenger F1 (*Zea mays* L.) sweet corn variety, which is recommended as the primary cultivar for Bursa due to its high yield potential, was utilized. Corn seeds were manually sown with row spacing of 70 cm and depth of 5 cm on May 25th, 2017, and May 15th, 2018. The planting densities for low and high plant populations for the corn plants were 57000 and 95000 plants ha^{-1} for the initial year and 76000 plants ha^{-1} (the average of applied plant densities in the first year) for the second year. A split-plot design consisted of four rows, each 7.5 m in long, with a distance of 2 m between plot.

Before sowing, 80 P_2O_5 (DAP; 18%N and 46%P) fertilizer was implemented in the experiment area in the respective years (Jafarikouhini *et al*., 2020b; Kara *et al*., 2016). Nitrogenous fertilizer was applied in two periods; urea ($CO(NH_2)_2$, 46% N) during sowing and ammonium nitrate (NH_4NO_3, 33% N) when the plants reached 40-50 cm in height. In 2017, all plots were treated equally with amounting to 280 kg ha^{-1} nitrogen (Turgut, 2000). In 2018, the specified amounts of nitrogen were applied to experiment treatments.

Before seed sowing, soil samples were taken from three different points in the experiment site to ascertain the soil moisture level, and current soil moisture was measured via the gravimetric method. Following sowing, irrigation was applied to all plots until reaching the field capacity for the soil layer between 0-90 cm depth (Ertek & Kara, 2013). Throughout all development phases of corn, manual weeding every other day was adopted as the weed control method. No disease or pests were seen during the entire plant growing period.

Irrigation water applied and productivity: A drip irrigation system installed for the experimental design was used in irrigation applications. Lateral pipes (Ø16 × 20 cm × 2 L h^{-1}) was installed right next to each row of plants. The laterals were attached to the manifold pipes using a miniature valve. In the connections to the manifolds from the main pipe, a ball valve and a water meter to ensure water control by volume were used.

The applied irrigation water was determined as a percentage of *ETc* according to the rates specified in experimental treatments (Fig. 1) (Allen *et al*., 1998).

$$IWA = (A \times ETc) / (Ea \times 1000) \qquad (1)$$

where, *IWA* refers to applied irrigation water (m^3), A refers to the irrigated plot area (m^2), *ETc* refers to the calculated crop evapotranspiration (mm), and *Ea* refers to water application effectiveness (%). Since a drip irrigation system was used, the *Ea* value was taken as 0.90. *ETc* was ascertain per the following equation (Allen *et al*., 1998):

$$ETc = ETo \times kc \qquad (2)$$

In the equation, *ETo* pertains to the reference evapotranspiration (mm) and *kc* pertains to the plant coefficient. As *ETc* coefficients were addressed as the experimental treatments in this study, *kc* was taken as 1 (*kc*=1). *ETo* was calculated daily per the formula below (Allen *et al*., 1998):

$$ETo = Epan \times kp \qquad (3)$$

In the equation, *Epan* refers to the Class A pan evaporation rate (mm) and *kp* refers to the pan coefficient.

Harvest, crop yield, and morphological measurements: Corn ears were manually harvested while the kernels were in the dough stage on August 4th, 2017, and July 27th, 2018. The plant height, seeds per ear, stem diameter, single ear weight, ear height, first ear height, and ear diameter values were measured on 10 randomly picked plants from the middle two rows of each split plot. All ears harvested from the central two rows of the lower plots were weighed, and the fresh ear yield was determined by proportioning this value to the unit area. In harvest, the humidity rate of the seeds on the ears was around 70% (El-Hendawy *et al*., 2008; Kara *et al*., 2016).

Irrigation water productivity: The irrigation water productivity (IWP, kg m^{-3}) was determined by dividing the fresh ear yield (kg ha^{-1}) by the total seasonal amount of irrigation water (m^3 ha^{-1}) (El-Hendawy *et al*., 2008).

Data analysis: Variance analysis (ANOVA) was conducted on the yield and morphological measurements. The statistical analyses employed IBM SPSS Statistics 23. The significance of the main effects was determined through the F test. In the comparison of the differences between treatment averages Duncan's multiple range test was used at a probability rate of 5% (Ertek & Kara, 2013).

Results and Discussion

Irrigation quantity: The irrigation water applied for each experimental treatment is presented in Fig. 1. Corn plants were applied 148-444 mm of seasonal irrigation water in 2017, and 258-400 mm in 2018. Similarly, Kara *et al*. (2016) applied 151-350 mm of seasonal irrigation amount for different irrigation regimes (40, 55, 70, 85, and 100% of ETc). The quantity and temporal pattern of rainfall throughout the growing season influenced the allocation of irrigation water. In 2017, no irrigation was applied for germination since the seed sowing season was rainy. In 2018, all experimental plots were applied 45 mm of irrigation water to increase the existing soil moisture rate in the soil profile of 0-90 cm level of field capacity since the sowing season was dry. Irrigation was applied in weekly intervals for specific experimental treatments. The amount of rainfall from sowing to harvest was measured as 109 mm in 2017 and 118 mm in 2018. Since the rainfall was sufficient (43.2 mm) and the evaporation rate was low between May 23-29 2018, no irrigation was performed. Therefore, a difference of 44 mm occurred between the experiment years for the treatment that was irrigated at a level of 100% of ETc.

Plant height: In the initial year, the influence of plant density and irrigation levels on plant height was determined to be statistically significant at a levels of $p<0.05$ and $p<0.01$, in that order (Table 4). The height of plant grown with high plant density were higher than those grown with low plant density. In a similar study, three different plant density experiments were conducted at 66666, 80000, and 100000 plants ha^{-1}, and the tallest plant height was determined to be 219.3 cm at a plant density of

100000 plants ha^{-1}. According to this result, as plant density increases, plant height also increases (Bhatt, 2012). Plant height values increased as the amount of seasonally irrigation water applied did. In both years of experimentation, the tallest plant height was observed in the 100% ETc treatment in our investigation. Oktem (2008) reported the highest plant height as 177.3 cm from 100% Epan irrigation in four different irrigation treatments (70% Epan, 80% Epan, 90% Epan, and 100% Epan). Plant density × irrigation treatment and irrigation × nitrogen treatment interaction did not have a statistical significance for plant height. In spite of that, the effect of N rate on plant height values was determined to be significant at a level of p<0.01, with greater plant heights in those applied 300 and 450 kg N ha^{-1} than in those applied 150 kg N ha^{-1} (Table 4). Shirazi *et al.*, (2011) documented that irrigation (IW/CPE ratio of 0.0 (I_0), 0.2 (I_1), 0.5 (I_2), 0.8 (I_3), and 1.0 (I_4)) and nitrogen (0.0 N_0, 70 N_1, 100 N_2, and 120 N_3 N kg ha^{-1}) interaction was significant, and plant height was 290.4 cm in the I_3N_1 interaction. Piazzoli *et al.*, (2021) found that nitrogen doses affected plant height at five different nitrogen doses (0, 60, 120, 180, and 240 N kg ha^{-1}). In the interaction of plant densities (105000, 90000, 75000, and 60000 plants ha^{-1}) and nitrogen, the maximum plant height was observed from 169 kg ha^{-1} of N and 60000 plants ha^{-1} plant density. Khan *et al.*, (2017) also reported that the maximum plant height of 173.5 cm from the highest nitrogen dose (0, 120, 160, and 200 N kg ha^{-1}).

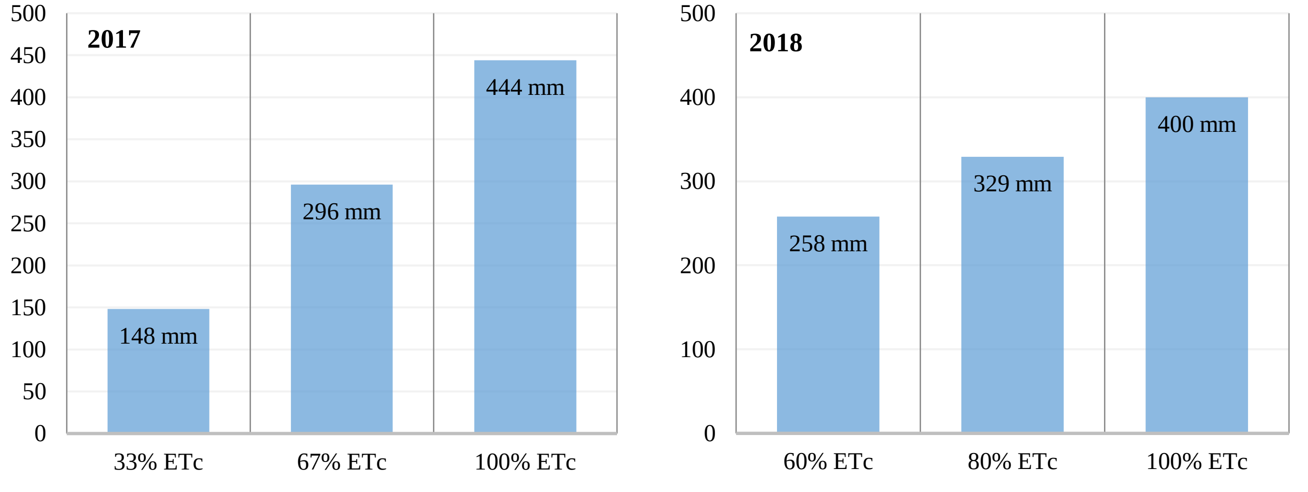

Fig. 1. Amounts of irrigation water applied in experimental years of 2017 and 2018.

Table 4. Yield components of sweet corn grown on a clay-loam soil at different plant densities, irrigation levels, and nitrogen doses.

Year	Treatment	Plant height (cm)	Ear height (cm)	Stem diameter (mm)	Ear diameter (mm)	Ear length (cm)	Seeds per ear
2017	**Plant densities (PD, plant ha^{-1})**						
	95000	185.14 a	57.4	19.8 b	42.9	20.2 b	610
	57000	181.87 b	56.3	21.0 a	43.7	20.9 a	612
	Irrigation ratio (IR)						
	100% ETc	204.7 a	68.3 a	23.9 a	47.6 a	22.1 a	681 a
	67% ETc	194.8 b	58.4 b	21.6 b	41.6 ab	21.2 b	642 ab
	33% ETc	187.7 c	54.6 c	18.8 c	44.4 ab	20.6 b	595 bc
	No irrigation (Rainfed)	147.1 d	46.3 d	17.3 d	39. 9 b	18.4 c	526 c
	Significance						
	PD	*	ns	**	ns	*	ns
	IR	**	**	**	*	**	*
	PD×IR	ns	**	*	ns	ns	ns
2018	**Irrigation ratio (IR)**						
	100% ETc	193.7 a	55.6 a	25.9 a	47.1 a	21.7 a	676 a
	80% ETc	188.6 b	52.9 b	24.8 a	47.2 a	21.8 a	671 a
	60% ETc	179.2 c	50.4 c	23.0 b	44.9 b	20.6 b	628 b
	Nitrogen ratio (NR, kg ha^{-1})						
	150	176.5 b	48.2 c	22.8 b	45.1 b	20.9 b	621 b
	300	194.3 a	54.1 b	25.3 a	47.3 a	21.4 ab	679 a
	450	190.8 a	56.7 a	25.6 a	46.7 a	21.8 a	675 a
	Significance						
	IR	**	**	**	**	**	**
	NR	**	**	**	*	*	**
	IR×NR	ns	**	ns	ns	ns	ns

*and **: Significant at the levels p<0.05 and p<0.01, in that order
ns: Non-significant

Table 5. Effects of the plant densities × irrigation level on ear height (cm) of sweet corn.

Treatments	Irrigation ratio			
Plant densities (plant ha^{-1})	100% ETc	67% ETc	33% ETc	No irrigation (Rain fed)
95000	70.40 a	61.13 c	54.87 d	43.33 f
57000	66.2 b	55.67 d	54.27 d	49.20 e

Ear height: The effect of irrigation levels on the first ear height was determined to be significant at the possibility $p<0.01$ level in both years (Table 4). In parallel with plant height, the first ear height was greater in the plants irrigated at the level of 100% ETc. The lowest ear height values were obtained under no irrigation (rainfed) conditions. Çelebi & Türk (2021) reported that first ear height increased parallel to the irrigation treatment from six different irrigation treatments ($I_{1.50}$, $I_{1.25}$, $I_{1.00}$, $I_{0.75}$, $I_{0.50}$, and $I_{0.25}$), but the first ear height decreased at the highest irrigation treatment, and the maximum first ear height was found to be 122.6 cm from $I_{1.25}$ irrigation treatment. The first ear height increased as the nitrogen rates increased, with the highest being achieved from the application of 450 kg N ha^{-1}, and the lowest was observed with the application of 150 kg N ha^{-1}. (Table 4). On the other hand, Piazzoli *et al*., (2021) reported that an excessive nitrogen dose had a negative effect on the height of the first ear. The researchers also reported the maximum first ear height was recorded as 123.15 cm for a density of plant of 88.660 plants ha^{-1}. The effect of plant density × irrigation treatment and irrigation treatment × N treatment interactions on ear height was significant at a level of $p<0.01$. The highest first ear height was obtained from the interaction of 95000 plants ha^{-1} × 100% ETc, followed by the treatments of 57000 plants ha^{-1} × 100% ETc and 95000 plants ha^{-1} × 67% ETc, in that order (Table 5). On the other hand, in 2018, the greatest ear height values were obtained from the irrigation applications implemented under the 450 kg N ha^{-1} application and at the level of 80% and 100% ETc while the lowest were obtained from those below 150 kg N ha^{-1} and 60% ETc and 80% ETc applications (Table 6). Turgut (2000) reported the maximum first ear height (60.9 cm) at the highest plant density.

Table 6. Effects of the irrigation ratio × nitrogen ratio on ear height (cm) of sweet corn.

Treatments	Nitrogen ratio		
Irrigation ratio	150 kg N ha^{-1}	300 kg N ha^{-1}	450 kg N ha^{-1}
60% ETc	44.7 d	52.9 c	53.7 c
80% ETc	46.0 d	54.4 c	58.4 a
100% ETc	53.8 c	55.0 bc	57.9 ab

According to Duncan's Multiple Range Test, lowercase letters indicate differences in the first ear height due to the interaction between irrigation and Nitrogen exhibited statistical significance at the $p<0.05$ significance level

Stem diameter: The effect of plant density on stem diameter was significant at the $p<0.01$ significance level. The stem diameter values were higher in corn grown in low plant density (57000 plant ha^{-1}). Mathukia *et al*., (2014) reported that the stem diameter (2.01, 2.05, and 2.10 cm) insignificant ($p<0.05$) at different plant densities (60×15, 45×20, and 30×30 cm). The effect of irrigation ratios on stem diameter was significant at a level of $p<0.01$ in both experiment years (Table 4). In 2017, the highest stem diameter value was obtained from the 100% ETc irrigation treatment while the lowest was obtained from the rainfed treatment. In 2018, higher values were measured in the 100% and 80% ETc irrigation treatment (statistically in the same group) than in the 60% ETc irrigation treatment. de-Souza *et al*., (2015) determined that irrigation applications during the summer/autumn season had a quadratic effect on stem diameter. They found the maximum stem diameter to be 19.89 mm with 83.0% of ETc irrigation applications. In another study on corn by Ertek & Kara (2013), it was reported the increase in irrigation amount also increased the stem diameter. Finding the effect of nitrogen doses on stem diameter to be significant at the $p<0.01$ significance level, this study demonstrated higher stem diameter values from the applications of 300 and 400 kg N ha^{-1} compared to the application of 150 kg N ha^{-1}. According to de-Souza *et al*., (2015) nitrogen had no significant effects on stem diameter. Otherwise, Alimohammadi *et al*., (2011) determined that stem diameter was not significantly affected by different nitrogen treatments, phosphorus levels and their interactions, but the interaction between 200 kg urea ha^{-1} and no phosphorus fertilizer application also produced the maximum stem diameter (1.72 cm). In 2017, the interaction effect of plant density × irrigation on stem diameter was determined to be significant ($p<0.05$). The highest stem diameter was determined in the treatment with a plant density of 57000 plants ha^{-1} × 100% ETc application, while the lowest was observed in the treatments with plant densities below those of the rainfed experimental treatment (Table 7).

Ear diameter: The impact of various irrigation applications on ear diameter was deemed significant at the $p<0.05$ and $p<0.01$ significance level, correspondingly, throughout the experimental years. In 2017, the ear diameter values obtained from the full-irrigated (100% ETc) and deficit-irrigated (67% and 33% of ETc) experimental treatments were higher than the no-irrigation treatment. In 2018, the ear diameter obtained from the plants irrigated at the100% and 80% ETc levels was higher than that obtained from the 60% ETc treatments. Ertek & Kara (2013) reported that maximum ear diameter (46.4 mm) with full irrigation treatment. The effect of N doses on ear diameter was significant at the $p<0.05$ significance level. The ear diameter attained from the treatments of 300 and 450 kg N ha-1 exceeded that of the 150 kg N ha-1 treatment (Table 4). Bhatt (2012) reported that the maximum ear diameter at the lowest plant density (66666 plants ha^{-1}), and the highest nitrogen application (240 N kg ha^{-1}). Shirazi *et al*., (2011) reported that ear diameter to be 4.88 cm and 4.78 cm for 0.2 (I_1) and 0.5 (I_2) irrigation treatments. They found the ear diameter to be 4.69 cm in 120 kg N ha^{-1} application.

Ear length: The influence of plant density and irrigation ratio in 2017, along with irrigation ratio and nitrogen ratio in 2018, on ear length, exhibited statistical significance ($p<0.05$). Longer ears were obtained in low plant density in 100% ETc irrigation treatments in 2017, and in 100% ETc and 80% ETc irrigation treatments in 2018, and relatively in the 300 and 450 kg ha^{-1} nitrogen applications (Table 4). Dehghanisanij & Kouhi (2020) found the maximum ear length from I_2 (80% ETc) and I_3 (100% ETc) irrigation treatment, maximum ear length was obtained with N_3 (100 N kg ha^{-1}) and N_4 (150 N kg ha^{-1}) nitrogen treatment and moreover, the maximum ear length was found with I_1N_4 in the irrigation x nitrogen interaction. In Oktem (2008) study, the maximum ear length (19.50cm) was obtained from I_{100} treatment. In another irrigation study, the ear length was 18.8 cm for the I_{100} treatment (Ertek & Kara, 2013). On the other hand, Bhatt (2012) reported that maximum ear length obtained from 66.600 plants ha^{-1} of plant density, and 240 N kg ha^{-1} nitrogen application.

Seeds per year: The impact of irrigation and nitrogen applications on seeds per ear showed statistical significance. In both experiment years, higher seeds per ear values were obtained under full-irrigated (100% ETc) and relatively milder deficit irrigation (80% and 67% ETc) conditions (Table 4). Similarly, the number of seeds per ear from the full irrigation treatment was found to be 581.3 (Ertek & Kara, 2013). The results obtained in another irrigation and plant density study showed that high water application and low plant density affected seeds per ear (El-Hendawy *et al*., 2008).

Fresh ear yield: In the initial year of the study, the impact of plant density or irrigation ratio on fresh ear yield was significant at a level of $p<0.01$. The fresh ear yield value obtained at the 95000 plant ha-1 plant density was higher than that obtained from the 57000 plant ha^{-1} plant density. The highest fresh ear yield was obtained as 22.59 tons ha^{-1} from the irrigation treatments 100% ETc while the lowest was obtained in the rainfed treatment (Table 8). Esmaily *et al*., (2023) stated that water limitation affects yield parameters. In the irrigation study undertaken by Niknam *et al*. (2023) it was reported that irrigation had a positive effect on ear yield. Prior research has indicated that as the quantity of irrigation rises, there is a corresponding increase in fresh ear yield (Kashiani *et al*., 2011).

In the second year of the trial, the impact of various irrigation and nitrogen ratios on fresh ear yield was statistically significant $p<0.01$ significance level, whereas the significance level for the interaction between irrigation and nitrogen was $p<0.05$. The highest yield was obtained from the 100% ETc irrigation treatment, with yield decreasing as the irrigation levels did. With the direction of nitrogen levels, the effect of the 300 and 450 kg N ha^{-1} applications on yield was statistically in the same group and the yield with these N doses was higher than it was in the 150 kg N ha^{-1} application. With the direction of irrigation × nitrogen interactions, the highest fresh ear yield values were obtained under the conditions of 100% ETc × 300 kg N ha^{-1}, 100% ETc × 450 kg N ha^{-1}, and 80% ETc × 300 kg N ha^{-1} while the lowest was obtained from the 60% ETc × 150 kg N ha^{-1} interaction (Table 9). Similarly, (Saed-Moucheshi *et al*., 2022) found that irrigation and N responded significantly to fresh ear yield, and decreasing the amount of N led to a lower yield.

Table 7. Effects of the plant densities × irrigation level on stem diameter (mm) of sweet corn.

Treatments	Irrigation ratio			
Plant densities (plant ha^{-1})	100% ETc	67% ETc	33% ETc	No irrigation (Rain fed)
57000	25.20 a	22.33 b	18.85 d	17.58 e
95000	22.60 b	20.92 c	18.75 d	17.03 e

According to Duncan's Multiple Range Test, lowercase letters indicate differences in the first ear height due to the interaction between irrigation and nitrogen at the statistical significance $p<0.05$ significance level

Table 8. Fresh ear yield values under different plant densities and irrigation ratio conditions (tons ha^{-1}).

Treatments	Irrigation ratio (IR)				Average
Plant densities (PD, plant ha^{-1})	100% ETc	67% ETc	33% ETc	No irrigation (Rain fed)	
57000	24.23	22.02	16.03	8.33	15.32 B
95000	20.95	19.20	15.47	5.69	17.65 A
Average	22.59 A	20.61 B	15.75 C	7.01 D	

PD** IR** PD x IR^{ns}

As per Duncan's Multiple Range Test, uppercase letters denote disparities in yield at a significance $p<0.05$ significance level concerning irrigation and nitrogen dose

Table 9. Fresh ear yield values under different irrigation ratio and nitrogen ratio conditions (tons ha^{-1}).

Treatments	Nitrogen ratio (NR)			Average
Irrigation ratio (IR)	150 kg N ha^{-1}	300 kg N ha^{-1}	450 kg N ha^{-1}	
60% ETc	17.18 e	21.10 c	21.14 c	19.80 C
80% ETc	18.77 d	25.66 a	23.60 b	22.68 B
100% ETc	21.41 c	25.71 a	25.72 a	24.28 A
Ortalama	19.12 B	24.16 A	23.49 A	

IR** NR** IR x NR*

According to Duncan's Multiple Range Test, at a significance $p<0.05$ significance level, lowercase letters indicate yield disparities in the context of irrigation × nitrogen interaction, while uppercase letters denote yield disparities concerning irrigation or nitrogen dose

Table 10. Irrigation water productivity values under different plant densities, irrigation rate and nitrogen rate conditions (kg m^{-3}).

2017 year			2018 year		
Plant densities (plant ha^{-1})	**Irrigation ratio**	**IWP (kg m^{-3})**	**Irrigation ratio**	**Nitrogen ratio (kg ha^{-1})**	**IWP (kg m^{-3})**
57000	100% ETc	5.45	60% ETc	150	6.66
	67% ETc	7.43		300	8.18
	33% ETc	10.83		450	8.19
95000	100% ETc	4.72	80% ETc	150	5.71
	67% ETc	6.49		300	7.80
	33% ETc	10.45		450	7.17
			100% ETc	150	5.35
				300	6.43
				450	6.43

IWP: Irrigation water productivity

Irrigation water productivity: In the inaugural year of the study, the highest IWP in both plant densities was obtained from the 33% ETc treatment, while IWP values decreased when the applied irrigation water increased. The IWP values obtained under the 57000 plant ha^{-1} plant density treatment were relatively higher. In the second year, IWP values varied between 5.35 and 8.19 kg m^{-3}. Current findings are consistent with the outcomes reported by El-Hendawy *et al*., (2008), as plant density increases, water productivity decreases. In parallel with the results obtained in the first year, the limitation of the irrigation water led to an increase in IWP values. Generally, no difference was observed between IWP values in the 300 and 450 kg ha^{-1} nitrogen applications, the IWP value was lower in the 150 kg ha^{-1} application (Table 10). The study conducted by de-Souza *et al*., (2015) ascertain that increasing the nitrogen dose had a positive effect on water productivity. In a separate investigation, both plant density and nitrogen quantity, as well as the interaction between nitrogen and plant density, were observed to exert a substantial influence on water productivity (Lai *et al*., 2022).

Conclusion

The findings of this study elucidate the profound impact of varying irrigation water quantities, plant densities, and nitrogen fertilizer levels on the irrigation water productivity, yield, and certain yield components of sweet corn crops grown in a sub-humid climate. Higher fresh ear yields were obtained at high plant density (95000 plants ha^{-1}) compared to low plant density (57000 plants ha^{-1}). On the other hand, average plant density (76000 plants ha^{-1}) was competitive with high plant density. The 67%ETc and 80%ETc treatments were competitive with 100%ETc, but the 33%ETc and 60%ETc was not competitive with the 100%ETc and 67%ETc irrigation treatments in terms of fresh ear yields. At nitrogen fertility of 300 kg N ha^{-1}, more optimal results were obtained compared to 150 kg N ha^{-1} and 450 kg N ha^{-1} doses. High levels of nitrogen application had no effect on increasing yield. In order to provide a sustainable agricultural production system, 300 kg N ha^{-1} dose can be applied in sweet corn cultivation considering the soil test results. It is suitable to suggest that the combination of 0.80 ETc, 300 kg N ha^{-1}, and 76000 plants ha^{-1} constitutes the optimal management strategy for achieving maximum sweet corn yield within this particular environmental setting.

Acknowledgments

The authors express their gratitude to the Deanship of the Faculty of Agriculture at Bursa Uludağ University for granting access to the land and laboratory resources.

References

Abd El-Fattah, D.A., M. Maze, B.A.A. Ali and N.M. Awed. 2023. Role of mycorrhizae in enhancing the economic revenue of water and phosphorus use efficiency in sweet corn (*Zea mays* L. var. *saccharata*) plants. *J. Saudi Soc. Agri. Sci.*, 22(3): 174-186. https://doi.org/10.1016/j.jssas.2022.10.001

Akman, Z. 2002. Effect of tiller removing and plant density on ear yield of sweet corn (*Zea mays saccharata* Sturt). *Pak. J. Biol. Sci.*, 5(9): 906-908.

Alimohammadi, M., M. Yousefi and P. Zandi. 2011. Impact of nitrogen rates on growth and yield attributes of sweet corn grown under different phosphorus levels. *J. Amer. Sci.*, 7(10): 201-206. https://doi.org/10.7537/marsjas071011.25

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO Irrig. Drain. Paper*, 300(9): 60-64 D05109.

Altinel, B., F.A. Tonk, D. Istipliler, M. Tosun and F. Pazir. 2019. Improving sweet corn x dent corn hybrids based on kernel color, size and quality properties. *Fresenius Environ. Bull.*, 28(4): 2368-2374.

Anonymous. 2024. Corn production. [Access Date: 15.02.2024]. https://www.fao.org/faostat/en/#data/QCL

Atasever, M., Ş. Yılmaz and İ. Ertekin. 2020. The effect of sowing time on grass yield and quality in some corn (*Zea mays* L.) varieties grown in Amik plain conditions. *Mustafa Kemal Uni. J. Agri. Sci.*, 25(3): 326-340 https://doi.org/10.37908/mkutbd.694216.

Bhatt, P.S. 2012. Response of sweet corn hybrid to varying plant densities and nitrogen levels. *Afr. J. Agri. Res.*, 7(46): 6158-6166. https://doi.org/10.5897/ajar12.557

Burcu, Y. and İ. Akgün. 2018. The effect of different planting time and plant density on fresh cob yield and quality characteristics in sugar corn (*Zea mays saccharata* Sturt.) in Isparta conditions. *Süleyman Demirel University J. Nat. Appl. Sci.*, 22(2): 679-684 https://doi.org/10.19113/sdufbed.70486.

Çelebi, F.G. and M. Türk. 2021. Effects of restricted water applications on yield and quality in silage corn (*Zea mays* L.) irrigated by subsurface drip irrigation method. *SDU J. Faculty of Agri.*, 16(2): 207-213.

Chowchong, S. and S. Ngamprasitthi. 2003. Suitable plant spacing for Insee 2 sweet corn hybrid. Proceedings of 41st Kasetsart University Annual Conference Bangkok.

Dehghanisanij, H. and N. Kouhi. 2020. Interactive effects of nitrogen and drip irrigation rates on root development of corn (*Zea mays* L.) and residual soil moisture. *Gesunde Pflanzen*, 72(4): 335-349.

de-Souza, E.J., F.F. da-Cunha, F.F. Magalhães, T.R. da-Silva and O.F. dos-Santos. 2015. Effect of irrigation and nitrogen fertilization on agronomic traits of sweet corn1. *Pesquisa Agropecuária Trop.*, 45(3): 282-290. https://doi.org/10.1590/1983-40632015v4533628

El Osta, M., M. Masoud, A. Alqarawy, S. Elsayed and M. Gad. 2022. Groundwater suitability for drinking and irrigation using water quality indices and multivariate modeling in makkah Al-Mukarramah province, Saudi Arabia. *Water*, 14(3): 483-495. https://doi.org/10.3390/w14030483

El-Hendawy, SE., E.A. Abd El-Lattief, M.S. Ahmed and U. Schmidhalter. 2008. Irrigation rate and plant density effects on yield and water use efficiency of drip-irrigated corn. *Agri. Water Manag.*, 95(7): 836-844. https://doi.org/10.1016/j.agwat.2008.02.008

Ertek, A. and B. Kara. 2013. Yield and quality of sweet corn under deficit irrigation. *Agri. Water Manag.*, 129: 138-144. https://doi.org/10.1016/j.agwat.2013.07.012

Esmaily, M., M.R. Dadashi, M.T. Feyzbakhsh, K. Kabousi and F. Sheikh. 2023. Influence of deficit irrigation regimes on the quantitative and qualitative yield of forage maize hybrids. *J. Crop Health*. https://doi.org/10.1007/s10343-024-00973-1

Feng, Z., D. Liu and Y. Zhang. 2007. Water requirements and irrigation scheduling of spring maize using GIS and CropWat model in Beijing-Tianjin-Hebei region. *Chinese Geograph. Sci.*, 17(1): 56-63. https://doi.org/10.1007/s11769-007-0056-3

Jafarikouhini, N., S.A. Kazemeini and T.R. Sinclair. 2020a. Sweet corn nitrogen accumulation, leaf photosynthesis rate, and radiation use efficiency under variable nitrogen fertility and irrigation. *Field Crops Res.*, 257, 107913. https://doi.org/10.1016/j.fcr.2020.107913

Jafarikouhini, N., S.A. Kazemeini and T.R. Sinclair. 2020b. Sweet corn ontogeny in response to irrigation and nitrogen fertilization. *J. Hort. Plant Res.*, 10: 23-29.

Kara, B., A. Ertek and B. Atar. 2016. Mineral nutrient content of sweet corn under deficit irrigation. *Tarım Bilimleri Dergisi*, 22(1): 54-61. https://doi.org/10.1501/Tarimbil_0000001367

Karaşahin, M. and B. Sade. 2011. Effects of different irrigation methods on grain yield and yield elements in hybrid corn (*Zea mays* L. *indentata* S.). *J. Uludag Uni. Faculty Agri.*, 25(2): 47-56.

Kashiani, P., G. Saleh, M. Osman and D. Habibi. 2011. Sweet corn yield response to alternate furrow irrigation methods under different planting densities in a semi-arid climatic condition. *Afr. J. Agri. Res.*, 6(4): 1032-1040. https://doi.org/10.5897/AJAR10.963

Kazemeini, S.A., M.J. Bahrani, H. Pirasteh-Anosheh and S.M.M. Momeni. 2014. Maize growth and yield as affected by wheat residues and irrigation management in a no-tillage system. *Arch. Agron. Soil Sci.*, 60(11): 1543-1552. https://doi.org/10.1080/03650340.2014.896457

Khan, Z.H., S.K. Khalil, F. Shah, A. Iqbal, F. Ali, I.I. Badshah and M. Ali. 2017. Plant density and nitrogen doses can affect growth of sweet corn. *Fresenius Environ. Bull.*, 26(6): 3872-3879.

Lai, Z., J. Fan, R. Yang, X. Xu, L. Liu, S. Li, F. Zhang and Z. Li. 2022. Interactive effects of plant density and nitrogen rate on grain yield, economic benefit, water productivity and nitrogen use efficiency of drip-fertigated maize in northwest China. *Agri. Water Manag.*, 263: 107453. https://doi.org/10.1016/j.agwat.2021.107453

Mathukia, R.K., R.P. Choudhary, A. Shivran and N. Bhosale. 2014. Response of rabi sweet corn to plant geometry and fertilizer. *J. Crop Weed*, 10(1): 189-192.

Moretti, N.N.M. 2012. Response of yield and quality to plant density and nitrogen fertilizer levels in sweet corn California State University, Fresno. Ann Arbor.

Niknam, N., H. Farajee, D.M. Movahhedi and A. Yadavi. 2023. Improvement of physiological indices and sweet corn performance by sowing methods and wheat residue mulching under two irrigation regimes. *Gesunde Pflanzen*, 75(6): 2853-2863. https://doi.org/10.1007/s10343-023-00922-4

Oktem, A. 2008. Effects of deficit irrigation on some yield characteristics of sweet corn. *Bang. J. Bot.*, 37(2): 127-131. https://doi.org/10.3329/bjb.v37i2.1718

Oktem, A., A.G. Oktem and H.Y. Emeklier. 2010. Effect of nitrogen on yield and some quality parameters of sweet corn. *Comm. Soil Sci. Plant Anal.*, 41(7): 832-847. https://doi.org/10.1080/00103621003592358

Özsoy, G. and E. Aksoy. 2007. Characterization, classification and agricultural usage of vertisols developed on neogen aged calcareous marl parent materials. *J. Biol. Environ. Sci.*, 1(1): 5-10.

Peng, Y., C. Li and F.B. Fritschi. 2014. Diurnal dynamics of maize leaf photosynthesis and carbohydrate concentrations in response to differential N availability. *Environ. Exp. Bot.*, 99: 18-27. https://doi.org/10.1016/j.envexpbot.2013.10.013

Piazzoli, D., S.M.J.L. Costa, A.M. Prando, J.J.A. Oliveira and C. Zucareli. 2021. Densidade de plantas e doses de nitrogênio em cobertura no milho safra em elevada altitude. *Semina: Ciências Agrárias*, 42(5): 2651-2668. https://doi.org/10.5433/1679-0359.2021v42n5p2651

Rafiullah, K.M.J., D. Muhammad, S. Fahad, M. Adnan, F. Wahid, S. Alamri, F. Khan, K.M. Dawar and I. Irshad. 2020. Phosphorus nutrient management through synchronization of application methods and rates in wheat and maize crops. *Plants*, 9(10): 1389. https://doi.org/10.3390/plants9101389

Reddy, S.R. and Y.R. Ramu. 2016. Agronomy of field crops. New Delhi: Kalyani Publishers.

Saed-Moucheshi, A., M. Pessarakli, A. Mozafari, A. Rezaizad, P. Froozesh, A. Tabarzad and H. Alipour. 2022. Modeling and determining the best combination of nitrogen and irrigation levels for achieving high yield in sweet corn. *J. Plant Nutr.*, 45(18): 2748-2757. https://doi.org/10.1080/01904167.2022.2067063

Shirazi, S., M. Sholichin, M. Jameel, S. Akib and M. Azizi. 2011. Effects of different irrigation regimes and nitrogenous fertilizer on yield and growth parameters of maize. *Int. J. Phys. Sci.*, 6(4): 677-683. https://doi.org/10.5897/IJPS11.145

Soler, C.M.T., G. Hoogenboom, P.C. Sentelhas and A.P. Duarte. 2007. Impact of water stress on maize grown off-season in a subtropical environment. *J. Agron. Crop Sci.*, 193(4): 247-261. https://doi.org/10.1111/j.1439-037X.2007.00265.x

Turgut, İ. 2000. Effects of plant populations and nitrogen doses on fresh ear yield and yield components of sweet corn (*Zea mays saccharata* Sturt.) grown under Bursa conditions. *Turk. J. Agri. Forest.*, 24(3): 341-348.

Yetik, A.K. and B.N. Candogan. 2022. Optimisation of irrigation strategy in sugar beet farming based on yield, quality and water productivity. *Plant Soil Environ.*, 68(8): 358-365. https://doi.org/10.17221/234/2022-PSE

Zhanbota, A., R.S. Noor, A.I. Khan, G. Wang, M.M. Waqas, A.N. Shah and S. Ullah. 2022. A two-year study on yield and yield components of maize-white bean intercropping systems under different sowing techniques. *Agronomy*, 12(2): 240. https://doi.org/10.3390/agronomy12020240

(Received for publication 28 May 2024)