ROLE OF NANO AND METALLIC BORON FOLIAR NUTRITION ON WATER STRESS REDUCING IN SWEET CORN YIELD AND ITS COMPONENTS

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ABSTRACT

A field experiment was conducted in the experimental field of the Crop Sciences Department at the College of Agricultural Engineering Sciences - University of Baghdad during fall seasons of 2021 and 2022. The aim of this study was to investigate the role of nano and metallic boron foliar nutrition on yield, components, water use efficiency, and water consumption under water stress for sweet corn (*Zea mays* L.). Randomized Complete Block Design was used within split -plot arrangement with three replicates, where the main plots included three levels of water stress (irrigation at 40, 60, and 80% of available water) coded as W_1, W_2, and W_3, respectively. The nano and metallic boron spray concentrations represented 5, 10, 20, and 40 mg L^{-1} coded as N_1, N_2, M_1, and M_2, respectively. Results showed that nano and metallic boron concentrations significantly affected all the studied traits. The concentration of 5 mg L^{-1} of nano boron N1 significantly exceeded other concentrations under study in increasing ear length, number of rows per ear, number of grains per row, and weight of 500 grains, which positively reflected on improving grain yield of 5.93 and 5.96 t ha^{-1}. The interaction between water stress treatments and nano and metallic boron concentrations was significant for all the studied traits except for ear length.

Keywords: Yield and its components, water use efficiency, water consumption, sweet corn.

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مجلة العلوم الزراعية العراقية -2023 :54(5):1421-1432 رواد وعلك

دور التغذية الورقية بالبورون النانوي والمعدني في تقليل الشد المائي في حاصل الذرة السكرية ومكوناته

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المستخلص

نفذت تجربة حقلية في حقل تجارب قسم المحاصيل الحقلية– كلية علوم الهندسة الزراعية– جامعة بغداد خلال الموسمين الخريفيين 2021 و2022، بهدف دراسة دور التغذية الورقية بالبورون النانوي والمعدني في الحاصل ومكوناته لمحصول الذرة السكرية. استعمل تصميم القطاعات الكاملة المعشاة بترتيب الألواح المنشقة بثلاثة مكررات تضمنت الألواح الرئيسة ثلاثة مستويات من الشد المائي وهي الري عند استنفاذ 40 و60 و80% من الماء الجاهز ورمز لها W_1 وW_2 وW_3 بالتتابع. بينما مثلت تراكيز رش البورون النانوي والمعدني 5 و10 و20 و 40 ملغم. لتر$^{-1}$ ورمز لها N_1 وN_2 وM_1 وM_2 بالتتابع، فضلاً عن معاملة المقارنة (رشت بالماء المقطر فقط) ورمز لها CO في الألواح الثانوية. بينت النتائج أن تراكيز البورون النانوي والمعدني أثرت معنوياً في جميع الصفات المدروسة, إذ تفوق التركيز 5 ملغم لتر$^{-1}$ من البورون النانوي N_1 معنوياً على التراكيز الأخرى قيد الدراسة في زيادة طول العرنوص وعدد الصفوف في العرنوص وعدد الحبوب في الصف ووزن 500 حبة، مما انعكس ايجاباً في تحسين حاصل الحبوب بلغ 5.93 و 5.96 ط هـ$^{-1}$. في حين أعطت معاملة الري 60% من الماء الجاهز افضل كفاءة لأستعمال الماء بلغت 1.45 و1.38 كغم حبوب م$^{-3}$ ماء لكلا الموسمين بالتتابع.

الكلمات المفتاحية: الحاصل ومكوناته، كفاءة استعمال الماء، الاستهلاك المائي، الذرة السكرية.

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INTRODUCTION

Sweet corn (*Zea mays* L.) one of the cereal crop Poaceae family. Its environmental requirements are identical to those of maize, making it possible to successfully cultivate and produce this crop in Iraq. It has nutritional value for humans, and can be consumed throughout the year for its diverse manufacturing uses, thereby improving our food system. Researchers about plant physiology showed great interest in water stress and its negative effects on the environment and plants (13, 20, 27). It affects all stages of crop growth, from germination to maturity, and has a negative impact on all physiological and biological processes. This is reflected in the economic yield of crops. Water stress is defined more accurately by Sarwata and Tuteja (28) as a deficiency in the available water in terms of quantity and distribution during the plant growth season. Nejat *et al.* (24) observed significant decreases in grain yield when 50%, 60%, and 70% of the available water was depleted, with the lowest values recorded ranging from 6.14 to 5.34 then to 3.85 µg ha^{-1}, respectively. The results of studies by Ahmed and Hassan (7), Abed *et al.* (5), Ati *et al.* (15), Abraheem (6),and Abass and Alag (1), all confirmed a significant decrease in grain yield under water stress. The increased demand for food has led to the search for modern methods to increase agricultural production, which can be achieved through the effective use of modern nanotechnology applications. Nanotechnology is a multidisciplinary science for various economic sectors, especially the agricultural sector, which has contributed to the production of various types of nutrients that plants need, including nano micronutrients. This allows for their use in fertilizing many crops, despite the availability of different mineral or chelated fertilizer sources and various methods of adding them. However, the efficiency of using these traditional fertilizers does not exceed 5% of the added amount (11). Therefore, the use of nano-fertilizers manufactured with effective nanotechnology techniques is adopted at lower costs and more effective methods, such as using nano-boron spray, which plays an important role in physiological processes inside plants and has a crucial role in transporting sugars over short and long distances by forming sugar-borate complexes. Nano-boron technology is characterized by its speed and ease of absorption by plants, and it is an effective alternative to metallic boron, which aims to convert materials and elements into their atoms due to its ease of entering cells, helping to fertilize plants and overcome problems of soil and water pollution and resistance to different environmental conditions. The particle size of nano-fertilizers, which is less than 100 nanometers, facilitates penetration into plants when sprayed on the leaves, thereby improving nutrient absorption efficiency (17), leading to dry matter accumulation, increasing plant nutrient content, and increasing yield (26). Abdul-Razak and Abbas (4) showed that spraying boron at three concentrations of 40, 80, and 120 mg L^{-1}, in addition to the control treatment, resulted in the concentration of 120 mg L^{-1} was superior giving the highest mean weight of 1000 seeds, which was 228.26 and 244.72 g, respectively, and the highest grain yield of 10.877 and 11.410 t ha^{-1}, respectively, for both seasons. Aziz *et al.* (16) confirmed that treating sweet corn plants with nano-boron at three concentrations of 0, 50, and 75 mg L^{-1}, the concentration of 50 mg L^{-1} gave the highest mean length of ears, which was 17.61 cm, the highest number of grains per row (16.61 grains row^{-1}), and the highest grain yield of 5.64 t ha^{-1}, respectively. The concentration of 75 mg L^{-1} achieved the highest mean of water use efficiency (2.68 kg grain m^{-3}) compared to the control treatment. Despite the fact that sweet corn is not a focus of producers and researchers in Iraq, the climatic conditions are favorable for the cultivation and production of this crop, so this was aimed to investigate the role of nano and metallic boron foliar nutrition on yield, yield components, water use efficiency, and water consumption under water stress for sweet corn.

MATERIALS AND METHODS

A field experiment was conducted in the research fields of the Department of Field Crop Sciences - College of Agricultural Engineering Sciences - University of Baghdad (Al-Jadiriyah) during fall seasons of 2021 and 2022. The aim of the study was to investigate the role of nano and metallic boron foliar nutrition on yield, yield components, water use efficiency, and water consumption under water stress for sweet corn. Randomized Complete Block Design was used within split-plot arrangement with three replicates, where the main plots included three levels of water stress (irrigation at 40, 60, and 80% of available water) coded as W1, W2, and W3, respectively. The nano and metallic boron spray concentrations of 5, 10, 20, and 40 mg L^{-1} coded as N_1, N_2, M_1, and M_2, respectively, in addition to the control treatment (sprayed with distilled water only) coded as CO allocated to the sub- plots. The experimental plots were prepared for planting by two perpendicular plowing, smoothing, and leveling, and dividing them into plots according to the mentioned design. The area of each experimental unit was 9 m^2, consisting of four rows, each 3 m long, 75 cm apart and 25 cm between plants to obtain a plant density of 53333 plants ha^{-1}. Two meters were left between the main plots and the same was left between the replicates to control horizontal water movement from one plot to another and to prevent water from leaking from the irrigated plots to the non-irrigated plots. Seeds of the American hybrid sweet corn (CASH F1) from Snowy River Seeds were sown manually on 3 August 2021 for the first season and 1 August 2022 for the second season by placing three seeds per hill. The experimental plots were fertilized with urea at a 174 kg ha^{-1} (46% N) in two doses. The first dose was added at the stage of six fully developed leaves, and the second dose was added before the male flowering stage. Triple superphosphate (46% P_2O_5) was added at a rate of 109 kg ha^{-1} in a single dose during soil preparation. Weeds were removed by manual hoeing as needed, and preventive control of corn stem borer insect infestation was performed using Diazinon insecticide in two doses: the first at the stage of 4-5 leaves and the second at the beginning of the male flowering stage, for both seasons (9). Plants of the two experiments were harvested upon reaching full maturity on November 7, 2021 for the first autumn season and November 5, 2022 for the second autumn season. The relationship between volumetric moisture content ($\boldsymbol{\theta}$) and soil tension (W) was estimated for soil samples sieved through a 2 mm mesh and at moisture content at 0, 3, 5, 7, and 15 bars of suction in the laboratory of the College of Agricultural Engineering Sciences at the University of Baghdad. This was done to estimate the soil water holding capacity for a depth of 0-40 cm and to determine the availability of soil moisture content by calculating the difference between the volumetric moisture content at field capacity and the permanent wilting point, which was determined from the moisture-tension curve and graphically represented in the moisture retention curve (Figure 1).

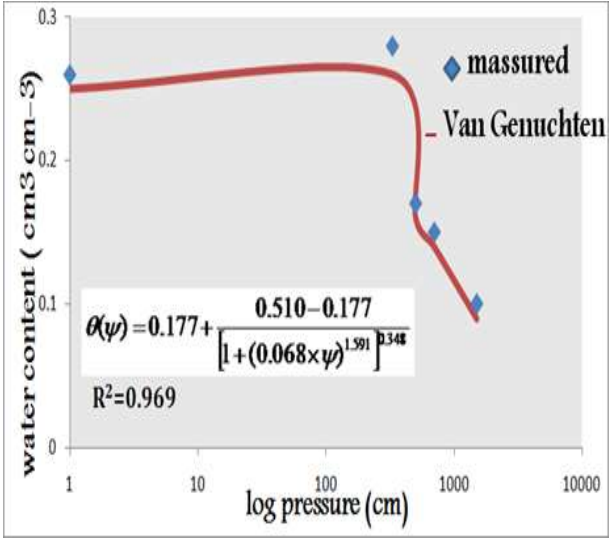

Figure 1. the moisture tension curve for the soil used in the study for the seasons 2021-2022

The volumetric method was used to measure soil moisture content. Soil samples were taken using an Auger, one day before and two days after irrigation at a depth of 20 and 40 cm. They were placed in an aluminum container, weighed while still moist, and then placed in a microwave oven for twelve minutes after adjusting the drying time with dried samples in an electric oven at 105°C for 24 hours, following the method proposed by Zein (29) for sample drying. Then the samples were weighed, and the moisture content was calculated using the following equation:

$$P_w = \left(\frac{M_{sw} - M_s}{M_s}\right)100 \quad \ldots\ldots\ldots\ldots\ldots..(1)$$

Where:

P_w = percent moisture by weight

M_{sw} = mass of wet soil (g)

Ms. = dry soil mass (g).

Then, the volumetric moisture content was calculated based on the bulk density of the soil, as shown in the following equation:

$$\mathbf{Q = P_w \; x \; P_b \; \ldots\ldots\ldots\ldots\ldots(2)}$$

Where:

Q = Moisture content based on volume

P_w = Moisture content based on weight

P_b = bulk density of soil (μ_g m^{-3}).

The irrigation process was carried out using flexible plastic pipes connected to a gasoline-powered pump with a constant discharge rate and equipped with a meter to measure the amount of water added in liters for each experimental unit. Equal amounts of water were added to all experimental units to ensure field emergence. The water stress treatments were carried out at 40%, 60%, and 80% of available soil moisture when the plants reached the stage of six fully developed leaves. The amount of water applied per irrigation at a depth of 20 cm was (129, 194, and 259) liters per experimental unit, respectively. Whereas, for the amount of water applied per irrigation at a depth of 40 cm, was (258, 388, and 518) liters per experimental unit, respectively, until the final irrigation when the plants reached the physiological maturity stage for both seasons. The depth of water added to compensate for the depleted moisture was calculated using the following equation (12):

$$\boldsymbol{d=(\theta fc-\theta_d) \times D} \; \ldots\ldots\ldots\ldots(3)$$

$\boldsymbol{\theta}_{d=}\, \boldsymbol{\theta fc}$ - depletion rate × available water

Where:

d = depth of added irrigation water (cm)

$\boldsymbol{\theta fc}$ = volumetric moisture content at field capacity (cm^3 cm^{-3})

$\boldsymbol{\theta}d$ = volumetric moisture content at the percentage of depletion

D = depth of soil at effective root zone (cm).

After that, the volume of water to be added to each experimental unit is calculated according to the following equation:

$$\mathbf{V = d \; x \; A} \; \ldots\ldots\ldots\ldots(4)$$

Where:

V = volume of water needed to be added per irrigation in liters

A = irrigated area in square meters.

Preparation of nano and mineral boron

Boron nanoparticles were supplied by Nano Shell, India and examined by Scanning Electron Microscope (SEM) in the physics laboratory of the University of Al-Nahrain to determine the particle size. Mineral boron was prepared from the English company Analar in the form of boric acid (H_3BO3). To prepare concentrations of 5 and 10 mg L^{-1} of nano boron and 20 and 40 mg L^{-1} of the mineral boron, the amount of boric acid containing boron must be calculated. The molecular weight of boric acid is 62 g and the molecular weight of boron is 11 g, and make a ratio and proportion to get a solution with the required concentrations of nano and metallic boron. The plants were sprayed with nano and mineral boron solutions in three applications during the first growing season: the first application was done when the plants reached the stage of six fully developed leaves, the second when 10% of the male flowers appeared, and the third **at** the stage of silk appearance (female flowering). The spraying was done in the early morning to avoid high temperatures using a backpack sprayer with a capacity of 20 liters until the plants were wetted and the first drop of water appeared on the plants. A wetting agent was added to the solution to reduce surface tension and increase the efficiency of the spray solution. These procedures were carried out for both seasons.

Studied Characters

Yield and yield components: 10 plants were randomly selected from each experimental unit to calculate the components of yield, which included ear length, number of rows per ear, number of grains per row, mean weight of 500 grains (g), and total grain yield (t ha^{-1}) at full physiological maturity. All treatments were corrected to a standard moisture content of 15.5%.

Water use efficiency for grain yield (kg ha^{-1} m^{-3}): calculated using the equation (12)

$$\mathbf{WUE = GY / W.A} \; \ldots\ldots\ldots(5)$$

Where:

WUE = water use efficiency (kg ha^{-1} m^{-3}),

GY = grain yield (kg ha^{-1}),

W.A = water applied (m^3 ha^{-1}).

Water consumption: calculated from moisture content data after irrigation and before the next irrigation at depths of 20 and 40 cm.

Statistical analysis: the experimental data were analyzed using the Genstat program according to the design used, and the mean values of the variables were compared using the least significant difference test at a significance level of 5%..

RESULTS AND DISCUSSION

Ear length (cm)

The results of Table (1) indicate a significant effect of water depletion treatments and nano and metallic boron spraying concentrations on mean ear length. There was no significant interaction between the two factors in this trait for both seasons. The treatment with 80% water depletion (W3) gave the lowest mean ear length (16.23 and 16.96 cm) for both seasons, respectively. Whereas, the plants treated with water depletion W1 gave the highest mean ear length (20.05 and 20.27 cm), respectively, and did not differ significantly from the W2 treatment, with an increase of 23.53% and 19.51%, respectively, compared to the W3 treatment for both seasons. This decrease in ear length is attributed to the effect of water stress in the early stages of growth, especially in the transition from vegetative to reproductive stage, which reduces most growth traits such as plant height, number of leaves, leaf area, and their weight (acceptable data for publication). This led to a lack of supply of carbon metabolite materials to different parts of the plant, including ear length. This result is consistent with the results of Karasu *et al.* (21), and Abduladheem (2), who showed that water stress, caused a reduction in the ear length of maize plants. The results of Table (1) also show that the nano and metallic boron spraying treatments outperformed significantly in this trait. Treatment N1 (with a concentration of 5 mg L^{-1}) recorded the highest mean of 19.98 and 20.54 cm, respectively, for both seasons. While the control treatment CO (distilled water spraying) gave the lowest mean of 17.00 and 17.46 cm, for both seasons respectively. Also, there were no significant differences between treatments N2 and M2, as their means for this trait at 19.16, 19.35, 19.00, and 19.38 cm, respectively, for both seasons. The increase in ear length when spraying nano boron N1 is attributed to the increase plant height, leaf area, dry weight, and crop growth rate (acceptable data for publication), due to its role in maintaining water balance inside plant tissue cells. This led to the improved production and transportation of carbon metabolism products in the leaves to the rest of the plant, providing the ear with the nutrients it needs, leading to an increase in ear length. This was confirmed by the results of Aziz *et al.* (16), who showed a significant increase in ear length when spraying maize plants with boron.

Table 1. Effect of depletion of available water and boron spray concentrations on average of ear length (cm) for the two fall seasons of 2021 and 2022

Concentration of nano and metallic boron (mg L^{-1})	Water depletion (W)			Mean
	W1 40%	**W2 60%**	**W3 80%**	
		2021		
CO (0)	18.23	18.16	14.60	17.00
N1 (5)	21.60	21.10	17.26	19.98
N2 (10)	20.40	20.36	16.73	19.16
M1 (20)	19.66	19.53	16.10	18.43
M2 (40)	20.36	20.20	16.43	19.00
LSD 0.05		N.S		0.39
Mean	20.05	19.87	16.23	
LSD 0.05		0.23		
		2022		
CO (0)	18.60	18.30	15.50	17.46
N1 (5)	21.70	21.60	18.33	20.54
N2 (10)	20.50	20.46	17.10	19.35
M1 (20)	20.13	20.06	16.46	18.88
M2 (40)	20.43	20.33	17.40	19.38
LSD 0.05		N.S		0.24
Mean	20.27	20.15	16.96	
LSD 0.05		0.29		

Number of rows per ear

The results show that there was a significant effect of water stress treatments and spraying with nano and metal boron and their interaction in the mean number of rows per ear for both seasons (Table 2). The depletion treatment W3 gave the lowest mean (13.31 and 13.33 in row ear^{-1}), with a decrease rate of 13.96 and 12.12% than the depletion treatment W1 which gave the highest mean of 15.47 and 15.17 row ear^{-1}, for both seasons respectively, which did not differ significantly from the depletion treatment W2, which gave an mean of 15.42 and 15.10 row ear^{-1}. The reason may be attributed to the insufficient carbon assimilation for the formation of more rows since it is the first part to be determined in the ear after determining its size, which is affected by environmental stresses, especially water stress (19), as well as the scarcity of water available for the plant with increasing temperatures and decreasing relative humidity during the vegetative and reproductive growth stages. This has affected the reduction of growth traits such as plant height, number of leaves, and leaf area (acceptable data for publication), thus reducing the necessary dry matter production, resulting in a reduction in the length and diameter of the ear (Unpublished data) and hence the number of rows in the ear (18). These results are consistent with the findings of Khodarahmpour and Hamidi (22), and Abdulameer (3), who indicated that water stress caused a reduction in the number of rows in maize. The results of Table (2) indicate a significant effect of boron spraying treatments on increasing the number of rows per ear. Plants treated with nano boron spraying treatment N1 recorded the highest mean number of rows per ear (15.52 and 15.51 rows ear^{-1}) for both seasons respectively. Whereas, the control treatment CO gave the lowest mean of 13.84 and 13.50 rows ear^{-1}, for both seasons respectively. The reason for this could be the role of boron in improving vegetative growth characters such as plant height, number of leaves, and leaf area (acceptable data for publication), The result of this was an increase in the transfer of carbon metabolites and their accumulation in the ear, and then an increase in the diameter of the ear. (unpublished data). This was reflected in an increase in the number of rows per ear, and this result is consistent with the results of Al-Beiruty *et al.* (10), and Al-Ameri (8). The results of Table (2) indicated a significant interaction effect between the study factors on the mean row per ear. The W1N1 treatment recorded the highest mean of 16.20 and 15.90 rows ear^{-1}, respectively, with a non-significant difference from the W2N2 treatment, which recorded a mean of 16.13 and 15.83 rows ear^{-1}, respectively. While, the control treatment W3CO recorded the lowest mean of 11.70 and 11.33 rows ear^{-1}, for both seasons respectively. The significant effect of nano boron spraying may be attributed to its role in improving the water content of plants, which reduces their exposure to water stress, the factor that affects this trait, in addition to its role in increasing vegetative growth characters and root weight (Unpublished data). This, in turn, led to an increase in the plant's ability to absorb water and nutrients, which was reflected in an increase in ear diameter (unpublished data), and therefore an increase in the number of rows in the shoot under water stress conditions.

Table 2. Effect of depletion of available water and boron spray concentrations on average of number of rows per ear for the two fall seasons of 2021 and 2022

	2021			
	Water depletion (W)			
Concentration of nano and metallic boron (mg L^{-1})	W1 40%	W2 60%	W3 80%	Mean
CO (0)	14.93	14.90	11.70	13.84
N1 (5)	16.20	16.13	14.23	15.52
N2 (10)	15.63	15.53	13.63	14.93
M1 (20)	15.13	15.10	13.53	14.58
M2 (40)	15.46	15.46	13.47	14.80
LSD 0.05		0.40		0.23
Mean	15.47	15.42	13.31	
LSD 0.05		0.18		
	2022			
CO (0)	14.63	14.53	11.33	13.50
N1 (5)	15.90	15.83	14.80	15.51
N2 (10)	15.30	15.26	13.60	14.72
M1 (20)	14.80	14.73	13.40	14.31
M2 (40)	15.23	15.16	13.53	14.64
LSD 0.05		0.48		0.28
Mean	15.17	15.10	13.33	
LSD 0.05		0.18		

Number of grains per row

The data in Table (3) show a significant effect of water depletion treatments, nano and metallic boron spraying concentrations, and their interaction on the mean number of grains per row in both seasons. Treatment W1, which resulted in the highest mean number of grains per row of 34.95 and 35.86 in both seasons respectively, Which did not differ significantly from the depletion treatment W2, which recorded a mean of 34.83 and 35.78 grains row^{-1}, with an increase of 14.32 and 16.80% over the depletion treatment W3, which recorded the lowest mean of 30.57 and 30.70 grains row^{-1}, for both seasons respectively. The reason for the decrease in the number of grains per row with increasing water stress is attributed to the reduction in the ear length (Table 3), negatively reflected on the number of grains per row, as well as on water stress, which negatively affected the availability of nutrients, enzyme activity, and hormone content inside the plant, which in turn contributes to the improvement of carbon assimilation. It negatively affected the determination of the grain establishments and the reduction of the carbon metabolization products, and then reduced their transmission to the grain sites, and this in turn caused the abortion of pollinating grains. These results are consistent with Abdulameer and Ahmed (3), Amin (14), who stated that water stress caused a decrease in the number of grains per row with increasing water stress. Plants treated with nano-boron spray N1 recorded the highest mean number of grains per row at 35.12 and 35.80 grains row^{-1}, respectively, which was significantly different from the other spray treatments. While, plants in the control treatment recorded the lowest mean of 31.74 and 32.11 grains row^{-1}, for both seasons respectively. The increase in the number of grains per row could be attributed to the role of boron in increasing leaf area, as indicated by the chlorophyll content and relative water content of leaves (unpublished data). This, in turn, led to an accumulation of dry matter production and its transfer to the sink (seed), resulting in a positive effect on the number of grains per row. This result is consistent with the findings of Aziz et al. (16) who reported that treating sweet corn with nano-boron led to an increase in the number of grains per row. Treatments of depletion of available water and treatments of spraying with nanoparticles and metallic boron interact in their effect significantly. The interaction between depletion of available water treatments and nano- and metallic boron spraying had a significant effect on this trait, with the highest mean of 36.63 and 37.40 grains row^{-1} resulting from the W1 N1 treatment, which had an increase percentage of 8.05% and 8.53% compared to the W1CO treatment, over both seasons respectively. The lowest mean for this trait was 27.56 and 27.46 grains row^{-1}, respectively, for the W3CO treatment for both seasons. The results also showed that spraying nano-boron at N1 and N2 concentrations, along with depletion of 80% of the ready water (W3), increased the trait's mean by (17.41% and 19.19%), and (14.40% and 14.09%), respectively, for both seasons compared to the CO treatment (distilled water spraying) at the same depletion level of W3. These results suggest that nano-boron spraying plays a vital role in improving plant growth under water stress conditions, which positively reflected in increasing the mean length of the ear (Table 1) and consequently the number of grains in the ear.

Table 3. Effect of depletion of available water and boron spray concentrations on average of number of grains per row for the two fall seasons of 2021 and 2022

	2021			
Concentration of nano and metallic boron (mg L^{-1})	Water depletion (W)			
	W1 40%	W2 60%	W3 80%	Mean
CO (0)	33.90	33.76	27.56	31.74
N1 (5)	36.63	36.36	32.36	35.12
N2 (10)	35.10	35.03	31.53	33.89
M1 (20)	34.33	34.26	30.23	32.94
M2 (40)	34.80	34.73	31.16	33.57
LSD 0.05		0.86		0.49
Mean	34.95	34.83	30.57	
LSD 0.05		0.85		
	2022			
CO (0)	34.46	34.40	27.46	32.11
N1 (5)	37.40	37.26	32.73	35.80
N2 (10)	36.50	36.40	31.33	34.74
M1 (20)	35.40	35.33	30.93	33.89
M2 (40)	35.56	35.50	31.06	34.04
LSD 0.05		0.71		0.41
Mean	35.86	35.78	30.70	
LSD 0.05		0.53		

Weight of 500 grain (gm)

The results shown in Table (4) reveal significant differences between available water depletion, concentrations of nano and metallic boron spray, and their interaction in the mean weight of 500 grains for both seasons. Treatment W1 had the highest mean weight of 102.32 and 102.75 g to 500 grains, respectively, for both seasons, and did not differ significantly from treatment W2. However, treatment W3 had the lowest mean weight of 83.00 and 83.57 g for both seasons, respectively. The decrease in grain weight under water stress may be attributed to its negative effect on the plant aging rate, including tissues involved in carbon metabolism, causing a reduction in leaf number, leaf area, and chlorophyll content (unpublished data), accompanied by water shortage, high temperature, low relative humidity, and high wind speed. This led to a shorter period of carbon metabolism and less accumulation of dry matter and nutrients in the grain, which negatively affected the amount of material transferred to the grain, resulting in smaller and shriveled grains. These results agree with Zhao et al. (30), Nielsen and

Schneekloth (25), Abdulameer and Ahmed (3), and Ahmed and Hassan (7), who found a decrease in grain weight due to water stress in maize. Additionally, the results in Table (4) show that boron spray, in its nano and metallic forms, has a role in reducing the damage caused by water stress in 500 grain weight. Treatment N1 had a significantly higher mean weight of 100.69 and 101.31 g and an increase rate of 11.49% and 11.78%, respectively, compared to the control treatment (CO), which had the lowest mean weight of 500 grains, with 90.31 and 90.63 g for both seasons, respectively. This may be attributed to the effective role of boron in regulating cell osmotic pressure, by enhancing water consumption efficiency through water balance and maintaining the relative content of leaves (unpublished data), improving growth traits such as plant height, leaf area, leaf area index, chlorophyll content, and root dry weight (data under publication). Which led to an increase in the investment of sunlight and prompted the plant to increase its ability to absorb water and nutrients, and then processing of carbon metabolism, which increased the amount of metabolites received from the source to the sink (grain), as well as the efficiency of the transport process towards the grain, and this would be reflected positively increasing the grain weight. This result agrees with the results of the study of Al-Ameri (8), and Abdul-Razak, and Abbas (4), who showed that spraying with boron caused a significant increase in the grain weight of maize. The results show a significant interaction between the study factors in the mean weight of 500 seeds for both seasons. The treatment W1N1 was superior with the highest mean weight of 500 seeds at 107.66 and 108.30 grams respectively. While the treatment W3CO recorded the lowest mean weight of 75.20 and 76.48 grams respectively for both seasons. It is also noticeable that boron spraying reduced the effect of water stress, as the treatment W3N1 significantly outperformed in increasing the weight of 500 seeds compared to the control treatment W3CO, with an increase of 15.86% and 14.21% respectively for both seasons. This indicates that boron spraying led to an increase in the weight of 500 seeds by increasing the content of proline acid (Unpublished data), which reduces the effect of water stress through its role in reducing the transpiration process by regulating the water balance in plant tissues, improving physiological processes within the plant by increasing the products of carbon assimilation and their transportation to the sink (grain), which positively reflected on the mean weight of the grain.

Table 4. Effect of depletion of available water and boron spray concentrations on average of weight of 500 grain (gm) for the two fall seasons of 2021 and 2022

	2021			
Concentration of nano and metallic boron (mg L^{-1})	**Water depletion (W)**			**Mean**
	W1 40%	**W2 60%**	**W3 80%**	
CO (0)	**97.90**	**97.83**	**75.20**	**90.31**
N1 (5)	**107.66**	**107.26**	**87.13**	**100.69**
N2 (10)	**103.20**	**103.13**	**85.20**	**97.18**
M1 (20)	**101.00**	**100.50**	**83.33**	**94.94**
M2 (40)	**101.86**	**101.46**	**84.16**	**95.83**
LSD 0.05		**0.57**		**0.99**
Mean	**102.32**	**102.04**	**83.00**	
LSD 0.05		**0.62**		
		2022		
CO (0)	**97.76**	**97.63**	**76.48**	**90.63**
N1 (5)	**108.30**	**108.26**	**87.35**	**101.31**
N2 (10)	**103.76**	**103.56**	**85.81**	**97.72**
M1 (20)	**101.36**	**101.25**	**83.81**	**95.84**
M2 (40)	**102.55**	**102.48**	**84.40**	**96.48**
LSD 0.05		**0.27**		**0.47**
Mean	**102.75**	**102.64**	**83.57**	
LSD 0.05		**0.34**		

Total grain yield (ton ha^{-1})

The results indicate a significant effect of water depletion treatments and concentrations of nano and mineral boron spraying, as well as their interaction, on the mean grain yield for both seasons (Table 5). The 40% water depletion treatment (W1) gave the highest mean grain yield per unit area (5.91 and 5.98 tons ha^{-1}) for both seasons respectively, which was not significantly different from the 60% water depletion treatment (W2). While the 80% water depletion treatment (W3) recorded the lowest mean of 3.63 and 3.66 tons ha^{-1} for both seasons respectively, with a decrease percentage compared to the W1 treatment of 38.57% and 38.79% for both seasons respectively. The reason for the decrease in grain yield under water shortage conditions is attributed to the significant decrease in stem length, number of rows per ear, number of grains per row, and weight of 500 seeds

(Tables 1, 2, 3 and 4), which reflected the significant effect in reducing vegetative growth characteristics represented by plant height, leaf number, leaf area, and dry weight, which represent the source (accepted data for publication). These results are consistent with the findings of Nejat et al. (24), and Ahmed and Hassan (7), who found that exposing maize plants to water stress led to a decrease in grain yield.

Table 5. Effect of depletion of available water and boron spray concentrations on average of total grain yield (ton ha^{-1}) for the two fall seasons of 2021 and 2022

Concentration of nano and metallic boron (mg L^{-1})	2021 Water depletion (W) W1 40%	W2 60%	W3 80%	Mean
CO (0)	5.28	5.24	2.58	4.37
N1 (5)	6.81	6.71	4.25	5.93
N2 (10)	6.04	5.98	3.90	5.31
M1 (20)	5.59	5.54	3.63	4.93
M2 (40)	5.84	5.81	3.76	5.14
LSD 0.05		0.16		0.09
Mean	5.91	5.86	3.63	
LSD 0.05		0.16		
	2022			
CO (0)	5.26	5.20	2.76	4.41
N1 (5)	6.86	6.81	4.20	5.96
N2 (10)	6.18	6.13	3.90	5.41
M1 (20)	5.66	5.62	3.70	5.00
M2 (40)	5.92	5.88	3.72	5.18
LSD 0.05		0.17		0.10
Mean	5.98	5.93	3.66	
LSD 0.05		0.15		

The results also indicate that spraying nano and mineral boron caused an increase grain yield. The nano boron spraying treatment N1 outperformed all other spraying treatments with the highest mean grain yield (5.93 and 5.96 tons ha^{-1}), with an increase percentage compared to the control treatment CO of 35.69% and 35.14%, respectively, which recorded the lowest mean of 4.37 and 4.41 tons ha^{-1}, respectively, for both seasons. The reason for the increase in yield in the N1 nano boron treatment is due to its positive effect on the growth characters, which caused significant effects in stem length, number of grains per row, and weight of 500 seeds, all of which reflected in the increase in grain yield. These results are consistent with the findings Al-Ameri (8), Abdul-Razak and Abbas (4), and Aziz *et al.* (16). The highest mean grain yield was 6.81 and 6.86 tons ha^{-1}, which resulted from the W1N1 treatment, with a non-significant difference from the W2N1 treatment, which recorded a mean of 6.71 and 6.81 tons ha^{-1}, respectively, for both seasons. While the lowest average grain yield was 2.58 and 2.76 tons ha^{-1} for the W3CO treatment, respectively, for both seasons. The reason for the increase in grain yield is attributed to the role of boron in enhancing these treatments, represented by the number of grains per row and the weight of 500 seeds (Tables 3 and 4), which reflected in the increase in grain yield under water stress conditions.

Water use efficiency of grain yield (kg grain m^{-3} water)

The results indicate a significant effect of both available water depletion treatments and concentrations of nano and metallic boron spraying and their interaction for both seasons (Table 6). The W2 depletion treatment significantly outperformed with a higher average water use efficiency of 1.45 and 1.38 kg grain m^{-3} water for both seasons respectively, while the W3 depletion treatment showed the lowest average of 1.04 and 0.94 kg grain m^{-3} water for both seasons. Increasing water use efficiency for the W2 depletion treatment (60% water depletion) means achieving the same grain yield with less water, indicating an increase in water productivity. Water use efficiency is an indicator of a plant's ability to invest available water resources in producing grain yield per unit area (21), and this result is consistent with the findings of studies conducted by Zhao et al. (30), Li et al. (23), and Ahmed and Hassan (7), which showed that water use efficiency increases when reducing irrigation amounts. Therefore, it can be concluded that increasing water use efficiency may come from an increase in the productivity of the unit of water used, in other words, using less water to achieve a higher yield. The N1 nano-boron spraying treatment recorded the highest average water use efficiency of 1.48 and 1.41 kg grain m^{-3} water for the two seasons, while the control treatment (CO) recorded the lowest average of 1.08 and 1.03 kg grain m-3 water for the two seasons. The superiority of water use efficiency with the N1 nano-boron spraying treatment may be attributed to the important role of boron in improving plant water status and controlling the opening and closing of stomata by regulating stomatal aperture length and width (Unpublished data), which reduces water loss through transpiration, positively reflecting on water use efficiency. The W2N1 treatment recorded the highest average of 1.66 and 1.59 kg grain m^{-3} water for both seasons, which was not significantly different from the W1N1 treatment in the second season, which recorded an average of 1.58 and 1.55 kg grain m^{-3} water for both seasons. While, the W3CO treatment recorded the lowest average of 0.74 and 0.71 kg grain m^{-3} water for both seasons. The increase in water use efficiency may be attributed to the role of boron in increasing root biomass (unpublished data), thus increasing the amount of water absorbed, which helps to maintain plant water content, leading to an increase in grain yield and thus water use efficiency, which increased the ability of sweet corn plants to withstand water stress.

Table 6. Effect of depletion of available water and boron spray concentrations on average of water use efficiency of grain yield (kg grain m^{-3} water) for the two fall seasons of 2021 and 2022

Concentration of nano and metallic boron (mg L^{-1})	2021 Water depletion (W) W1 40%	W2 60%	W3 80%	Mean
CO (0)	1.22	1.29	0.74	1.08
N1 (5)	1.58	1.66	1.22	1.48
N2 (10)	1.40	1.48	1.12	1.33
M1 (20)	1.29	1.37	1.05	1.24
M2 (40)	1.35	1.44	1.08	1.29
LSD 0.05		0.04		0.02
Mean	1.37	1.45	1.04	
LSD 0.05		0.04		
		2022		
CO (0)	1.19	1.21	0.71	1.03
N1 (5)	1.55	1.59	1.09	1.41
N2 (10)	1.39	1.43	1.01	1.28
M1 (20)	1.28	1.31	0.96	1.18
M2 (40)	1.34	1.37	0.96	1.22
LSD 0.05		0.04		0.02
Mean	1.35	1.38	0.94	
LSD 0.05		0.04		

Actual water consumption (mm $season^{-1}$)

The results in Table (7) clarify the average actual evapotranspiration (crop water consumption) ET_a for sweet corn for the two autumn seasons. A difference was observed between the mean ET_a and the level of water depletion due to different irrigation levels used during the growing season in the different irrigation treatments, which resulted in a difference in the number of irrigations during the growing season. The W1 irrigation treatment (at 40% water depletion) recorded the highest average actual water consumption of 430.66 and 441.33 mm $season^{-1}$ with an average of 435.99 mm $season^{-1}$ for the two seasons. This was followed by the W2 depletion treatment (at 60% water depletion) with an average of 402.66 and 427.77 mm $season^{-1}$, and an average of 415.21 mm $season^{-1}$ for the two seasons. While, the W3 depletion treatment (at 80% water depletion) recorded the lowest average of 345.77 and 385.44 mm $season^{-1}$, with an average of 365.60 mm $season^{-1}$ for the two seasons.

Table 7. Average actual water consumption (ET_a) of sweet corn For the two fall seasons of 2021 and 2022

Trait	2021 Water depletion (W) W1 40%	W2 60%	W3 80%
Irrigation umber	19	15	12
Water applied m^3 ha^{-1}	4306.66	4026.66	3457.77
Water depth applies mm season	430.66	402.66	345.77
Rain mm	0	0	0
Ground water contribution mm	0	0	0
Moisture storage depth mm	0	0	0
Actual consumptive use mm $season^{-1}$	430.66	402.66	345.77
		2022	
Irrigation umber	19	15	12
Water applied m^3 ha^{-1}	4413.33	4277.77	3854.44
Water depth applies mm season	441.33	427.77	385.44
Rain mm	0	0	0
Ground water contribution mm	0	0	0
Moisture storage depth mm	0	0	0
Actual consumptive use mm $season^{-1}$	441.33	427.77	385.44

The percentage of water consumption reduction for the W2 and W3 irrigation treatments at 60% and 80% water depletion, respectively, compared to the W1 irrigation treatment (at 40% water depletion) was 4.76% and 16.14%, respectively, for both seasons. These percentages can be utilized to increase the area of cultivation for this crop or other crops. Also, results showed that the water consumption for the W1 depletion treatment was the highest possible, which is normal because the soil moisture in this treatment is close to field capacity, which positively reflected on the plant height and leaf area (unpublished data) and the total grain yield of sweet corn (Table 5), leading to an increase in the amount of water lost through transpiration. We can conclude from this that irrigation methods and quantities added are effective methods in making water available and regulating it for cultivation under conditions of limited water resources in Iraq.

Conclusion

It can be concluded from this that treatment W2 (60% water depletion) had the same effect on the studied characteristics as treatment W1 (40% water depletion), without significant differences. In other words, the same effect can be achieved with less irrigation water added to meet the requirements of sweet corn crop production. This highlights the functional role of boron in reducing the harmful effects of water stress, leading to improved yield and its components. This is due to the positive effect reflected in the vegetative growth characters of sweet corn plant.

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