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Effect of boron spraying, potassium levels, and irrigation interval on some physiological traits and cabbage productivity

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Abstract: Water shortages directly impact human malnutrition and agricultural productivity. However, the ideal irrigation times must accommodate crop seasons in various climates and address the effects of climate change. Thus, this research aimed to quantify the impact of fertilizers, including boron and potassium, and irrigation intervals on cabbage. In 2021, two irrigation intervals, 3 and 6 days were used in a field trial. Potassium fertilizer was applied at 0. 75 and 150 kg K ha^{-1}. Boron was sprayed at 0. 50, and 100 mg B l-1 using boric acid. The data showed that antioxidants were increased at the 6-day irrigation interval compared to the 3-day irrigation interval. Proline, peroxidase, carotene, and catalase enzymes increased at the longer irrigation interval. Since plants use potassium to maintain their water content, potassium was associated with increased antioxidants and the rate of boron fertilizer application. The highest proline content in plant tissue was in the control treatment 22.90 µg g^{-1} FM (fresh mass) and 31 .23 µg g^{-1} FM for 3 and 6-day irrigation intervals, respectively. The control treatment achieved a higher peroxidase content value at the 6-day irrigation interval (47.20 µg g^{-1} FM). The highest total cabbage yield was observed at the 3-day irrigation interval.

Key words: boron spraying, potassium levels, irrigation interval, cabbage, proline content, carotene, peroxidase enzyme

Učinki škropljenja s pripravki bora, dodatki kalija in intervalov namakanja na nekatere fiziološke lastnosti zelja

Izvleček: Pomankanje vode neposredno prizadane prehrano ljudi in pridelavo v kmetijstvu. Pri namakanju morajo biti časovni presledki namakanja prilagojeni fenološkim fazam poljščin v različnih podnebnih razmerah, upoštevajoč spremembe podnebja. Namen raziskave je bil opredeliti učinke gnojenja z borom in kalijem ter intervale namakanja na rast zelja. V rastni sezoni 2021 sta bila v poljskem poskusu uporabljena 3 in 6 dnevni interval namakanja. Kalijeva gnojila so bila uporabljena v odmerkih 0, 75, in 150 kg K $ha^{-1.}$ Škropljenja z borom so bila v odmerkih 0, 50 in 100 mg B l^{-1} z uporabo borove kisline. Podatki iz raziskave so pokazali, da se je vsebnost antioksidantov povečala pri šestdnevnih intervalih namakanja v primerjavi s tridnevnimi intervali. Vsebnosti prolina, peroksidaze, karotena in katalaze so se povečale pri daljših intervalih namakanja. Vsebnosti odmerkov kalija in gnojenja z borom so bile povezane s povečanjem vsebnosti antioksidantov zaradi vloge kalija pri ohranjanju vsebnosti vode v rastlinah. Največja vsebnost prolina v rastlinskih tkivih je bila izmerjena v kontrolnem obravnavanju in sicer 22,90 µg g^{-1} in 31,23 µg g^{-1} na svežo maso pri 3 in 6-dnevnih intervalih namakanja. Kontrolna obravnavanja so imela večjo vsebnost peroksidaze pri 6-dnevnem intervalu namakanja, 4720 µg g^{-1} na svežo maso. Največji pridelek zelja je bil izmerjen pri 3-dnevnem intervalu namakanja.

Ključne besede: škropljenej z borom, vsebnosti kalija, intervali namakanja, zelje, vsebnost prolina, karotena, peroksidaze

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1 INTRODUCTION

Cabbage is a leafy crop belonging to the Brassicaceae family. It can be planted for the leafy head and the bud as a yield in cold weather. According to Ahmed et al. (2023), cabbage leaves can be cooked, simmered, or immersed in vinegar. Cabbage is grown in Iraq in an area estimated at 1170 ha, with total productivity valued at 16.24 Mg ha^{-1} UNESCO (2019). Cabbage is deemed rich in nutrients, including vitamins C and E and the minerals potassium and calcium, Altıntaş et al. (2024). Moreover, cabbage is an outstanding source of B vitamins, including thiamine, folate, and riboflavin. Given that it contains about 4 g of carbohydrates per 100 g of fresh mass, 15 g of protein per 100 g of fresh mass, 0.2 g of fatty acids per 100 g of fresh mass, and 93 mL of water per 100 g of fresh mass, it can be a good source of protein, carbohydrates, and hydration. Ibukunoluwa (2015).

Water reservoirs have experienced a progressive reduction, notably in the last two decades, mostly owing to the increased water use by urban, industrial, and agricultural sectors. This is especially evident in arid and semi-arid regions, where climate change is a significant concern and new irrigation techniques for vegetable production exist. (Al-Lami et al.,2023). Establishing periodic irrigation schedules is crucial for maintaining optimal soil moisture levels in crops and enhancing crop yield Abdel-All and Seham (2013). Several studies have provided evidence about irrigation scheduling (Abdel-All and Seham, 2013; Bhattacharyya et al., 2022). A study performed by Pandey et al. (2023) has shown that the timing of irrigation intervals may significantly impact cabbage production, depending on the growth stage. Maximum yield can be achieved when the soil is well-watered and unaffected by water stress. In this scenario, irrigation timing can be employed to mitigate excessive irrigation or under-irrigation. Mndela et al. (2023) have demonstrated that the sustainability of water resources has been enhanced by irrigation schedules for various crops cultivated throughout the year in small-scale fields.

Potassium is an essential macronutrient found in plants, that exerts a substantial influence on the growth and physiological processes of cells throughout crop development (Abdel-All and Seham, 2013; Mahmood et al., 2019; Shahinul et al., 2020). Hydraulic equilibrium, photosynthesis, and nutrition intake are notable contributors (Ahmad et al., 2020; Battie-Laclau et al., 2014; Juma et al., 2024). The inadequacy of K suplay in the edaphic environment interrupts these processes, diminishing crop yield and lessening the photosynthesis process (Battie et al., 2014; He et al., 2022; Salem et al., 2022). In addition to the fertility preference of forage crops, the scarcity of K impairs the absorption of essential nutrients such as phosphorus and nitrogen, which subsequently creates disarray in element equilibrium (Choudhary et al., 2024; Soumare et al., 2023). In addition to the considerable role of nutrient constituents in the soil environment, low K levels have a precise impact on the development of the crops' roots, which is a critical aspect of nutrient and moisture acquisition (Kumar et al., 2015; Xu et al., 2020). Moreover, the soil contains potassium (K) that is unavailable to plants. It can be categorized into three pathways: available K, which includes soluble K and exchangeable K; non-exchangeable K; and mineral K (Abood and Sherif, 2022; Ahmad et al., 2020). Mostly, soil K is introduced to the soil through fertilizers or verdant and decomposed manure (Das et al., 2022). The K demand can make a crop's absorption of K a core concern (El-Mageed et al., 2022). Soil erosion, leaching in porous soils, extensively irrigated soils, and even inattentive soil management practices are all potential causes of K loss from the soil (Guo et al., 2019; Thakur et al., 2023). Although K can be reintroduced into the soil through soil balancing, it can be adversely impacted by excessive nitrogen and phosphorus applications (Das et al., 2022).

Boron is an indispensable micronutrient that is required by most if not all cereals (Farrag et al., 2021; Shahinul et al., 2022). Boron is essential for the transportation of sugar within plants (Bankar et al., 2024; Farag et al., 2022). It boosts the formation of roots and stimulates the development of the meristematic cells. (Kumar et al., 2023). Further, boron is involved in synthesizing proteins, amino acids, and carbohydrates, along with improving ATPase. Moreover, it is necessary for the formation and development(Al-Kahachi et al., 2024; Mostafa et al., 1999; Trees & Iraqi, 1999). Oxidative damage can occur from an insufficient amount of boron (Shahinul et al., 2020). Unquestionably, the accumulation of materials from lipid peroxidation and cell membrane seepage is frequently observed in the presence of low boron availability (Hopkins, 2015; Kumar et al., 2023; Meena et al., 2023). The cells can extrude sugars, ions, and phenolic forms once membranes are damaged (Ullah et al., 2024; Yadav and Kumar, 2023). A concealed hunger is a condition in which crop boron deficiency can manifest without any obvious signs on the plants. Boron shortages can occur in soils that are particularly sandy, calcareous, leached, or contain significant amounts of zinc (Khatun and Reza, 2024 ; Akhtar et al., 2022). Likewise, the xylem and phloem vessels, which play a crucial role in the transportation of water throughout plants, are susceptible to destruction due to the scarcity of boron (Gs et al., 2023; Ullah et al., 2024). Furthermore, a lack of boron has a detrimental impact on the rates of transpiration and the density of stomata. It additionally contributes to the degradation of guard cells, which subsequently damages the process of photosynthesis (Hopkins, 2015). This may imply that plants lacking in boron become more prone to drought stress than plants that have sufficient amounts of boron.(Riwad and Alag, 2023; Shahinul et al., 2020). This study aimed to ascertain how irrigation interval impacts cabbage production and assess the optimal administration of potassium and boron at the most suitable irrigation interval.

2 MATERIALS AND METHODS

2.1 STUDY SITE DESCRIPTION

In the 2021-2022 season, one-year research was conducted at the University of Baghdad, College of Agricultural Engineering Sciences Station. The precipitation throughout the cabbage growth period ranged from 100 to 150 mm, while the temperature ranged from 15 to 25 °C. The soil physiochemical characteristics have been described in Table 1.

2.2 EXPERIMENTAL DESIGN

The experimental design encompassed a split-split design with three replications. The primary plots were allocated to irrigation intervals of 3 and 6 days. The secondary plots consisted of three distinct potassium rates: 0 kg K ha^{-1}, 75 kg K ha^{-1}, and 150 kg K ha^{-1}. These rates were applied three times during the beginning of the season: on the planting day, 20 days after planting, and 40 days after planting time. The potassium was applied as potassium sulfate, which contained 41.5 % K. In the sub-secondary plots, plants were sprayed with boron at dosages of 0, 50, and 100 mg B l^{-1}. This spraying procedure was performed 20, 40, and 60 days after the plants were planted, using boric acid containing a 17.4 % boron concentration. The cabbage ('Glob Master') was sown in a container and subsequently transplanted to the field after 30 days. The cabbage was planted in rows, with a spacing of 70 cm between rows and 40 cm between plants inside the row. A distance of around 2 meters was preserved between replicates to avoid the movement of nutrients or irrigation water between treatments. Urea was applied at 100 kg N ha^{-1}, while diammonium phosphate (DAP) was utilized to apply 75 kg P ha^{-1}. Weeds were removed manually as needed. The experimental treatments for both irrigation intervals of 3 and 6 days are set as follows:

Treatments	Description
T1	Control (0 kg K ha^{-1} + 0 mg B l^{-1})
T2	(0 kg K ha^{-1} + 50 mg B l^{-1})
T3	(0 kg K ha^{-1} + 100 mg B l^{-1})
T4	(75kg K ha^{-1} + 0 mg B l^{-1})
T5	(75 kg K ha^{-1} + 50 mg B l^{-1})
T6	(75 kg K ha^{-1} + 100 mg B l^{-1})
T7	(150 kg K ha^{-1} + 0 mg B l^{-1})
T8	(150 kg K ha^{-1} + 50 mg B l^{-1})
T9	(150 kg K ha^{-1} + 100 mg B l^{-1})

2.3 SOIL SAMPLE ANALYSIS

Soil samples were gathered at the study site at a depth of 0–25 cm before planting cabbage and continued to be collected for 80 days after the cabbage planting date. The soil samples are placed through the process of air drying out, crushing, and then passing through a sieve with a mesh size of 2 mm. The combined concentration of nitrogen in the form of nitrate (N-NO_3^-) and ammonium (N-NH_4^+) was determined as available nitrogen using the Kjeldahl method. The phosphorus concentration was measured using the Olsen method with a spectrophotometer at an absorption wavelength of 882 nm. Phosphorus (P), a macronutrient, was quantified using a flame photometer.

2.4 PLANT SAMPLING AND ANALYSIS

Five plants were picked for each treatment of nitrogen (N), phosphorus (P), potassium (K), and boron (B) analysis. Four inner leaves of cabbage were selected from each plant before being matured. The leaves were rinsed with distilled water to remove any dust or contaminants that could potentially impact the accuracy during the analysis. The leaves were dried in an oven with airflow at a temperature of 65 °C for 96 hours, and subsequently ground. The crushed material was prepared for analysis.

2.5 CABBAGE YIELD DETERMINATION

The cabbage head was randomly selected for six plants in each plot. Several harvesting dates were used to calculate the cabbage yield. The cabbage yield per hectare was determined by measuring the kilograms obtained from each experimental patch.

Table 1:. Physiochemical and fertility characteristics of soil

Soil Properties	Value	Unit
pH	7.26	-
EC	2.95	dS m^{-1}
$CaCO_3$	327.19	g kg^{-1} soil
O. M	1.19	%
N	17.80	mg kg^{-1} soil
P	11.23	mg kg^{-1} soil
K	135.01	mg kg^{-1} soil
B	1.12	mg kg^{-1} soil
Texture	Silty loam	

2.6 PROLINE ACID CONCENTRATION DETERMINATION

The analysis of proline was conducted by the methodology outlined by Tamayo & Bonjoch (2006). The proline concentration in the leaves was analyzed using toluene dye (methylbenzene). An acid-ninhydrin solution was made by dissolving 1.25 grams in 30 milliliters of glacial acetic acid and 20 milliliters of 6 M phosphoric acid. The solution was then stored in a refrigerator at a temperature of 4 degrees Celsius in a dark location for one day. Ground 0.5 grams of fresh plant tissue with 10 milliliters of a 3 % solution of sulphosalicylic acid to precipitate proteins. Afterward, the mixture was filtered using filter paper. Two milliliters of filtered materials, which were previously prepared, are inserted in a test tube. The test tubes were treated with 2 ml of glacial acetic acid and 2 ml of acid ninhydrin reagents. The test tubes were immersed in a water bath at a temperature of 95 degrees Celsius, while other test tubes were directly placed in an ice bath. Each test tube was filled with four milliliters of toluene dye and then shaken. The mixture was left undisturbed for approximately thirty minutes. The color transitioned to a red hue, and the samples were prepared for measurement using a spectrophotometer at an absorbance wavelength of 520 nm.

2.7 CAROTENE CONCENTRATION DETERMINATION

Beta carotene was determined following the methodology described by Srivastava and Kumar (2004). Pulverized 10 g of recently harvested plant tissue using a ceramic mortar. Introduced a small amount of anhydrous sodium sulfate and 10 ml of acetone. A volume of 10 ml was extracted from the sample, thereafter, subjected to filtration, and then mixed with 15 ml of petroleum ether. The plant samples were combined with reagents and then immersed in a water bath. After approximately 10 minutes, the mixture was transferred into a test tube. The volume was adjusted up to 100 ml by adding 10 ml of petroleum ether, and then it was measured using a spectrophotometer at an absorption wavelength of 452nm.

2.8 VITAMINE C DETERMINATION

The measurement of Vitamin C was accomplished according to the methodology stated by Yurena et al. (2006). One gram of fresh plant tissue was crushed, followed by the application of oxalic acid. The samples were refrigerated at a temperature of 4 degrees Celsius for 12 hours in a location devoid of light. The materials underwent filtration and were then combined with 0.5 ml of a mixture containing phosphoric and acetic acid. Two milliliters of ammonium molybdate were initially added, and subsequently, the volume was adjusted to reach a total of 25 ml. The measurement of this sample was conducted using a spectrophotometer, specifically at a wavelength absorbance of 760 nm.

2.9 DETERMINATION OF PEROXIDASE

The primary reagent utilized is Guaiacol liquid, which is prepared by adding 1.36 ml to a flask and then completing the volume to 250 ml with distilled water. A spectrophotometer was used to measure the absorbance of one milliliter of hydrogen peroxide at a wavelength of 420 nm. Enzyme activity was quantified by adding 2 ml of the reaction mixture(Shabnam et al., 2016).

2.10 TOTAL CHLOROPHYLL DETERMINATION

One gram of freshly crushed plant tissue was combined with 20 ml of cooled acetone (85 %). The sample, which has been filtered, has a volume of 100 ml after being finished with water. Centrifuge the previously applied samples at 5000 rpm for 5 minutes in the centrifuge. The samples were analyzed using a spectrophotometer at certain wavelengths of absorbance, namely 663 nm and 644 nm (Witham et al., 1971), and then calculated using the following formula:

$$\text{Total Chlorophyll} = [20.2 * D\ (644\ nm) + 8.02 * D\ (663\ nm)] * V / 1000 * M$$

D denotes the light intensity.
V is the final volume of extraction 100 m
M is the mass of plant tissue.

2.11 STATISTICAL ANALYSIS OF DATA

The study dataset tested at the least significant differences (LSD) at a probability level of $p < 0.05$. The software used to analyze the data was R Studio version 2024.04.0+735, Boston, MA, USA. All figures were performed using Microsoft Excel (Microsoft Corporation, USA).

3 RESULTS

3.1 IMPACT OF BORON, POTASSIUM, AND IRRIGATION INTERVALS ON PROLINE CONTENT, PEROXIDASE, AND CAROTINE

The proline concentration in cabbage leaves was measured, and it was found that the highest average value

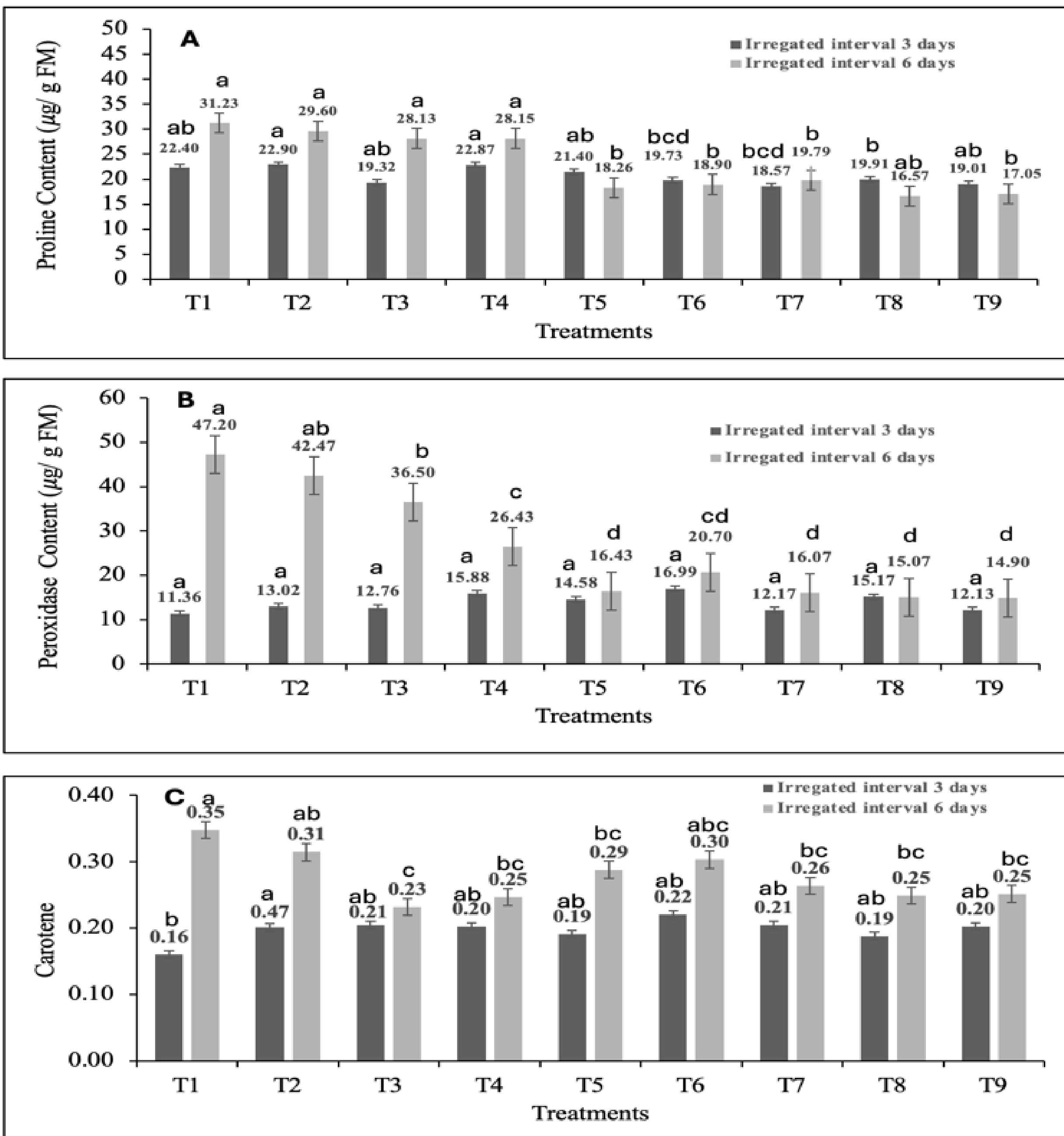

Figure 1: Effect of irrigation intervals, potassium, and boron on (A.) proline content, (B.) peroxidase content, (C.) carotene. The different letters denote significant differences among the mean values of treatments.

was observed at T2 and T1, which were 22.90 μg g^{-1} FM and 31.23 μg g^{-1} FM, respectively. These values represent the control and K0B1 (No potassium + 50 mg B l^{-1}) treatments with irrigation intervals of three and six days. The proline content reached its minimum value at treatment T5 with K1B1 (75kg K ha^{-1} and 50 mg B l^{-1} application), measuring 18.26 μg g FM. There are no significant variations among the T1, T2, T3, T4, and T8 treatments when irrigated every six days, as shown in Figure 1a. The only notable distinction observed was in the T6 and T7 treatments when there was a six-day delay between irrigations compared to the other treatments. However, no substantial distinction was observed between them. Nevertheless, independent of the treatments, the values obtained from irrigating at six-day intervals were more valuable

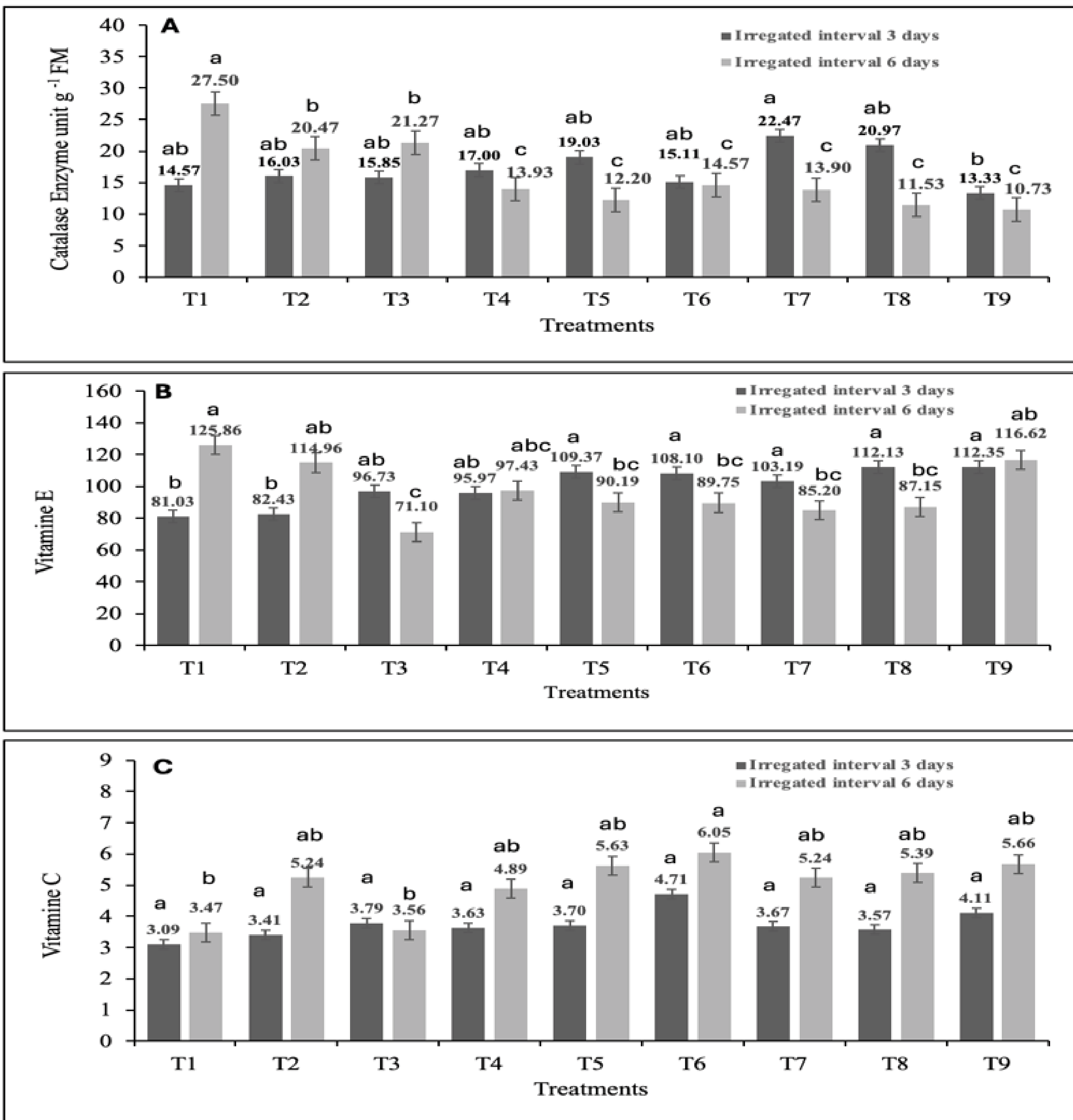

Figure 2: Effect of irrigation intervals, potassium, and boron on (A.) catalase enzyme, (B.) vitamin E, (C.) vitamin C. The different letters denote significant differences among the mean values of treatments.

than those obtained from irrigating at three-day intervals.

The peroxidase content is displayed in (Fig 1B). The minimum values were attained when the plants were irrigated every three days, as opposed to every six days. Extended irrigation periods lead to an increase in the peroxidase content of crops. The control treatment at six six-day irrigation intervals generated the highest peroxidase content value of 47.20 μg g^{-1} FM. When the irrigation interval was set at six days, the values declined as the applications of boron and potassium increased. Conversely, the peroxidase levels were lower when the intervals between irrigation were three days, as opposed to six days. The values of treatment applications increased somewhat, except for T7 and T9 at three-day irrigation intervals, which attained values of 12.17 μg g^{-1} FM and 12.13 μg g^{-1} FM respectively, compared to the other values. Nevertheless, no notable effect was observed in peroxidase content across all treatments with three-day irrigation intervals. When boron was applied every six days, it reduced the peroxidase content in plants, which means it reduced the water stress on plant tissue. The second highest value was obtained by applying 0 kg K ha^{-1} and 50 mg B l^{-1}, resulting in a decrease of approximately 10.02 % relative to the control treatment. The peroxidase concentration was lowest at T9, with a value of 14.90 μg g^{-1} FM. This was a 68.43 % decrease compared to the highest value of 47.20 μg g^{-1} FM T9 was reached with the application of 150 kg K ha^{-1} and 100 mg B l^{-1}.

Figure 1 C. shows substantial differences in the irrigated interval treatments at T1 and T2, with values of 0.16 mg g^{-1}FM and 0.47 mg g^{-1}FM, respectively, observed at three days. On the other hand, there was no substantial increase observed in the other treatments. When the irrigation is performed every six days, the findings show a notable increase in all the treatments. The control application, with a rate of 0 kg K ha^{-1} and 0 mg boron l^{-1}, exhibited the highest value of 0.35 mg g^{-1} FM, surpassing the values of the other treatments. The results indicate that the values fell as the administration of potassium and boron increased. The highest value was recorded at T6 (75 kg K ha^{-1} and 100 mg B l^{-1}), reaching a value of 0.30 mg g^{-1}FM, which did not show a significant increase compared to T1 and T2. Nevertheless, the T3 treatment, which involved the application of 0 kg K ha^{-1} and 100 mg B l^{-1}, resulted in the lowest value. This treatment exhibited a substantial percentage decrease of 34.28 % compared to T1. However, the carotene levels in the treatments with an irrigation interval of three days were lower than those with six days.

3.2 IMPACT OF BORON, POTASSIUM, AND IRRIGATION INTERVALS ON CATALYZE ENZYME, VITAMINE E, AND VITAMINE C

Exposing cabbage to water stress enhances the production of antioxidants by activating plant cells responsible for cabbage‘s defense mechanism (Fig 2 A). The results indicate that the catalase enzyme reached its greatest value during the T1 treatment (control with no potassium and boron applied) at six-day irrigation intervals (27.50 unit g^{-1} FM). The data indicate that the levels of catalase enzyme reduced with potassium and boron treatments, regardless of the irrigation intervals. Treatment T3, which involved an irrigation interval of six days, produced the second-highest value of 20.47 unit g^{-1} FM. This result represented a percentage drop of approximately 25.56 % compared to the T1 treatment. T3 treatment consisted of 0 kg K ha^{-1} and 100 mg B l^{-1}. The minimum values were achieved with three different irrigation interval treatments. Conversely, the greatest values were attained during the T7 and T8 treatments for three days of irrigation intervals. The treatments T7 and T8, which received 150 kg K ha^{-1} and 0 mg B l^{-1}, and 150 kg K ha^{-1} and 50 mg B l^{-1}, respectively, yielded values of 22.47 unit g^{-1} FM and 20.97 unit g^{-1} FM. According to the findings, the average values of the catalase enzyme showed a gradual increase when the watered interval treatments were set at three days. However, these values steadily declined when the irrigated interval treatments were imposed at six days

The impact of potassium and boron treatments on Vitamin E and Vitamin C was observed in both three-day and six-day irrigation intervals, as represented in (Fig 2 B and C). The results indicate that the highest concentrations of vitamin E and vitamin C were observed at T1 and T6, respectively, when employing a six-day irrigation interval. The values recorded were 125.86 for vitamin E and 6.05 for vitamin C. Vitamin E typically declined with increasing treatments, except for T9 (150 kg K ha^{-1} and 100 mg B l^{-1}) where it increased, at irrigation intervals of six days. However, when the irrigation interval was extended to three days, the levels of vitamin C gradually increased with the increase in treatments. Although there was no a significant difference observed between treatments, the increase in vitamin C levels was still noteworthy. The data on Vitamin E indicates that the mean values were significantly influenced by the application of potassium and boron to plants. This effect was observed in treatment T9, which had irrigation intervals of three days and achieved a value of 112.35. This value represents a percentage increase of about 38.35 % compared to the control treatment, which had no potassium (0 kg K ha^{-1}) and no boron (0 mg B l^{-1}) and attained a value of 81.03. The outcome of the T9 treatment (150 kg K ha^{-1} and 100 mg B l^{-1}) was significantly different from the control treatment. The data on Vitamin C indicates that the treatment T6, which involved irrigating every three days with 75 kg K ha-1 and 100 mg B l^{-1}, had the greatest value of 4.71. This value represents a percentage increase of 52.43 % compared to the control treatment, which had a value of 3.

3.3 IMPACT OF BORON, POTASSIUM, AND IRRIGATION INTERVALS ON TOTAL CHLOROPHYLL

The chlorophyll content level indicates the extent of photosynthetic activity in the cabbage plant. The data presented in Figure 3 demonstrates that a three-day interval of irrigation increased chlorophyll content. Furthermore, the use of potassium and boron further enhanced the elevation. The highest value of (236.33 mg 100 g^{-1} FM) occurred at T8, with a percentage increase of about 66.82 % compared to the control treatment, which yielded a value of 141.67 mg 100 g^{-1} FM. This observation was made at three-day intervals of irrigation. However, there was no substantial difference between T8 and T7 and T9. The lowest achievable value was attained at T1, representing the control treatment with no potassium (0 kg K ha^{-1}) and no boron (0 mg B l^{-1}). The T6 treatment, with irrigation intervals of three days, reached the greatest value of 181.33 mg 100 g^{-1} FM, which was a 34.00% increase compared to the control treatment's value of 135.33 mg 100 g^{-1} FM. The T6 treatment had a potassium concentration of 75 kg ha^{-1} and a boron concentration of 100 mg l^{-1}. Nevertheless, the chlorophyll content was influenced by the amount of irrigation over three days, as the application of potassium and boron led to a gradual increase in chlorophyll content. The irrigation interval of six days did not show a significant difference between the application of potassium and boron, and it resulted in lower values compared to the three-day irrigation interval.

3.4 RELATIONSHIP BETWEEN TOTAL CABBAGE YIELD AND SOIL NITROGEN, PHOSPHORUS, AND POTASSIUM, FOR THREE AND SIX IRRIGATION INTERVAL DAYS UTILIZING LINEAR REGRESSION

The primary aim of this study is to evaluate the potential influence of different parameters on yield productivity. This can be achieved by analyzing the correlation between the response variable, which is the total cabbage yield, and the explanatory variables or predictors, including soil nitrogen concentration (Total nitrogen NO_3^- and NH_4^+), soil phosphorus, and soil potassium (Fig 4 A-C). When soil nitrogen levels increased, the overall yield improved throughout a three-day irrigation cycle. Not-

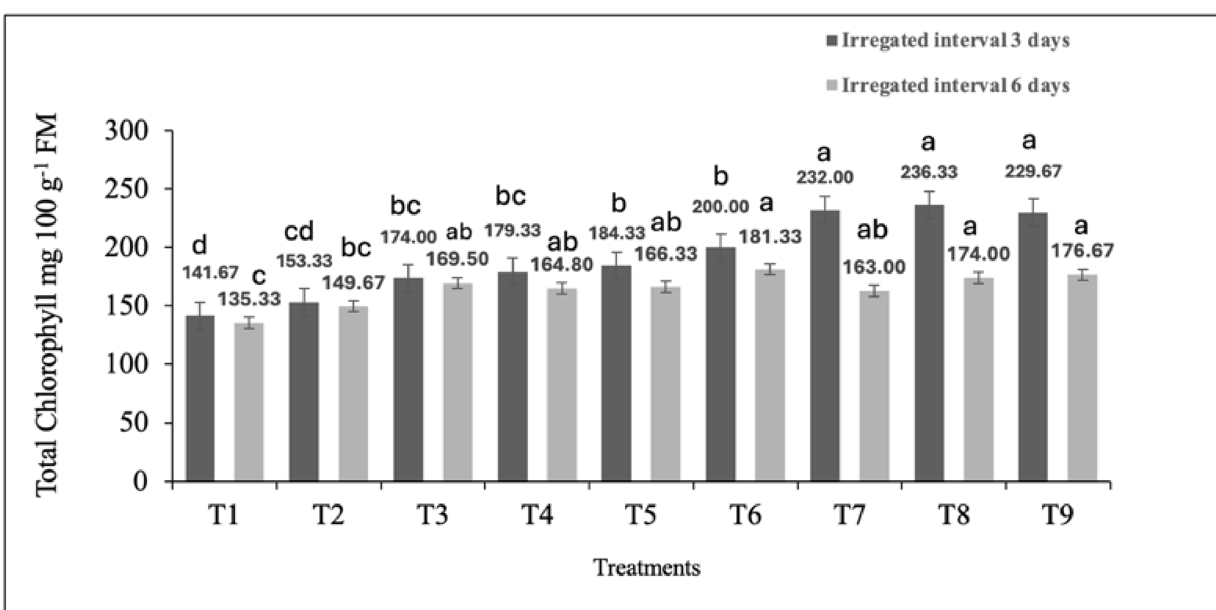

Figure 3: Effect of irrigation intervals, potassium, and boron on total chlorophyll. The different letters denote significant differences among the mean values of treatments.

withstanding the coefficient of determination (R^2) being relatively low at 0.23, there was still a strong correlation between the responsive variable and soil nitrogen. The results of the six-day irrigated interval indicate that the linearity was enhanced, as seen by the increase in R^2 to a value of 0.44. Figure 4.b. illustrates the correlation between the dependent variable (Total yield) and the independent variable (soil phosphorus concentration). The coefficient of determination (R^2) was found to be 0.50 for three-day irrigated intervals, while it was 0.59 for six-day irrigated intervals. The soil phosphorus and total yield showed improvement at a six-day irrigation interval, but there was no significant difference. In contrast, the results from a three-day irrigation interval did reveal a significant difference in the data. The linearity in (Fig 4 C) demonstrates a strong correlation between the response variable (Total yield) and the explanatory variable

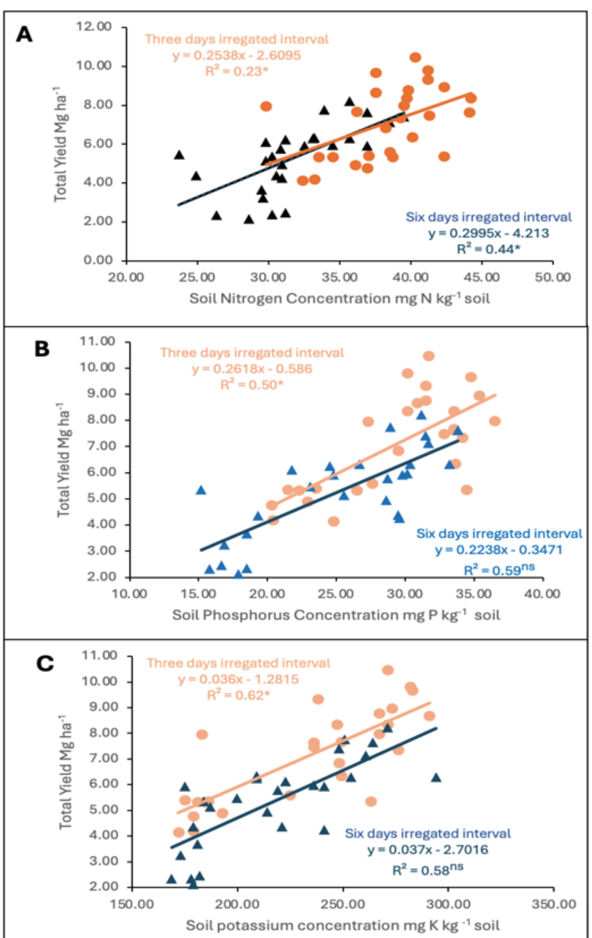

Figure 4: The relationship between cabbage total yield and (A.) soil nitrogen concentration. (B.) soil phosphorus concentration. (C.) soil potassium concentration for three and six irrigation interval days. The significant level is 0.05.

(soil potassium content). This correlation obtained an R^2 value of 0.62 at a three-day irrigation interval, and there was a significant difference noticed between the two variables. In contrast, the data did not show a significant difference when analyzed at six-day intervals. The coefficient of determination was calculated to be $R^2 = 0.58$. Nevertheless, the content of phosphate and potassium in the soil had a greater impact on the overall yield of cabbage, as indicated by the coefficient of determination for both irrigation intervals.

3.5 RELATIONSHIP BETWEEN TOTAL CABBAGE YIELD AND LEAF NITROGEN, PHOSPHORUS, POTASSIUM, AND BORON FOR THREE AND SIX IRRIGATION INTERVAL DAYS UTILIZING LINEAR REGRESSION

The (Figure 5 A-D) illustrates the correlation between leaf nitrogen, phosphorus, potassium, and boron and the total cabbage production. Figure 5a demonstrates a strong linear relationship between total yield and leaf nitrogen concentration. The coefficient of determination for the irrigated interval dates is 0.28 and 0.38, respectively. Although the coefficient of determination did not exhibit a significant disparity, it maintains value for irrigation intervals of three and six days. There was no significant difference in leaf phosphorus concentration when the plants were irrigated every three days. Additionally, the relationship between the total yield and leaf phosphorus concentration was not clear enough to provide significant details, on irrigation interval, as depicted in Figure 5b. The cabbage yield was strongly correlated with the concentration of potassium in the leaves at three and six intervals of irrigation ($R^2 = 0.36$ and $R^2 = 0.43$) (Figure 5 C). The coefficient of determination ($R^2 = 0.43$) showed a significant difference between the six irrigation interval days and the three three-day irrigation intervals, with the former having a higher coefficient of determination. The relationship between the total yield and leaf boron content is elucidated in (Fig. 5.D). The cabbage results were not significantly affected by the leaf boron content, regardless of the application of boron to the plants during both irrigated dates.

4 DISCUSSION

Numerous studies have consistently demonstrated the importance of irrigation schedules, along with the application of potassium and boron, for the long-term sustainability of crops (Al-Lami et al., 2023; Burhan and AL-Hassan, 2019; Saaseea and Al-a'amry, 2023; Sulaiman

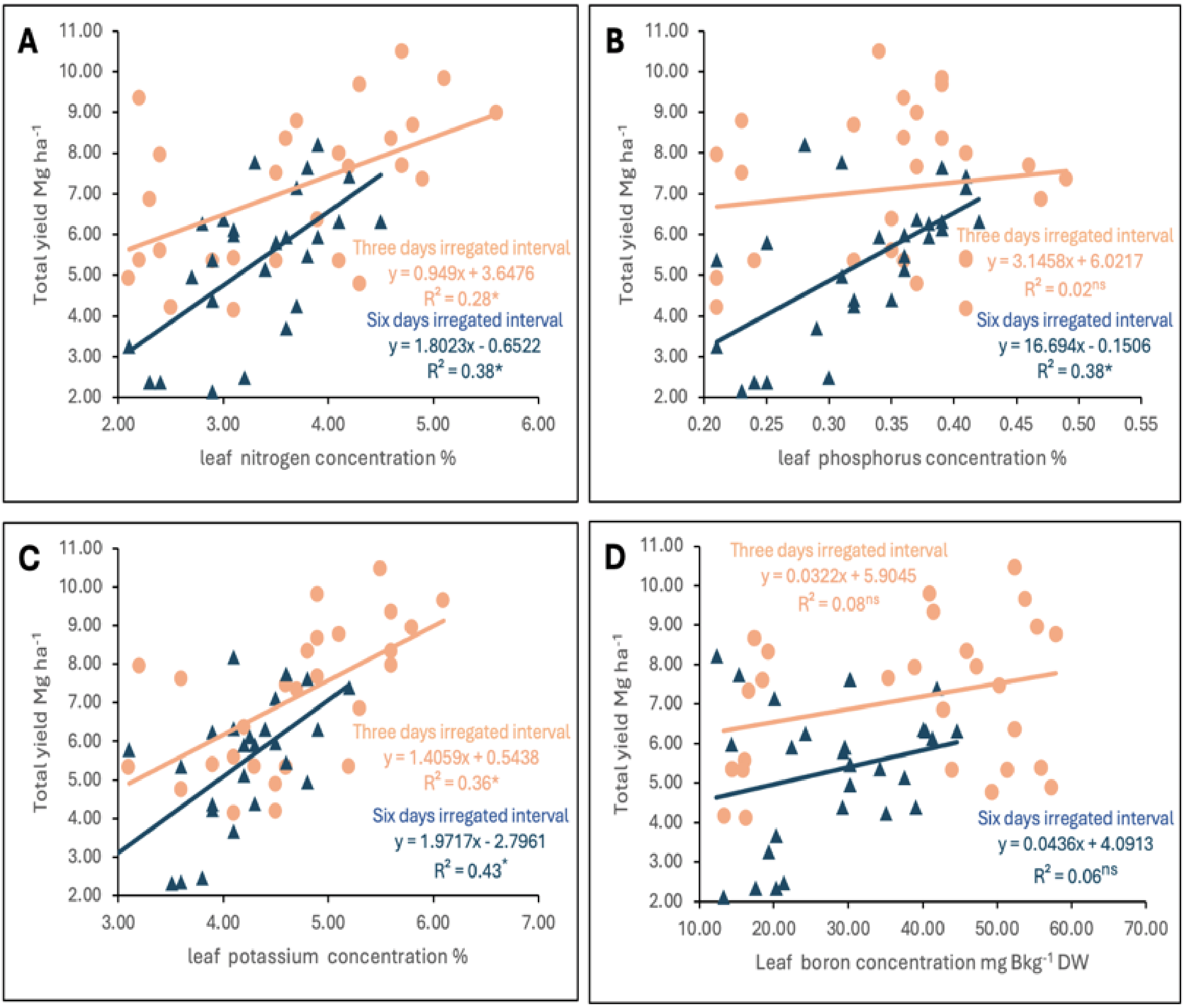

Figure 5: The relationship between (A.) leaf nitrogen concentration, (B.) leaf phosphorus concentration, (C.) leaf potassium concentration, and (D.)leaf boron concentration, and cabbage total yield. the significant level is 0.05.

and Sadiq, 2020). Effective soil-water-nutrient management may efficiently regulate crop needs uniformly across agricultural areas, without being influenced by spatial differences in soil-water-nutrient levels and crop water and nutrient demands (Dhannoon et al., 2020; Dizayee and Saleh, 2017; Khattab et al., 2019; Al-Ubaydi et al., 2017; Yadav et al., 2023. The present study found that the content of antioxidants such as proline, peroxidase, and carotene increased when the irrigation interval increased from 3 days to 6 days. The highest values were obtained at T1 for all antioxidants (Fig 1 A, B, and C), these results corresponded to the observations obtained by El-beltagi et al. (2020) who reported an elevation in antioxidant enzyme activity, non-enzymatic antioxidant levels, and proline in crops under stress. This phenomenon can occur as a result of crops producing enzymatic and non-enzymatic antioxidants that aid in reducing oxidative damage and improving crop yield and resilience to drought. Farrag et al. (2021) observed similar findings, attributing the increases in yield, vitamin C content, and total soluble solids % to sufficient water availability. They also suggested that this could enhance nutrient availability and therefore improve nutrient uptake. In contrast, deficit irrigation decreases cell formation, extension, and growth in plant elements such as roots, stems, and leaves. This can happen as a result of a decrease in the movement and absorption of nutrients, as well as a delayed uptake of nutrients through the roots due to the absence of the carrier factor, namely water (Al-Wasel and El-Rayes, 2024; Jasim et al., 2020). Applying high levels of potassium during a three-day irrigation period, which was the shorter interval, could result in a significant decrease in total crop production and a substantial increase in antioxidant content (Al-Wasel and El-Rayes, 2024). The greatest values of catalase enzyme, vitamin E, and vitamin C were obtained with T1, T1, and T6, where the values were 27.50 units g^{-1} FM, 125.86, and 6.05, respectively (Fig 2 A, B, and C). The application of potassium and boron can contribute to a drop in antioxidants, as the plant's roots can uptake more nutrients and water from the soil. Nevertheless, the limited supply of irrigated water can potentially lead to an increase in root length as a means to search for water and nutrients (Riaz et al., 2021). However, total chlorophyll increased with the longer irrigation interval. Furthermore, T7 treatment achieved the highest value at the six-day irrigation interval (236.33 mg 100 g^{-1} FM) (Fig 3). This phenomenon can be attributed to the application of potassium, which regulates the turgor pressure and perhaps enhances cell division, expansion, and the growth of meristematic tissues(Riaz et al., 2021). Adding boron has been found to increase root length, root hair, and development (Wang et al., 2021). Boron treatments can enhance the production of specific stress-related genes that are crucial for safeguarding crops. The study's findings are consistent with the research conducted by Akhtar et al. (2022). Optimal irrigation and nutrition play a crucial role in improving agricultural productivity, maintaining cell structures, and enhancing crop metabolisms (Anokye et al., 2021; Jasim et al., 2020; Maize et al., 2021). The correlation analysis revealed a significant impact of nitrogen on cabbage yield (Fig 4 A), particularly when using six-day irrigation intervals which attained a significant $R^2 = 0.44$, which outperformed three-day irrigation intervals. This finding corresponds to the study conducted by Terefa (2021), which indicated that the application of nitrogen fertilizer had a substantial impact on cabbage output. Specifically, the largest irrigation interval of 9 days resulted in the greatest effect. The improvement in nitrogen uptake can be attributed to the reduction in nitrogen losses caused by excessive watering, namely through the implementation of a more precise irrigation schedule. This allows for the restoration of soil nitrogen levels.

Contrary to expectations, there was no significant difference in cabbage production when the soil phosphorus content increased at a six-day watering interval (Fig 4 B). However, the results did demonstrate an increase in cabbage outcomes (Ahmed and Al-Tameemi, 2023). Soil phosphorus concentration obtained higher values at three-day irrigation interval compared with six-days interval. When the irrigation was performed every three days, there was a noticeable difference in the coefficient of determination, which led to significant crop production. This conclusion is similar to the findings reported by Farrag et al. (2021). The observed results could be attributed to the fact that phosphorus is usually considered a non-mobile or slow-moving nutrient in the soil. Consequently, the current watering schedule does not facilitate its absorption by plants, as reported by Onkoba et al. (2021).

A consistent correlation was observed between soil potassium levels and cabbage yield at both irrigation intervals (Fig 4 C). The linear regression between soil potassium concentration and total cabbage yield significantly differed at three days irrigation interval ($R^2 = 0.62$). The six-day irrigation interval did not present a significant coefficient of determination ($R^2 = 0.58$). This finding coincides with the research conducted by Yadav et al. (2023), which suggests that the increase in soil potassium availability can be ascribed to the increase in irrigation water.

Furthermore, this research denoted that the total yield at three-day irrigation interval was ultimately responsive to nitrogen, phosphorus, potassium, and boron concentrations in the leaves (Fig 5 A, B, C, and D). However, the nutrient content of cabbage leaves, specifically nitrogen, phosphorus, potassium, and boron, increased when the irrigation schedule was reduced. More specifically, when irrigation was applied once every three days, there was a valuable association, and a significant difference compared to irrigation performed every six days. This can be attributed to the increase in water availability, which would enhance the absorption of nutrients.

5 CONCLUSIONS

The current study exhibited that applying potassium and boron with a three-day irrigation interval positively impacted cabbage yield. The cabbage irrigation schedules, and potassium and boron applications impacted antioxidant enzymes and some vitamins, such as E and C. From the results, antioxidant enzymes increased with less frequent watering, this is one of the plant's defense systems against drought stress. Moreover, the data showed that total chlorophyll increased with a six-day irrigation interval, potassium application, and boron spray. In particular, the highest total chlorophyll was attained with T7 treatment at the six-day irrigation interval (236.33 mg 100 g^{-1} FM). The linear regression results revealed that soil test potassium achieved the highest significant $R^2 = 0.62$ at the three-day irrigation interval compared to the non-significant R^2 achieved at the six-day interval. The concentration of nitrogen, phosphorus, potassium, and boron in the cabbage leaves increased with the longer irrigation interval. However, boron concentration did not achieve a significant coefficient of determination or effect on total cabbage yield.

To recap the findings of this research, increasing the irrigation interval for a while with a drought-tolerant plant can mitigate the water needed in the arid and semi-arid areas that have water availability issues due to climate change, such as high ambient temperature, rain amount reduction, dry winds, etc. Thus, growers, large agrarian farmers, and investors must utilize these techniques with drip irrigation systems or other regimes, followed by applying appropriate fertilizer to increase the nutrient concentration, which is reflected in the crop yield. For further information, we encourage farmers and researchers to use various fertilizer applications with different irrigation schedules and crops.

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