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Influence of agriculture sulphur and boron on growth and productivity of red beet (*Beta vulgaris* L.)

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Abstract

Two filed experiments were conducted during 2018/2019 and 2019/2020 in a private farm, Sennouris district, Fayoum, Egypt, to study the effect of sulphur and boron on morphological characteristics, plant water status (RWC and MSI), leaf photosynthetic pigments content, leaf N, P, K, S and B contents and yield and its segments of red beet plants (*Beta vulgaris* L.). The experimental design used was a split-plot in randomized complete blocks design with three replications. Two agricultural Sulphur (95% S) levels (0 and 150 kg fed^{-1}) were distributed in the main plots, while boron concentrations (0,50, 100, 200, 300 and 400 ppm) were randomly allocated to the sub-plots. Each experimental unit covered an area of 16.8 m^2. During soil preparation, sulphur was broadcasted, while boron concentrations were foliarly applied to run off, three times; 30, 45 and 60 days after seed sowing. Soil supplemented with 150 kg fed^{-1} sulphur gave the highest significant values on previously mentioned measurements as compared to soil without sulphur treatment, except leaf area leaf^{-1}. Whereas, Soil supplemented with sulphur showed a decreased level of leaf chlorophyll b and roots yield fed^{-1} for < 4 cm diameter. Foliar application of boron at 200 ppm was significantly recorded higher mean values of previously mentioned measurements as compared to other concentrations. While foliar spraying with boron at concentration of 50 ppm gave higher values in number of roots for < 4 cm diameter per 1 m^2 and the concentration of 400 ppm boron was given higher mean values in fresh weight of roots fed^{-1} for < 4 cm diameter.

Key Words: *Beta vulgaris* L., Sulphur, Boron, Morphological characters, Membrane permeability (RWC and MIS), Leaf photosynthetic pigments, Leaf N, P, K, S and B contents and yield and its segments.

Introduction

The red beet, *Beta vulgaris* is a plant in the Chenopodiaceae family. It is best known in its numerous cultivated varieties, the most well-known of which is the purple root vegetable known as beetroot or table garden beet. Beetroot can be eaten raw, used for juice extraction, baked or boiled. Red beets are delicious roasted, pickled, eaten in salads, or made into soup. In contrast to fruits, the main sugar in beetroot is sucrose **(Babarykin et al., 2019)**. Red beets have been used in traditional medicine for hundreds of years to treat constipation, gut and joint pain, dandruff **(Hamedi and Honarvar, 2018)**.

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Sustainability of environmental quality and food production remains threatened by alkaline soil of agricultural lands due to climate change and poor agricultural practices. Improving alkaline affected soils is a major challenge that must be met before plant production in these regions can be feasible. Therefore, in arid environments, including Egypt, suffer from high pH and the unavailability of essential nutrients, including sulphur (S), as well as low fertility and poor structure (**Osman and Rady, 2012; Mekdad and Rady, 2016**). For such soils, the application of sulphur may assist in eliminating soil alkalinity during biological S oxidation, and it could enhance crop yield and quality. It is essential for the desired plant growth because it is a component of many key coenzymes and amino acids, such as methionine and cysteine, which are required for the production of structural proteins, and is concerned with the synthesis of chlorophyll, some vitamins, proteins, and carbohydrates (**Willenbrink, 1967; Thomas et al., 2000; Mekdad et al., 2021**).

Severe problems may result from a boron deficiency when the soil pH is above 6, boron is not readily available for plant growth as is the case in Egyptian soils **(Osman & Rady, 2012; Mekdad & Rady, 2016)**. The most frequent nutrient deficiency encountered in cultivated red beets is boron deficiency. Boron deficiency results in stunted plants, the deformation and death of the growing point, and slow growth **(Nottingham, 2004)**. Boron was found to reduce the severity of many diseases because of the function, which boron has on cell wall structure, plant membranes and plant metabolism **(Dordas, 2008)**, and its deficiency caused some diseases **(Томсон, Троу, 1982)**. Boron deficient beets had brown tops and roots were rough, scabby, and off colour **(Gupta, Cutcliffe, 1985).** Also, boron plays important functions in red beet as maintaining the balance between sugar and starch; translocation of sugar and carbohydrates, standard cell division, nitrogen metabolism and protein formation, and cell wall configuration **(Kobayashi et al., 2004)**. Also, it plays a main roles in the correct function of cell membranes and the transport of K+ to guard cells to the internal water balance control system **(Camacho & Gonzalez, 2007)**.

In view of the above-mentioned reports, it has been assumed that the integral application of sulfur and boron could mitigate the harmful effects of the soil pH is above 7 on the growth and productivity of red beet plants. Accordingly, the present work was designed with the objective to evaluate the potential beneficial effects of sulphur on decreasing soil pH enhance the availability of microelements and/or boron and consequently improve growth and productivity of *Beta vulgaris* plants. The study also aimed to establish a relationship between the positive changes in the contents of leaf photosynthetic pigments nutrients and the improvement in plant performance (growth and yields) in defected soil.

Materials and Methods

Physical and chemical properties of soil

Prior to the initiation treatment and on 75 day after soil treatment of each season, soil samples to 25 cm depth were collected to identify some physical and chemical properties of the experimental site. Soil samples were analyzed at Soil Testing Laboratory, Faculty of Agriculture, Fayoum University according to the standard published procedures **(Wilde et al., 1985)** and the results were presented in Table 1.

Table 1. Some physical and chemical characteristics of the experimental soil before treatment and on day-75 after treatment in 2018/2019 and 2019/2020 seasons.

Properties	2018/2019		2019/2020	
	Before	After	Before	After
Physical properties				
Clay (%)	52.6	52.7	52.9	52.7
Silt (%)	21.7	21.8	21.8	21.7
Sand (%)	25.7	25.5	25.3	25.6
Soil texture	Clay	Clay	Clay	Clay
Chemical properties				
pH	7.70	7.11	7.63	7.02
ECe (dsm^{-1})	4.31	3.89	4.23	3.66
Organic matter (%)	2.2	3.0	2.5	3.2
Ca CO_3 (%)	4.53	4.14	4.38	4.13
N (%)	0.54	0.84	0.66	1.04
B (ppm)	0.11	0.19	0.14	0.22
Available elements (mg kg^{-1} soil):				
P	45.3	55.4	50.8	61.8
K	318.2	342.4	327.5	456.8
B	4.01	4.86	4.33	5.43
Zn	0.74	0.97	0.80	1.03
Fe	3.57	4.21	3.63	4.53
Mn	7.81	8.55	8.10	8.97
Soluble cations (meq·100g^{-1} soil)				
SO^{--4}	1.23	2.02	1.36	2.19

Field experiments

Treatments comprised of soil application of 150 kg agricultural sulphur (95% S) fed^{-1} during soil preparation as well as untreated soil (control). In addition six concentrations of boron; 0, 50, 100, 200, 300 and 400 ppm as water-soluble B (Boric acid 17.2% B) was applied as foliar application to run-off, three times; 30, 45 and 60 days after seed sowing. Few drops of salient film were added to the spraying solution as a wetting agent. The experimental layout was a split-plot system in a randomized complete blocks design with three replications. agricultural sulphur (95% S) with two levels (0 and 150 kg fed^{-1}) were distributed in the main plots whilst, boron concentrations (0,50,100, 200, 300 and 400 ppm) were randomly allocated to the sub-plots. In order to protect against side effects, each two adjacent experimental unites (sub plot) were separated by 1.4 m alley. Imported seeds of red beet cv. Deitroit Superene were hand sown in the field, on two side of the ridges, sowing date was September 24 and 26 in both seasons 2018/2019 and 2019/2020, respectively. Plots were seeded in excess and after complete emergence were thinned to achieve in row spacing of 5 - 7 cm between plants. Each experimental unit was planned to cover an area of 16.8 m^2 including 6 rows of 4 m long and 0.7 m wide. Every experimental unites received recommended doses from N, P_2O_5 and K_2O at 50, 30 and 12 Kg fed^{-1}, orderly for red beet. The respective forms of N, P_2O_5 and K_2O were ammonium nitrate (33%

N), calcium superphosphate (15.5% P_2O_5) and potassium sulphate (48% K_2O), were applied, respectively. Calcium superphosphate was broadcasted during soil preparation, whilst ammonium nitrate and potassium sulphate were side banded at two equal portions; 4 and 8 weeks after seed-sowing date for red beet. All other agro-management practices such as cultivation, irrigation and pests control were performed whenever it was necessary and as recommended in the commercial production of red beet according to MLAR (Market-Led Agrarian Reform).

Plant sampling

In each experimental unit, plants of the two outer rows were allocated for morphological characters, plant water status, leaf photosynthetic pigments content, leaf N, P, K, S and B contents. While the four inward rows were chosen to calculate yield and its parts. Seventy- five days after sowing, 10 plants were haphazardly selected, in every test unite.

Data Recorded

Morphological characters; Canopy plant samples were classified into leaf-blades and plant stems were including leaf-petioles. The following morphological characters were measured; plant height (cm), leaves dry weight plant^{-1} (g), number of leaves plant^{-1}, leaf area plant^{-1} (cm) was measured using leaf-blades weight relationship as illustrated by **Taha and Osman (2018),** leaf area leaf^{-1} (cm).

Membrane permeability; Relative water content (RWC %) was calculated using the formula introduced by **Hayat et al. (2007)** and modified by **Osman and Rady (2014)** as follows: RWC (%) = [(FM - DM) / (TM - DM)] ×100, and Membrane stability index (MSI %) was calculated according to the following formula that mentioned by **Sairam (1994):** MSI (%) = [1 - (EC_1/ EC_2)] × 100.

Leaf N, P, K, S and B contents: Leaf samples from five randomly selected plants, in each experimental unit, were collected, washed with tap water, rinsed three times with distilled water and dried at 70°C in a forced-air oven till constant weight to measure: leaf N content (mg g^{-1} DW) was colorimetrically determined by using the technique of **Hafez and Mikkelsen (1981**). Leaf P content (mg g^{-1} DW) was colorimetrically estimated according to the stannous molybdate chloride method as illustrated in **A. O. A. C (1995).** Leaf K content (mg g^{-1} DW) was photometrically measured using Flame photometer as mentioned by **Wilde *et al.* (1985).** Leaf S content (mg g^{-1} DW) was measured by atomic absorption spectrophotometer (Analyst 300, Perkin-Elmer, Germany) by **Page et al. (1982).** Leaf B content (mg g^{-1} DW) was determined using an inductively coupled plasma spectrophotometer (Optima 2100 DV, ICP/OES; Perkin-Elmer, Shelton, CT, USA) by **Mertens (2005).**

Yield and its segments; Beet root yields were harvested and measured 120 days after sowing from area of 1.5 m from middle row (0.7 m wide × 1.5 m long = 1 m^2) from middle row. The roots were classified according to root diameter into three classes: < 4, 4 - 8 and > 8 cm. Roots less than 2 cm in diameter were not counted. The following data were recorded: Number of roots for three classes in 1m^2 and roots yield (ton) for three classes in fed^{-1}.

Statistical analysis; All data were subjected to analysis of variance (ANOVA) for a split-plot system in a randomized complete blocks design, after testing for homogeneity of error variances according to the procedure outlined by **Gomez and Gomez (1984)** using **InfoStat software estadistico (2016).** Significant differences between treatments were compared at $P \leq 0.05$ by Duncan's multiple range test.

Results and Discussion:

Morphological Characters

The supplemented soil with 150 kg fed^{-1} sulphur significantly increased plant height, leaves dry weight plant^{-1}, number of leaves plant^{-1} and leaf area plant^{-1} of beet plants as compared to soil without sulphur (Table 2), and the trend was parallel in both years. While, the leaf area leaf^{-1}, was not significantly affected, in both seasons. Generally, increasing foliar application of boron concentration from 0 to 200 ppm increased plant height, leaves dry weight plant^{-1} number of leaves plant^{-1} and leaf area plant^{-1}, but the leaf area leaf^{-1} increased with increasing foliar application of boron concentration up to 300, and the trend was parallel in both experimental seasons. The treatment combination of soil supplemented with 150 kg fed^{-1} sulphur together with foliar application of boron at 200 ppm recorded the higher values of plant height, leaves dry weight plant^{-1} number of leaves plant^{-1} and leaf area plant^{-1}. While, leaf area leaf^{-1} the best-combined treatment was without sulphur and boron, in both season.

Table 2. Effect of supplemented soil with sulphur and foliar application with boron on morphological characters of red beet.

Treatment		Plant height (cm)		Leaves dry Weight plant^{-1} (g)		Number of leaves plant^{-1}		Leaf area plant^{-1} (cm^2)		Leaf area leaf^{-1} (cm^2)	
Sulphur (kg fed^{-1})	Boron (ppm)	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
0		52 ^{B*}	57 ^{B}	7.60 ^{B}	8.18 ^{B}	13 ^{B}	13 ^{B}	545 ^{B}	587 ^{B}	43.2 ^{A}	43.6 ^{A}
150		58 ^{A}	63 ^{A}	8.41 ^{A}	9.04 ^{A}	15 ^{A}	16 ^{A}	613 ^{A}	660 ^{A}	40.6 ^{A}	41.1 ^{A}
	0	50 ^{E}	54 ^{E}	7.39 ^{D}	7.95 ^{D}	13 ^{D}	14 ^{D}	519 ^{D}	555 ^{C}	41.1 ^{C}	41.2 ^{C}
	50	55 ^{C}	60 ^{C}	8.12 ^{C}	8.74 ^{C}	14 ^{B}	15 ^{B}	603 ^{C}	648 ^{B}	42.4 ^{BC}	43.0 ^{BC}
	100	58 ^{B}	63 ^{B}	8.62 ^{B}	9.25 ^{B}	15 ^{B}	15 ^{B}	616 ^{B}	662 ^{B}	42.5 ^{BC}	43.1 ^{ABC}
	200	61 ^{A}	66 ^{A}	9.22 ^{A}	9.90 ^{A}	15 ^{A}	16 ^{A}	656 ^{A}	712 ^{A}	43.5 ^{AB}	44.5 ^{AB}
	300	54 ^{C}	59 ^{C}	8.19 ^{C}	8.83 ^{C}	14 ^{C}	15 ^{C}	604 ^{BC}	652 ^{B}	44.4 ^{A}	45.0 ^{A}
	400	52 ^{D}	57 ^{D}	6.50 ^{E}	6.99 ^{E}	13 ^{D}	14 ^{D}	476 ^{E}	510 ^{D}	37.3 ^{D}	37.5 ^{D}
0	0	45 ^{i}	50 ^{h}	7.07 ^{g}	7.62 ^{g}	11 ^{g}	12 ^{e}	520 ^{g}	557 ^{g}	46.2 ^{a}	46.0 ^{a}
	50	52 ^{g}	58 ^{f}	7.76 ^{ef}	8.35 ^{ef}	13 ^{ef}	14 ^{d}	548 ^{f}	592 ^{f}	43.0 ^{bcd}	43.8 ^{ab}
	100	55 ^{e}	60 ^{de}	8.08 ^{d}	8.70 ^{d}	13 ^{def}	14 ^{cd}	562 ^{ef}	604 ^{ef}	43.4 ^{bcd}	43.9 ^{ab}
	200	56 ^{d}	61 ^{cd}	8.43 ^{c}	9.04 ^{c}	14 ^{cd}	14 ^{c}	597 ^{d}	646 ^{d}	43.9 ^{bcd}	44.7 ^{ab}
	300	52 ^{g}	57 ^{f}	7.86 ^{e}	8.46 ^{e}	13 ^{ef}	14 ^{cd}	573 ^{e}	619 ^{e}	44.7 ^{ab}	45.3 ^{ab}
	400	50 ^{h}	55 ^{g}	6.41 ^{i}	6.89 ^{i}	12 ^{f}	13 ^{d}	471 ^{h}	503 ^{h}	38.0 ^{e}	38.1 ^{c}
150	0	54 ^{ef}	59 ^{ef}	7.71 ^{f}	8.27 ^{f}	14 ^{c}	15 ^{b}	518 ^{g}	553 ^{g}	36.1 ^{e}	36.4 ^{c}
	50	58 ^{c}	63 ^{c}	8.49 ^{c}	9.12 ^{c}	16 ^{b}	17 ^{a}	659 ^{b}	705 ^{bc}	41.8 ^{cd}	42.1 ^{b}
	100	61 ^{b}	67 ^{b}	9.16 ^{b}	9.81 ^{b}	16 ^{ab}	17 ^{a}	670 ^{b}	720 ^{b}	41.6 ^{d}	42.4 ^{b}
	200	65 ^{a}	70 ^{a}	10.00 ^{a}	10.75 ^{a}	17 ^{a}	18 ^{a}	716 ^{a}	777 ^{a}	43.1 ^{bcd}	44.3 ^{ab}
	300	56 ^{d}	61 ^{cd}	8.52 ^{c}	9.20 ^{c}	14 ^{c}	15 ^{b}	634 ^{c}	685 ^{c}	44.1 ^{abc}	44.7 ^{ab}
	400	53 ^{fg}	58 ^{ef}	6.58 ^{h}	7.08 ^{h}	13 ^{de}	14 ^{cd}	481 ^{h}	517 ^{h}	36.6 ^{e}	36.9 ^{c}

*Values marked with the same letter(s) within the main and interaction effects are statistically similar using Duncan's multiple range test at P = 0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

The enhancing effect of agricultural sulphur soil incorporation on morphological characteristics of beet plants compared to soil without sulphur (Table 2) may be attributed to the ability of sulphur to decrease soil pH compared to the soil without sulphur (Table1).

This decreasing in soil pH improves the availability of macro and microelements and improves the chemical properties of alkaline soils as shown in Table 1. Thus, all leading to increase in the absorption of nutrients N, P, K, S and B when an application soil supplemented with 150 kg fed^{-1} agricultural sulphur compared to control (Table 5). Sulphur is essential for the desired plant growth because it is a component of many key coenzymes and amino acids, such as methionine and cysteine, which are required for the production of structural proteins, and is concerned with the synthesis of chlorophyll, some vitamins, proteins, and carbohydrates (**Willenbrink, 1967; Thomas et al., 2000; Mekdad et al., 2021**). In turn, this may have led to an increase in photosynthetic efficiency (Table 4) and RWC, MSI (Table 3), also increase in vital physiological processes efficiency within plant cells thus; this was reflected in the increased growth of red beet plants (Table 2). Many other reports support our obtained results such as **Awad et al. (2013), Tawfic et al. (2014) and Mekdad et al. (2021) on beet, and Osman and Rady (2012**) on pea plants, **Osman and El-Shatoury (2014)** on pumpkin plants.

The enhancing effect of boron on morphological characters of red beet plants (Table 2) might be due to easier availability of optimum boron dose to plant resulted in better absorption and subsequent conversion into metabolic products whose accumulation culminates in more plant height. Which, might aid in various biological activities like cell division and cell elongation **(Huang et al.,** About ninety percent of boron content in plant is localized in the cell wall fraction (**Blevins and Lukaszewski, 1998).** Also, boron is involved in cell wall and cell membrane's structural and functional integrity, ion fluxes (H^+, K^+, PO_4^{3-}, Rb^+ and Ca^{2+}) across membranes, cell division and elongation, nitrogen and carbohydrate metabolism, sugar

2014). Also, it is involved in ion fluxes (H^+, K^+, PO_4^{3-}, Rb^+ and Ca^{2+}) across membranes, nitrogen and carbohydrate metabolism, sugar transport, cytoskeletal proteins and plasmalemma-bound enzymes, nucleic acid, indole acetic acid, polyamines, ascorbic acid and phenol metabolism and transport **(Shireen et al., 2018)**. In addition, foliar application of boron promoted plant growth by increasing RWC, MSI (Table 3) and leaf photosynthetic pigments (Table 4).

Plant water status

In both seasons, agricultural sulphur supplementation, significantly attained higher values of RWC% and MSI% than untreated plants (Table 3), and the trend was parallel in both experimental seasons. Foliar application of boron at 200 ppm, significantly, attained higher values of RWC% and MSI% than other concentrations boron, in both years. The treatment combination of 150 kg fed^{-1} agricultural sulphur with 200 ppm boron foliar application recorded the higher values of the membrane permeability, in both seasons.

Higher RWC and MSI values were observed in red beet plants treated with sulphur and boron than control (Table 3) this indicates that sulphur and boron reflected positive effect on water uptake or reduced water loss, which consequently causes increase in leaf water potential. This may be attributed to soil application of sulphur in turn lowers soil pH compared to the soil without sulphur (Table 1) promoting nutrient uptake notably N, P, K, S and B (Table 5), this reflected in an enhanced plant water status.

transport, cytoskeletal proteins and plasmalemma-bound enzymes, nucleic acid, indole acetic acid, polyamines, ascorbic acid and phenol metabolism and transport **(Brown, et al. 2002 and Shireen et al., 2018).** Optimum B concentration enhances the plasma membrane hyperpolarization, while B deficiency alters the membrane potential and reduces H^+-ATPase activity **(Goldbach and Wimmer, 2007).** In addition, **Camacho and Gonzalez (2007)** said that the boron plays a main roles in the correct function of cell membranes and the transport of K^+ to guard cells to the internal water balance control system. This led to an improvement in enzymatic antioxidants assays helps to maintain the turgor of plant cells **(Osman and Rady, 2012 and Osman and El-Shatoury, 2014)**. All that were reflected in an enhancing the permeability of root cell membranes of red beet plants favouring those physiological processes that enable plants to overcome the adverse conditions in alkaline soils.

Table 4. Effect of sulphur-supplemented soil and foliar application with boron plant water status of red beet.

Treatment		MSI (%)		RWC (%)	
Sulphur (kg fed^{-1})	Boron (ppm)	2019	2020	2019	2020
0		72.1 ^{B}	74.6^B	82.7 ^{B}	85.4 ^{B}
150		74.9 ^{A}	77.3 ^{A}	85.8 ^{A}	88.5 ^{A}
	0	72.2 ^{C}	74.6 ^{C}	83.3 ^{C}	85.7 ^{C}
	50	74.4 ^{B}	77.0 ^{B}	85.2 ^{B}	88.2 ^{B}
	100	75.2 ^{B}	78.0 ^{B}	85.6 ^{B}	88.2 ^{B}
	200	76.4 ^{A}	79.2 ^{A}	87.5 ^{A}	90.3 ^{A}
	300	73.0 ^{C}	74.9 ^{C}	82.9 ^{C}	85.8 ^{C}
	400	69.7 ^{D}	72.0 ^{D}	81.0 ^{D}	83.5 ^{D}
0	**0**	70.5 ^{e}	73.0 ^{f}	81.1 ^{e}	83.2 ^{e}
	50	72.3 ^{d}	75.0 ^{de}	84.3 ^{cd}	87.4 ^{bc}
	100	73.7 ^{c}	76.2 ^{cd}	84.5 ^{cd}	87.3 ^{bc}
	200	74.6 ^{c}	77.4 ^{c}	86.1 ^{b}	89.2 ^{b}
	300	72.2 ^{d}	74.7 ^{e}	82.1 ^{e}	84.8 ^{de}
	400	69.3 ^{e}	71.5 ^{g}	77.9 ^{f}	80.4 ^{f}
150	**0**	73.9 ^{c}	76.2 ^{cd}	85.5 ^{bc}	88.3 ^{bc}
	50	76.4 ^{b}	79.1 ^{b}	86.2 ^{b}	89.0 ^{b}
	100	76.8 ^{b}	79.8 ^{ab}	86.6 ^{b}	89.1 ^{b}
	200	78.2 ^{a}	81.1 ^{a}	88.8 ^{a}	91.4 ^{a}
	300	73.7 ^{c}	75.1d ^{e}	83.8 ^{d}	86.8 ^{c}
	400	70.2 ^{e}	72.6 ^{fg}	84.1 ^{cd}	86.6 ^{cd}

*Values marked with the same letter(s) within the main and interaction effects are statistically similar using Duncan's multiple range test at P = 0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

Leaf photosynthetic pigments content

Application of soil with 150 kg fed^{-1} sulphur gave the highest significant values in leaf chlorophyll a, a+b and carotenoids comparing to control (Table 4), but the soil application of sulphur significant decreased leaf chlorophyll b. While, Boron application with 200 ppm gave the highest significant values in leaf chlorophyll a, b, a+b and carotenoids contents and the trend was parallel in both years. Generally, the best-combined treatment was sulphur-supplemented medium at 150 kg fed^{-1}

with boron at 200 ppm gave the highest significant values in leaf chlorophyll a, a+b and carotenoids contents. While, the interaction between soil without sulphur and zero of foliar application of boron (control treatment) gave the highest value of leaf chlorophyll b.

In the experimental site soils, which are characterized by a rise in pH, application of 150 kg fed^{-1} sulphur reduced soil pH values by the oxidation of sulphur to sulphate through various species of soil microorganisms (Table 1) and many other reports support our obtained results such as **Osman and Rady (2012) and Osman and El-Shatoury (2014)**. This promoting nutrient uptake notably N, P, K, S and B (Table 5), also, increasing membrane permeability; WRC and MSI% (Table 3). In addition, adequate sulphur nutrition improves photosynthesis and the growth of plants **(Scherer, 2008).** Also, a larger accumulation of N maintains higher chlorophyll contents, higher activities of enzymes in the Calvin cycle **(Lawlor et al., 1989),** and enhances growth **(Khan et al., 2005)** because of the roles of S and N in cell differentiation, photosynthetic function, and the overall growth of plants **(Marschner, 1995).** In addition, the sulphur plays a vital role in chlorophyll formation as its constituent of succinyl Co-A which is involved in synthesis of chlorophyll **(Pirson, 1955).** Thus may be led to an increase in chlorophyll a concentration in Table 4, which, was reflected in the increased yield and its component of red beet plants under alkaline soils conditions (Tables 6 - 7). Many other reports support our obtained results such as **Thomas et al. (2000), Abu El-Fotoh et al. (2020) and Mekdad et al. (2021)** on beet plants**.**

Table 4. Effect of supplemented soil with sulphur and foliar application with boron on leaf photosynthetic pigments content of red beet.

Treatment		Chlorophyll (mg/mm^2 FW)						Carotenoid (mg/mm^2 FW)	
		a		b		a +b			
Sulphur (kg fed^{-1})	Boron (ppm)	2019	2020	2019	2020	2019	2020	2019	2020
0		0.187 ^{B}	0.197 ^{B}	0.249 ^{A}	0.265 ^{A}	0.436 ^{B}	0.462 ^{B}	0.70 ^{B}	0.75 ^{B}
150		0.221 ^{A}	0.231 ^{A}	0.228 ^{B}	0.243 ^{B}	0.449 ^{A}	0.474 ^{A}	0.90 ^{A}	0.96 ^{A}
	0	0.196 ^{D}	0.207 ^{D}	0.243 ^{A}	0.258 ^{A}	0.439 ^{B}	0.465 ^{B}	0.74 ^{D}	0.79 ^{D}
	50	0.201 ^{C}	0.212 ^{C}	0.238 ^{AB}	0.253 ^{AB}	0.439 ^{B}	0.465 ^{B}	0.80 ^{C}	0.85 ^{BC}
	100	0.207 ^{B}	0.219 ^{B}	0.241 ^{A}	0.256 ^{AB}	0.448 ^{A}	0.475 ^{AB}	0.84 ^{B}	0.88 ^{B}
	200	0.215 ^{A}	0.226 ^{A}	0.239 ^{AB}	0.253 ^{AB}	0.455 ^{A}	0.479 ^{A}	0.88 ^{A}	0.93 ^{A}
	300	0.207 ^{B}	0.218 ^{B}	0.240 ^{AB}	0.255 ^{AB}	0.446 ^{AB}	0.473 ^{AB}	0.80 ^{C}	0.84 ^{BC}
	400	0.195 ^{D}	0.201 ^{E}	0.233 ^{B}	0.248 ^{B}	0.428 ^{C}	0.449 ^{C}	0.77 ^{D}	0.81 ^{CD}
0	0	0.181 ^{f}	0.192 ^{g}	0.262 ^{a}	0.279 ^{a}	0.443 ^{cd}	0.470 ^{c}	0.67 ^{gh}	0.71 ^{ef}
	50	0.188 ^{e}	0.199 ^{ef}	0.252 ^{b}	0.268 ^{ab}	0.440 ^{cd}	0.467 ^{c}	0.71 ^{fg}	0.75 ^{e}
	100	0.191 ^{de}	0.202 ^{ef}	0.248 ^{b}	0.264 ^{bc}	0.439 ^{cd}	0.466 ^{c}	0.73 ^{ef}	0.77 ^{de}
	200	0.194 ^{d}	0.204 ^{e}	0.252 ^{ab}	0.268 ^{ab}	0.447 ^{bc}	0.473 ^{bc}	0.77 ^{e}	0.82 ^{cd}
	300	0.188 ^{e}	0.198 ^{f}	0.245 ^{bc}	0.261 ^{bcd}	0.433 ^{d}	0.459 ^{c}	0.70 ^{fg}	0.74 ^{e}
	400	0.177 ^{f}	0.187 ^{g}	0.237 ^{cd}	0.252 ^{cde}	0.414 ^{e}	0.439 ^{d}	0.64 ^{h}	0.68 ^{f}
150	0	0.211 ^{c}	0.223 ^{c}	0.223 ^{f}	0.238 ^{f}	0.435 ^{d}	0.460 ^{c}	0.82 ^{d}	0.86 ^{c}
	50	0.214 ^{c}	0.226 ^{c}	0.224 ^{ef}	0.239 ^{f}	0.439 ^{cd}	0.464 ^{c}	0.89 ^{c}	0.94 ^{b}
	100	0.224 ^{b}	0.236 ^{b}	0.234 ^{de}	0.249 ^{def}	0.457 ^{ab}	0.485 ^{c}	0.94 ^{b}	0.99 ^{ab}
	200	0.236 ^{a}	0.248 ^{a}	0.226 ^{ef}	0.238 ^{f}	0.462 ^{a}	0.486 ^{ab}	0.98 ^{a}	1.04 ^{a}
	300	0.226 ^{b}	0.239 ^{b}	0.234 ^{de}	0.249 ^{def}	0.460 ^{a}	0.487 ^{a}	0.90 ^{bc}	0.94 ^{b}
	400	0.213 ^{c}	0.216 ^{d}	0.229 ^{def}	0.244 ^{ef}	0.442 ^{cd}	0.460 ^{c}	0.90 ^{bc}	0.94 ^{b}

*Values marked with the same letter(s) within the main and interaction effects are statistically similar using Duncan's multiple range test at P = 0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

Foliar application of boron (200 ppm) increased leaf contents of chlorophyll a + b, carotenoids compared to untreated plants (Table 4). This improving effect may be due to improving membrane permeability; WRC and MSI % (Table 3) and promoting nutrient uptake notably N, P, K, S and B (Table 5). Which, led to an increase in the photosynthetic efficiency process especially that boron is an essential element for photosynthetic pigments, where it increases rates of photosynthetic O_2 evolution and CO_2 fixation, moreover, boron decreases the activities of oxidative pentose phosphate enzymes and respiration (**El Sayed et al., 2011 and Abd El-Hady, 2017**). Therefore, foliar application of boron increases in chlorophyll "a", "b" and carotenoids of red beet plants. Similar findings were documented by **Abd El-Hady (2017), Makhlouf et al. (2020) and El-Kalawy et al. (2021) on beet plants.**

Leaf N, P, K, S and B contents

Application of soil with 150 kg fed^{-1} sulphur gave the highest significant values on N, P, K, S and B contents (Table 5) of beet plants as compared to soil without sulphur, and the trend was parallel in both years. Increasing foliar application of boron concentration from 0 up to 300 ppm increased the mean values of leaf N, P, K and S. On the other hand, progressive increases in leaf B content occurred due to foliar application of boron up to 400 ppm, in the two growing seasons. The treatment combination of soil supplemented with 150 kg fed^{-1} sulphur together with 300 or 400 ppm boron recorded the higher values of leaf N, P, K and S content. While, combination of soil supplemented with 150 kg fed^{-1} sulphur together with 400 ppm boron recorded the best values of leaf B content, in both seasons.

The positive effect of sulphur on N, P, K, S and B leaf contents properties of soils because it reduced soil pH, thus increasing the availability of macro and microelements and improves the chemical properties of alkaline soils as shown in Table 1. This led to enhancing uptake N, P, K, S and B leaf contents when an application soil supplemented with 150 kg fed^{-1} sulphur comparing to control (Table 5). Also, boron is involved in ion fluxes (H^+, K^+, PO_4^{3-}, Rb^+ and Ca^{2+}) across membranes (**Shireen et al., 2018**). Also, its attributed to the enhanced effect of sulphur and boron on the activation of the bio-chemical processes in plants such as membrane permeability, which strongly connects with WRC and MSI% (Table 3), leaf chlorophyll content (Table 4). Which, was reflected in a raising the performance efficiency of red beet plants under alkaline soils conditions. Many other reports support our obtained results for effect of sulphur on chemical composition of plants such as **Osman and Rady (2012**) **Osman and El-Shatoury (2014) and Abd El-Mageed et al. (2020).** Also, Many reports support our obtained results for effect of boron on chemical composition of plants such as **Othman and El-Moursy (2020), Makhlouf et al. (2020) and El-Kalawy et al. (2021).**

Yield and its segments

The supplemented soil with 150 kg fed^{-1} sulphur significantly increased number of roots for three classes per 1 m^2 and roots yield for two classes (4 - 8 and > 8 cm diameter) fed^{-1}, when compared with the controls. Whereas, the supplemented soil with 150 kg fed^{-1} sulphur significantly decreased the roots yield fed^{-1} for < 4 cm diameter, in both seasons

(Tables 6 and 7). Foliar application of boron at concentration of 200 ppm was superior and significantly recorded higher mean values in number of roots and roots yield fed^{-1} for two classes (4 - 8 and > 8 cm diameter) when compared with the controls. While foliar spraying with boron at concentration of 50 ppm gave higher values in number of roots for < 4 cm diameter per 1 m^2, and the concentration of 400 ppm boron was given higher mean values in roots yield fed^{-1} for < 4 cm diameter, and the trend was parallel in both years. The treatment combination of growing soil supplemented with 150 kg fed^{-1} sulphur together with boron at 200 ppm recorded the higher values of the number of roots per 1 m^2 and roots yield fed^{-1} for two classes (4 - 8 and > 8 cm diameter), in both season. On the other hand, the treatment combination of sulphur at 150 kg fed^{-1} sulphur together without boron recorded the higher values of number of roots for < 4 cm diameter per 1 m^2. While, the best-combined treatment was the sulphur at 150 kg fed^{-1} sulphur and boron at 400 ppm for roots yield fed^{-1} for < 4 cm diameter, in both year.

Table 5. Effect of supplemented soil with sulphur and foliar application with boron on leaf N, P, K, S and B content of red beet.

Treatment		N (%)		P (%)		K (%)		S (%)		B (ppm)	
Sulphur (kg fed^{-1})	Boron (ppm)	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
0		1.82^{B}	1.96^{B}	0.22^{B}	0.22^{B}	1.93^{B}	1.89^{B}	0.27^{B}	0.31^{B}	51.0^{B}	56.7^{B}
150		2.00^{A}	2.05^{A}	0.26^{A}	0.26^{A}	2.04^{A}	1.96^{A}	0.33^{A}	0.41^{A}	55.9^{A}	60.6^{A}
	0	1.75^{E}	1.70^{E}	0.16^{E}	0.16^{E}	1.79^{E}	1.62^{E}	0.32^{A}	0.33^{D}	42.0^{F}	41.3^{F}
	50	1.82^{D}	1.85^{D}	0.19^{D}	0.19^{D}	1.87^{D}	1.76^{D}	0.32^{A}	0.34^{CD}	45.7^{E}	48.1^{E}
	100	1.89^{C}	1.97^{C}	0.23^{C}	0.23^{C}	1.96^{C}	1.90^{C}	0.32^{A}	0.36^{BC}	50.8^{D}	54.2^{D}
	200	1.98^{B}	2.10^{B}	0.26^{B}	0.27^{B}	2.04^{B}	1.99^{B}	0.33^{A}	0.38^{AB}	55.0^{C}	61.4^{C}
	300	2.02^{A}	2.24^{A}	0.30^{A}	0.30^{A}	2.13^{A}	2.14^{A}	0.30^{AB}	0.39^{A}	61.9^{B}	69.7^{B}
	400	2.03^{A}	2.17^{AB}	0.30^{A}	0.31^{A}	2.14^{A}	2.14^{A}	0.27^{B}	0.37^{AB}	65.5^{A}	77.1^{A}
0	0	1.67^{g}	1.62^{g}	0.16^{g}	0.15^{h}	1.73^{f}	1.58^{i}	0.29^{b}	0.31^{e}	39.4^{h}	38.4^{i}
	50	1.76^{f}	1.82^{ef}	0.18^{fg}	0.18^{gh}	1.83^{e}	1.73^{gh}	0.29^{b}	0.30^{e}	43.4^{g}	46.7^{h}
	100	1.81^{f}	1.96^{de}	0.20^{ef}	0.22^{ef}	1.89^{d}	1.88^{ef}	0.29^{b}	0.31^{e}	47.9^{f}	52.8^{f}
	200	1.89^{d}	2.05^{cd}	0.23^{de}	0.25^{de}	1.99^{c}	1.98^{de}	0.29^{b}	0.33^{de}	53.1^{e}	61.4^{d}
	300	1.89^{d}	2.20^{ab}	0.27^{c}	0.28^{cd}	2.08^{b}	2.10^{abc}	0.25^{c}	0.33^{de}	59.7^{c}	67.1^{c}
	400	1.91^{cd}	2.12^{bc}	0.27^{c}	0.28^{c}	2.08^{b}	2.08^{bc}	0.24^{c}	0.33^{de}	62.7^{b}	74.0^{b}
150	0	1.82^{ef}	1.78^{f}	0.17^{g}	0.17^{gh}	1.84^{e}	1.67^{hi}	0.34^{a}	0.36^{cd}	44.5^{g}	44.2^{h}
	50	1.87^{de}	1.88^{ef}	0.20^{ef}	0.20^{fg}	1.91^{d}	1.79^{fg}	0.35^{a}	0.39^{bc}	47.9^{f}	49.6^{g}
	100	1.96^{c}	1.98^{de}	0.25^{cd}	0.25^{de}	2.03^{c}	1.92^{de}	0.35^{a}	0.42^{ab}	53.7^{e}	55.7^{e}
	200	2.08^{b}	2.15^{abc}	0.30^{b}	0.29^{b}	2.10^{b}	2.01^{cd}	0.37^{a}	0.43^{a}	56.9^{d}	61.4^{d}
	300	2.14^{a}	2.28^{a}	0.34^{a}	0.33^{a}	2.18^{a}	2.18^{ab}	0.31^{b}	0.45^{a}	64.1^{b}	72.4^{b}
	400	2.15^{a}	2.22^{ab}	0.33^{ab}	0.34^{a}	2.19^{a}	2.20^{a}	0.29^{b}	0.42^{ab}	68.3^{a}	80.3^{a}

*Values marked with the same letter(s) within the main and interaction effects are statistically similar using Duncan's multiple range test at P = 0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

The use of sulphur at rate 150 kg fed^{-1} help in decreasing soil alkalinity through sulphur biological oxidation by soil microorganisms to sulphuric acid **(Osman and Rady, 2012; Osman and El-Shatoury, 2014)**, which in turn lowers soil pH (Table 1) and increase the availability of nutrients notably N, P, K, S and B comparing to soil without sulphur (Table 5). Thus, this led to an increase in all morphological measurements (Table 2). In addition, the essential role of sulphur in synthesis of amino acids that involved in chlorophyll production, vitamin-A and proteins, activates certain enzymes, plant function and structure **(Marschner, 1995)** this led to an improvement in the efficiency of membrane permeability (Table 3), leaf photosynthetic pigments content (Table 4). Which were reflected in an increased yield and its segments of red beets under alkaline soil conditions. Similar findings were documented by **Awad et al. (2013), Tawfic et al. (2014) and Mekdad et al. (2021) on beet.**

The enhancing effect of boron on red beet plants yield and its segments (Tables 6 and 7) might be due to easier availability of optimum boron dose to plant due to which might have better absorption and subsequent conversion into metabolic products whose accumulation culminates in more plant growth. Which, might aid in various biological activities like cell division and cell elongation in meristimatic tissues **(Huang et al., 2014).** Also, to the role of boron in nitrogen metabolism and hormonal action, in addition boron is involved in ion fluxes (H^+, K^+, PO_4^{3-}, Rb^+ and Ca^{2+}) across membranes, nitrogen and carbohydrate metabolism, sugar translocation to roots, cytoskeletal proteins and plasmalemma-bound enzymes, nucleic acid, indole acetic acid, polyamines, ascorbic acid and phenol metabolism and transport **(BARI, 2006).** Which, it was reflected in an increase in morphological characters (Tables 2) and positive effect of boron on stability of membrane permeability; MSI and RWC (Table 3) and increased contents of leaf photosynthetic pigments (Table 4). Which, it was reflected in an increase in yield and its segments of red beet. The obtained results are in harmony with those stated by **Makhlouf et al. (2020), Abu El-Fotoh et al. (2020), Bhatnagar et al. (2021) and El-Kalawy et al. (2021) on beet.**

Table 6. Effect of supplemented soil with sulphur and foliar application with boron on number of roots for three classes per 1 m² of red beet.

Treatment		Number of roots per 1 m² of different diameters							
Sulphur	Boron	< 4 cm		4 - 8 cm		> 8 cm		Total	
(kg fed⁻¹)	(ppm)	2019	2020	2019	2020	2019	2020	2019	2020
0		22 B	24 B	64 B	68 B	1.1 B	1.4 B	87 B	94 B
150		27 A	28 A	84 A	87 A	1.7 A	1.9 A	112 A	117 A
	0	25 B	28 AB	65 D	68 D	1.1 DE	1.3 C	91 D	98 D
	50	27 A	29 A	81 C	84 C	1.2 CD	1.3 C	109 C	114 C
	100	26 AB	27 B	88 B	93 B	1.7 B	2.0 B	115 B	122 B
	200	23 C	23 C	99 A	106 A	2.3 A	2.5 A	125 A	132 A
	300	26 AB	27 B	63 D	66 E	1.4 BC	1.8 B	91 D	94 E
	400	20 D	22 D	48 E	50 F	0.8 E	1.0 D	68 E	73 F
0	0	20 ef	23 f	47 h	50 h	0.8 ef	1.2 e	68 h	75 gh
	50	25 bc	27 d	67 f	70 f	1.0 def	1.2 e	93 f	98 f
	100	24 cd	25 de	76 e	83 d	1.2 de	1.3 e	102 e	110 e
	200	22 de	23 ef	96 bc	103 b	1.7 c	1.8 cd	120 b	128 c
	300	21 ef	23 ef	51 g	54 g	1.2 de	1.3 e	73 g	78 g
	400	20 ef	23 ef	48 gh	49 h	1.0 def	1.3 e	69 gh	74 gh
150	0	30 a	33 a	84 d	86 d	1.3 cd	1.5 de	115 c	121 d
	50	29 a	31 b	94 c	97 c	1.3 cd	1.5 de	125 a	130 bc
	100	27 b	29 c	99 ab	103 b	2.2 b	2.7 b	129 a	134 ab
	200	24 cd	23 f	102 a	109 a	2.8 a	3.2 a	129 a	135 a
	300	31 a	31 b	76 e	77 e	1.7 c	2.2 c	108 d	111 e
	400	19 f	20 g	47 gh	51 gh	0.7 f	0.7 f	67 h	72 h

*Values marked with the same letter(s) within the main and interaction effects are statistically similar using Duncan's multiple range test at P = 0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

Table 7. Effect of supplemented soil with sulphur and foliar application with boron on roots yield for three classes fed^{-1} of red beet.

Treatment		Roots yield (ton / fed) of different diameters							
Sulphur	Boron	< 4 cm		4 - 8 cm		> 8 cm		Total	
(kg fed^{-1})	(ppm)	2019	2020	2019	2020	2019	2020	2019	2020
0		0.66 ^{A}	0.57 ^{A}	8.2 ^{B}	8.9 ^{B}	0.29 ^{B}	0.35 ^{B}	9.1 ^{B}	9.9 ^{B}
150		0.62 ^{B}	0.54 ^{B}	11.5 ^{A}	12.8 ^{A}	0.46 ^{A}	0.54 ^{A}	12.6 ^{A}	13.8 ^{A}
	0	0.64 ^{B}	0.54 ^{C}	8.3 ^{E}	9.4 ^{D}	0.26 ^{D}	0.32 ^{E}	9.2 ^{E}	10.2 ^{E}
	50	0.64 ^{B}	0.56 ^{B}	10.5 ^{C}	11.6 ^{C}	0.32 ^{C}	0.37 ^{D}	11.5 ^{C}	12.6 ^{C}
	100	0.55 ^{C}	0.51 ^{D}	12.1 ^{B}	13.1 ^{B}	0.42 ^{B}	0.53 ^{B}	13.0 ^{B}	14.2 ^{B}
	200	0.54 ^{C}	0.49 ^{D}	13.8 ^{A}	14.9 ^{A}	0.64 ^{A}	0.70 ^{A}	15.0 ^{A}	16.1 ^{A}
	300	0.66 ^{B}	0.57 ^{B}	9.0 ^{D}	9.7 ^{D}	0.40 ^{B}	0.50 ^{C}	10.0 ^{D}	10.8 ^{D}
	400	0.80 ^{A}	0.67 ^{A}	5.4 ^{F}	6.3 ^{E}	0.22 ^{E}	0.25 ^{F}	6.4 ^{F}	7.2 ^{F}
0	0	0.68 ^{c}	0.55 ^{c}	5.2 ^{hi}	6.0 ^{i}	0.21 ^{fg}	0.25 ^{i}	6.1 ^{i}	6.8 ^{i}
	50	0.71 ^{bc}	0.61 ^{b}	8.8 ^{f}	9.5 ^{f}	0.25 ^{ef}	0.32 ^{g}	9.7 ^{f}	10.4 ^{f}
	100	0.58 ^{def}	0.54 ^{c}	10.1 ^{e}	11.2 ^{e}	0.30 ^{e}	0.39 ^{f}	10.9 ^{e}	12.1 ^{e}
	200	0.56 ^{fg}	0.52 ^{cd}	12.0 ^{c}	12.8 ^{d}	0.44 ^{cd}	0.50 ^{d}	13.0 ^{c}	13.8 ^{d}
	300	0.70 ^{bc}	0.60 ^{b}	7.9 ^{g}	8.4 ^{g}	0.31 ^{e}	0.36 ^{f}	8.9 ^{g}	9.4 ^{g}
	400	0.74 ^{b}	0.61 ^{b}	5.1 ^{i}	5.7 ^{i}	0.26 ^{ef}	0.28 ^{h}	6.1 ^{i}	6.6 ^{i}
150	0	0.61 ^{de}	0.53 ^{cd}	11.4 ^{d}	12.7 ^{d}	0.32 ^{e}	0.39 ^{f}	12.4 ^{d}	13.7 ^{d}
	50	0.58 ^{def}	0.51 ^{d}	12.2 ^{c}	13.8 ^{v}	0.38 ^{d}	0.43 ^{e}	13.2 ^{c}	14.7 ^{c}
	100	0.53 ^{g}	0.47 ^{e}	14.1 ^{b}	15.0 ^{b}	0.55 ^{b}	0.68 ^{b}	15.2 ^{b}	16.2 ^{b}
	200	0.52 ^{g}	0.45 ^{e}	15.6 ^{a}	17.1 ^{a}	0.84 ^{a}	0.90 ^{a}	17.0 ^{a}	18.4 ^{a}
	300	0.63 ^{d}	0.55 ^{c}	10.1 ^{e}	11.0 ^{e}	0.49 ^{bc}	0.63 ^{c}	11.2 ^{e}	12.2 ^{e}
	400	0.86 ^{a}	0.72 ^{a}	5.6 ^{h}	6.9 ^{h}	0.18 ^{g}	0.21 ^{j}	6.7 ^{h}	7.8 ^{h}

*Values marked with the same letter(s) within the main and interaction effects are statistically similar using Duncan's multiple range test at P = 0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

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تأثير الكبريت والبورن على نمو وإنتاجية نباتات البنجر الأحمر

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الملخص العربى

أجريت هذه الدراسة خلال عامي 2019/2018 و 2020/2019 بمزرعة خاصة بمركز سنورس، الفيوم، مصر، لدراسة التأثير التكاملى للإضافة الأرضية للكبريت والرش الورقى بالبورون على الصفات المورفولوجية، وثبات الأغشية، وصبغات التمثيل الضوئى للأوراق، ومحتوى الأوراق من N، P، K، S و B، والمحصول ومكوناته لنباتات البنجر الأحمر صنف (Deitroit Superene). وقد أتبع في تصميم التجربة نظام القطع المنشقة لمرة واحدة فى تصميم عشوائى كامل بثلاثة مكررات. وزعت مستويي الكبريت (0 و 150 كجم للفدان) في القطع الرئيسية، بينما وزعت عشوائيًا تركيزات البورون (0 ،50, 100، 200،300 , 400 جزء في المليون) في القطع تحت الرئيسية. اشتملت كل قطعة تجريبية على 6 خطوط؛ بطول 4 م وعرض 70 سم بمساحة إجمالية 16.8 م^2. تم إضافة الكبريت (أثناء تجهيز الأرض للزراعة، بينما الرش الورقى لتركيزات البورون المختلفة ثلاث مرات بعد 30 ، 45 و 60 يوم من زراعة البذور.

بشكل عام، أدت الإضافة الأرضية للكبريت بمعدل 150 كجم للفدان أعلى القيم معنويا لجميع الصفات المورفولوجية، وثبات الأغشية، وصبغات التمثيل الضوئى للأوراق، ومحتوى الأوراق من N، P، K، S و B، والمحصول ومكوناته في كلا الموسمين. في حين أن إضافة الكبريت أدت إلى انخفاض معنوى في محتوى الأوراق من كل من الكلوروفيل b بالأوراق ومحصول الفدان من الجذور التي يقل قطرها عن 4 سم.

وبشكل عام، أعطى الرش الورقى من البورون 200 جزء في المليون أعلى القيم معنويا للقياسات السابق ذكرها مقارنة بالتركيزات الأخرى. في حين أن رش البورون بتركيز 50 جزء في المليون أعطى أعلى القيم بشكل ملحوظ لعدد الجذور التي يقل قطرها عن 4 سم في المتر المربع. بينما أعطى الرش بتركيز 400 جزء في المليون قيم أعلى في محصول الفدان من الجذور التي يقل قطرها عن 4 سم.

وبشكل عام، فإن الإضافة الأرضية للكبريت بمعدل 150 كجم للفدان مع الرش الورقى بالبورون بتركيز 200 جزء في المليون تعمل على تيسر العناصر الغذائية وتحسين المكونات الفيزيوكيميائية الحيوية للنباتات مما ينعكس إيجابيًا على نمو والإنتاجية لنباتات البنجر الأحمر تحت الظروف البيئية السائدة بمحافظة الفيوم والمناطق المشابهة الأخرى.