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ORIGINAL PAPER

DETERMINATION OF THE EFFECTS OF URBAN SEWAGE SLUDGE AND BORON APPLICATIONS ON SEEDLING DEVELOPMENT AND NUTRITIONAL CONTENT OF COWPEA (*VIGNA UNGUICULATA* L.)

Mustafa Çirka[1,2]

[1] Department of Horticulture
Iğdır University, Iğdır-Turkey
[2] Department of Field Crops
Van Yuzuncu Yil University, Van-Turkey

Abstract

This study was carried out to determine the effects of urban sewage sludge and boron applications on some chemical and physiological properties of cowpea (*Vigna unguiculata* L.). The experiment was carried out in a factorial pattern with 3 replications according to a randomized plot design. In the study, Karagöz cowpea variety, 4 boron doses (B_0 – 0, B_1 – 50, B_2 – 100, B_3 – 200 mg kg^{-1}), and 4 sewage sludge doses (SS_0 – 0, SS_1 – 2.5%, SS_2 – 5%, SS_3 – 10%) were used. In the experiment, seedling and root length (cm), seedling and root fresh weight (g), seedling and root dry weight (g), number of leaves (number), leaf area (cm^2), and macronutrient elements in the plant were examined. As a result, the effects of sewage sludge and boron applications on seedling and root length, seedling and root fresh weight, leaf number, leaf area, and seedling and root dry weight were found to be significant. In the study, it was determined that the effect of the mutual interaction of the factors on the seedling and root length, seedling and root fresh weight, and root dry weight was significant. In addition, the effects of boron and sewage sludge applications on plant nutrients (P, Ca, K, Mg) were found to be significant. The effect of the interaction of the factors on the elements was found to be significant and the highest phosphorus, calcium, potassium, and magnesium values (1.662 mg kg^{-1}, 3.159-3.158%, 3.524% and 1.309%) were obtained from B_0xSS_3, B_0xSS_0-B_2xSS_0, B_0xSS_0, B_3xSS_0 applications, respectively, while the lowest values (0.414-0.413 mg kg^{-1}, 0.454%, 1.361%, and 0.312%) were obtained from B_1xSS_0-B_2xSS_1, B_1xSS_3, B1xSS_3, B_2xSS_2 applications, respectively.

Keywords: boron, cowpea, macro-elements, sewage sludge

Mustafa Çirka, Department of Horticulture, Faculty of Agriculture, Iğdır University, Iğdır-Turkey, e-mail: m_cirka@hotmail.com

INTRODUCTION

In 2020, cowpea, which belongs to the legume family and is very similar to beans, was grown on an area of 15.056.435 hectares worldwide, with the production yield of 8.901.644 tons (FAO, 2022). Cowpea shows high morphological similarity to *Phaseolus* L. The less prominent veining in the leaf structure of cowpea and its hairless, shiny structure enabled this plant to be evaluated as a different species from the bean (Ba et al. 2004). According to Çulha, Bozoğlu (2016), cowpea is similar to beans. However, compared to beans, cowpea is less affected by ecological conditions, drought, and high temperatures that may occur during flowering. Since cowpea has a high percentage of green parts, it is used in mixed cultivation to preserve the soil. In addition, these authors reported that cowpea should be used as an alternation plant in locations where paddy cultivation is carried out, thus it should be evaluated in such regions. Also, they stated that Turkey, which is the homeland of broad beans, peas, and chickpeas, has suitable conditions for edible grain legumes cultivation. Cowpea is more resistant to drought and heat in tropical and semi-arid regions than other legumes (Hall 2004). In addition, cowpea is preferred all over the world in terms of high-quality protein. Some studies have stated that cowpea has a protective effect against the progression of cancer and inflammation (Jayathilake et al. 2018).

Boron, which is one of the microelements, is a nonmetal element. Tourmaline, complex borosilicate, is an essential boron-containing mineral. Other boron minerals in the soil are borax, kernite, colemanite, ulexite, ludvigite, and cathode. In addition, the element boron is found in soil either attached to organic matter or in the form of borates, which are salts of boric acid, or linked to clay minerals (Foth 1984, Kantarcı 2000, Güzel et al. 2004, Gardiner, Miller 2008, Kacar, Katkat 2010). The main role of boron in the plant is to ensure the proliferation of tissues and the formation of the cell wall. It also plays a role in the activation of some dehydrogenase enzymes, in the synthesis of carbohydrates, and in the transportation of sugars in the plant (Plaster 1992, Boşgelmez et al. 2001, Gardiner, Miller 2008, McCauley et al. 2009). Boron deficiency in the plant appears in the form of chlorosis on young leaves. There is a decrease in the growth and development rate of the plant and, as a result of the damage to the cell wall, a brittle structure and an amorphous structure that can easily break occurs in seedlings and leaves. Leaf tips thicken and leaves acquire a dark blue-green color (McCauley et al. 2009, Kacar, Katkat 2010). When the element boron is present in both soil and water in high proportions, it is taken in excess by plants and then it has a toxic effect on plants, causing leaves to acquire a burnt appearance and then to shed very early. Yellowing occurs at the tip of old leaves, and then these symptoms begin to spread towards the leaf margins-middle vein (Özbek et al. 2001, Kacar, Katkat 2010).

Many institutions have acknowledged that they are in favor of using such products in agriculture as sewage sludge, which contains both macro- and micronutrients, applied as an alternative fertilizer source and as a soil conditioner owing to its organic matter content. This approach has led to an increase in the use of urban sewage sludge in many countries (Strauch 1991, Düring, Gäth 2002). In terms of physical properties, sewage sludge is odorous waste that occurs as both liquid and solid substance as a result of urban waste treatment. It contains 0.25-12% of solid matter depending on a sewage treatment process (Durak 2005). Sewage sludge and water provide benefits in terms of resources for beneficial bacteria in the soil. Sewage sludge can be important in removing pesticides and heavy metals, which are pollutants, and in bringing many beneficial bacteria to the soil, such as bacteria that can fix free nitrogen in the air (*Nitrosomonas*) (Oved et al. 2001, Hanjra et al. 2012). In this sense, the use of sewage sludge, which contains beneficial elements for plants, may help to solve the problem of the environmental pollution that may arise in different areas of the world (Kabata-Pendias 2011).

This study aimed to determine the effects of urban sewage sludge and boron applications on some chemical and physiological properties of cowpea (*Vigna unguiculata* L.) in light of the above information.

MATERIAL AND METHOD

Material

Preparation of herbal material

Karagöz cowpea (*Vigna unguiculata* L) variety was used as the plant material in the study. The seeds used in the experiment were obtained from Van Yuzuncu Yil University, Faculty of Agriculture, Department of Field Crops. The seeds were subjected to a germination test before sowing in order to determine their germination performance. During the study, the development of morphological features in the plants was followed, and leaf samples were taken from the plants. The leaf samples were dried and prepared for analyses of heavy metals and plant nutrients.

Preparation of the growing medium

The urban sewage sludge used as a solid material in the research was obtained from the Van Edremit Biological Sewage Department. The sewage sludge supplied in the form of sludge was kept outside in an airy environment for three months and dried. Then, the dried sludge was ground, passed through a 2 mm sieve, and applied to the pots at the specified doses. Physically, sewage sludge is odorous waste produced as a liquid or solid body, obtained as a result of the processing of urban waste. It usually contains

0.25% to 12% solid particles (Durak, 2005). The sludge content used in the study was based on the Regulation on the Use of Domestic and Urban Sewage Sludges in Soil issued by the Ministry of Environment and Forestry (Anonymous 2022). In Van Yuzuncu Yil University, Faculty of Agriculture, Soil Science and Plant Nutrition laboratory, the B, P, Ca, K and Mg contents were measured by Atomic Absorption Spectrophotometry (Khan, Frankland 1983) in the sewage sludge diluted 1:2.5 (Grewelling, Peech 1960). The salinity value of the solid medium was determined in samples diluted at a 1:2.5 ratio, and the lime value was determined as percent (%) by measuring the CO_2 volume resulting from the reaction of HCl acid and $CaCO_3$ (Richards 1954).

METHOD

The study was carried out in three replications in a factorial arrangement with four different sewage sludge applications (SS_0 – 0%, SS_1 – 2.5%, SS_2 – 5%, SS_3 – 10%) and four different boron applications (B_0 – control, B_1 – 50 ppm, B_2 – 100 ppm, B_3 – 200 ppm mg kg^{-1}) in a completely randomized experimental design. In the study, boric acid (H_3BO_3) was used as the boron source and the sludge used in the study was obtained from the Van Edremit Wastewater Sewage Plant. The pots were placed in the climatization room of Van Yuzuncu Yil University Field Crops Department. Sowing was done with 3 seeds in each pot. The first application of boron doses, which should be given to the pots twice, was given immediately after sowing (80cc), and the other application was given when the emergence was homogeneous. The water needs of the control group and plants were met by providing distilled water. Thinning was done so that one plant remained in each pot. Stress in plants was observed 15 days after sowing. The experiment was terminated 5 days after the emergence of stress in the plants. The effects of sewage sludge and boron applications on the morphological and chemical properties of cowpea were investigated. Morphologically, features such as seedling and root length, seedling and root fresh weight, seedling and root dry weight, leaf area and the number of leaves in the plant (Başdinç, Çirka 2021) were investigated, while chemically boron (B), phosphorus (P), calcium (Ca), potassium (K) and magnesium (Mg) elements were determined (Kaçar 1984). Leaf area (cm^2) was measured with the Easy Leaf Area program (Easlon, Bloom 2014), and seedling length and root length were measured with a ruler. Seedling and root fresh weight and seedling and root dry weight were weighed with precision scales. For macro-metal analysis, the plant samples were left to dry in an oven at 40°C for 48 h and the dried leaf samples were prepared according to Kacar and İnal (2008).

The content of B, P, Ca, K, and Mg (Table 1) in the sewage sludge was measured with the Atomic Absorption Spectrophotometer measurement method according to Khan, Frankland (1983). The salinity value of the sludge

Table 1

Some chemical analysis results of sewage sludge with 90% dry matter content

	$CaCO_3$ (%)	pH	E.C (μS cm^{-1})	P (mg kg^{-1})	Ca (%)	K (%)	Mg (%)
Results of analyses	14.54	7.1	1102.4	1.251	3.28	5.638	4.205

(1:2.5) was made by diluting the samples. The lime value of the sludge was measured as a percentage (%) to determine the volume of CO_2 gas that is formed as a result of the reaction of $CaCO_3$ with HCl acid (Richards, 1954). The pH values of the samples diluted at the same ratio (1:2.5) were determined according to the method reported by Greweling, Peech (1960) in Van Yuzuncu Yil University, Department of Soil Science and Plant Nutrition.

Statistical analysis of data

The data obtained in the experiment were subjected to analysis of variance according to the factorial order in a completely randomized experimental design using the Costat (version 6.34) package program. The comparison of the averages was made according to the LSD multiple comparison test.

RESULTS AND DISCUSSION

Seedling length

As seen in Table 2, the effects of boron and sewage sludge applications on seedling height are significant. As a result of boron applications, the longest seedlings (15.82 cm) were measured from the B_2 application, and the shortest seedlings (13.93 cm) were measured from the B_3 application. Baykal and Öncel (2006) reported that seedling length decreased in plants exposed to boron toxicity in a study they conducted on two wheat species. As a result of the sewage sludge applications, the highest seedling length (19.33 cm) was obtained from SS_0 and the lowest seedling lengths (12.01 and 12.58 cm) were obtained from SS_3 and SS_2 doses.

The interaction of the factors was significant, and the highest value (20.67 cm) was obtained from the B_2 x SS_0 application and the lowest values (9.73 cm) from the B_3xSS_3 applications (Figure 1A). The results obtained in this study confirm the hypothesis of Taşatar (1997), who states that sewage sludge with a high heavy metal content limits plant growth. Also, Akar and Atış (2019), who investigated the effects of cadmium and nickel on *Festuca rubra* L., reported that increasing heavy metal doses had a negative effect on the seedling length of the plant and caused a decrease in the seedling length.

Table 2

Effects of the sewage sludge and boron applications on observed growth parameters

Applications		SL (cm)	RL (cm)	SFW (g)	RFW (g)	LN (pieces)	LA (cm^2)	SDW (g)	RDW (g)
Boron (B) mean	B_0	14.48 **BC**	8.98 **C**	2.36 **AB**	0.50 **B**	5.00	22.23 **A**	0.25 **BC**	0.06 **C**
	B_1	14.89 **B**	10.46 **B**	2.16 **B**	0.63 **A**	4.58	19.65 **B**	0.24 **C**	0.07 **BC**
	B_2	15.82 **A**	11.03 **AB**	2.40 **A**	0.66 **A**	4.50	20.93 **AB**	0.29 **A**	0.11 **A**
	B_3	13.93 **C**	11.21 **A**	1.61 **C**	0.59 **AB**	4.08	16.84 **C**	0.26 **AB**	0.08 **B**
Sewage sludge (SS) mean	SS_0	19.33 *A*	19.63 *A*	3.25 *A*	1.46 *A*	7.83 *A*	30.21 *A*	0.37 *A*	0.16 *A*
	SS_1	15.22 *B*	11.51 *B*	2.47 *B*	0.52 *B*	6.08 *B*	20.90 *B*	0.29 *B*	0.10 *B*
	SS_2	12.58 *C*	6.01 *C*	1.45 *C*	0.22 *C*	2.25 *C*	15.60 *C*	0.22 *C*	0.03 *C*
	SS_3	12.01 *C*	4.52 *D*	1.35 *C*	0.18 *D*	2.00 *C*	12.94 *D*	0.17 *D*	0.02 *C*
LSD (%5) B		0.639 *	0.729 *	0.211 *	0.119 *	ns	2.173 *	0.029 *	0.012 *
LSD (%5) SS		0.639 **	0.729 **	0.211 **	0.119 **	10.532 **	2.173 **	0.029 **	0.012 **
LSD (%5) B x SS		0.700 ***	1.263 ***	0.732 ***	0.129 ***	ns	ns	ns	0.129 ***

* There is no statistically significant (5%) difference between the means shown with the same capital and bold letters in the same column.
** There is no statistically significant (5%) difference between the means shown with the same capital and italic letters in the same column.
*** There is a statistically significant (5%) difference between the applications shown in Figure 1A-C.

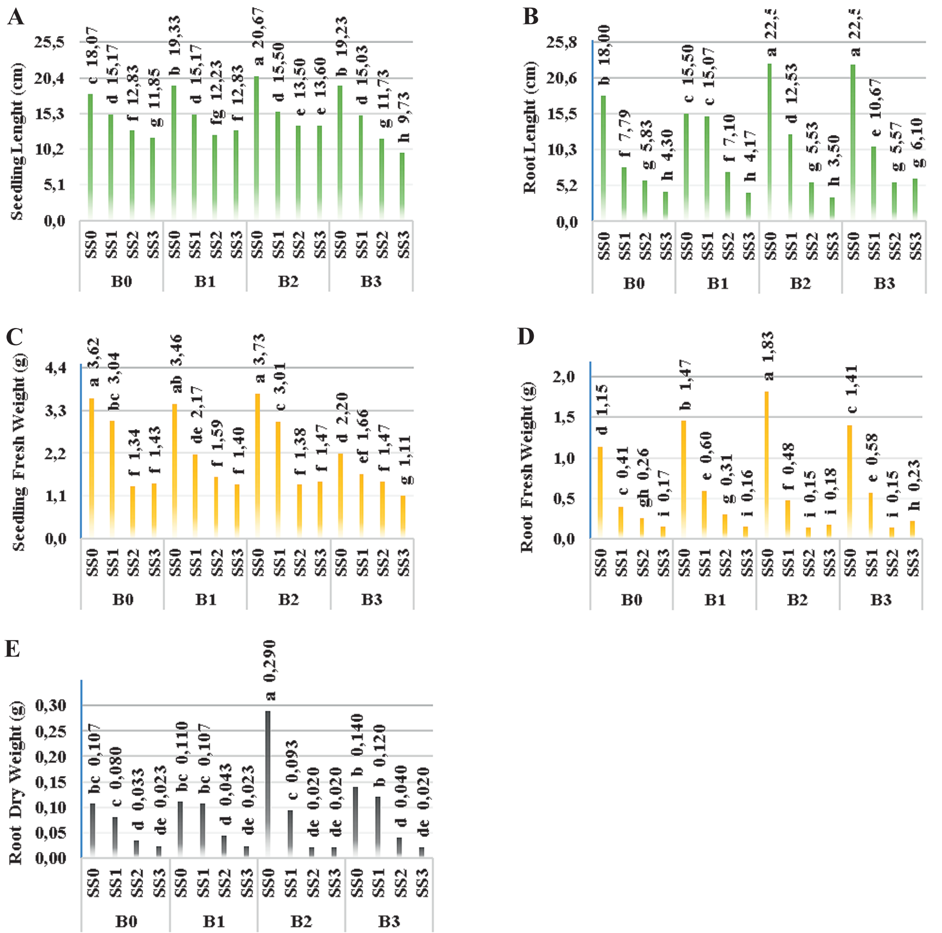

Fig. 1. The effects of boron and sewage sludge applications on observed parameters

Root length

As seen in Table 2, the effect of boron doses on root length was found to be significant and while the highest root length value (11.21 cm) was obtained from B_3 application, the lowest (8.98 cm) was measured from B_0 application. In the study, the effect of sewage sludge applications on root length was found to be significant. The highest root length (19.63 cm) was obtained from the SS_0 application and the lowest values (4.52 cm) were obtained from the SS_3 application (Table 2). In the study, it was determined that the effect of the interaction of boron and sewage sludge applications on root length was significant, and the highest root length value (22.53 cm) was obtained from B_2xSS_0 application, while the lowest values (3.50, 4.17 and 4.30 cm) were obtained from B_2xSS_3, B_1xSS_3, and B_0xSS_3 applications (Figure 1B). Korboulewsky et al. (2002), in their study in which the effects of sewage sludge on *Diplotaxis erucoides* L. plant were investigated, reported that increasing doses of sewage sludge had a positive effect on the root length of the plant. However, contrary to these results, it was determined that increasing doses of sewage sludge due to heavy metal contents adversely affected the root length of cowpea. It is thought that this situation is related to the heavy metal content of the sewage sludge and the species differences between the two trials. As a matter of fact, Ayhan et al. (2007) reported that Cd and Pb doses in maize significantly reduced plant root length.

Seedling fresh weight

The effect of sewage sludge and boron applications on seedling fresh weight was found to be significant. As seen in Table 2, while the highest seedling fresh weight values (2.40 g) were obtained from the B_2 application, the lowest (1.61 g) was measured from the B_3 boron application. Likewise, regarding the sewage sludge doses, while the highest seedling fresh weight value (3.25 g) was obtained from the SS_0 dose, the lowest values (1.35 and 1.45 g) were determined from the SS_3 and SS_2 doses. Contrary to our results, Çakır and Çimrin (2018) reported that increasing doses of sewage sludge in corn plants increased the wet weight of the plant and decreased it after 75% application. It was observed that the interaction effect of boron and sewage sludge on seedling fresh weight was significant. Therefore, while the highest values of seedling fresh weight (3.62 and 3.73 g) were achieved from the B_0xSS_0 and B_2xSS_0 applications (Figure 1C). Harite (2008), investigating the effects of boron on the cotton plant, stated that the fresh weight of the plant decreased with increasing boron doses. In a study conducted by Çakır and Çimrin (2018), the effects of sewage sludge on the corn plants were examined and they reported that the wet weight of the plant decreased after 75% doses of the sludge.

Root fresh weight

According to the data in Table 2, while the effects of boron and sewage sludge applications on root fresh weight were significant, the effect of the interaction of the factors was insignificant. As a result of the boron application, the highest root fresh weight values (0.66 and 0.63 g) were obtained from the B_2 and B_1 applications, and the lowest (0.50 g) was weighed from the B_0 application. According to the sewage sludge effects, while the highest root fresh weight value (1.46 g) was obtained from SS_0, the lowest values (0.18 g) were determined from the SS_3 application. In the study, it was determined that the effect of the interaction of boron and sewage sludge applications on root fresh weight was significant, and the highest root fresh weight value was obtained from the B_2xSS_0 application as 1.83 g (Figure 1B). Başdinç and Çirka (2021), in a previous study on beans, reported that the root fresh weight decreased due to increasing sludge doses in Öz Ayşe cultivar. Contrary to our study, Ortaca (2005) in a study conducted on sunflowers reported that root fresh weight decreased with increasing boron doses. In a study conducted by Hasnain et al., (2003) on mung beans, increasing doses of boron (0-20 ppm) were used and the root wet weight increased up to 5 ppm, but decreased in response to subsequently higher doses.

Leaf number

As seen in Table 2, it was determined that the effect of the sewage sludge on the number of leaves was significant and the highest leaf number value (7.83 pieces) was obtained from SS_0, and the lowest leaf number values (2.00 and 2.25 pieces) were obtained from the SS_3 and SS_2 applications. It was determined that the effect of boron doses and interactions between the factors on leaf number were not significant. The means value of the leaf number depending on the boron applications varied between 4.08-5.00 pieces, and the interaction values varied between 2.00-8.00 pieces. Contrary to the data we obtained in our study, Başdinç and Çirka (2021) reported that increasing sewage sludge doses increased the number of leaves in the Öz Ayşe bean cultivar. In addition, Türkmen et al. (2001) stated that increasing doses of sludge in the cultivation of cucumber had a positive effect on the number of leaves compared to the control groups. However, in a study conducted by Harite (2008), it was reported that increasing boron applications caused a decrease in the number of leaves in the cotton plant.

Leaf area

In the analyses made on the research material, it was determined that the effect of boron and sewage sludge applications on the leaf area was significant (Table 2). Considering the boron applications, it was determined that the highest leaf area value (22.23 cm^2) was obtained from the B_0 application and the lowest value (16.84 cm^2) was obtained from the B_3 application. In a study investigating the effects of boron applications on sugar beans, Akoğlu (2013) reported that increasing doses of boron applications caused a decrease in leaf area in beans. In the sewage sludge doses, the highest leaf area value (30.21 cm^2) was found in SS_0 and the lowest (12.94 cm^2) from the SS_3 dose. It was determined that the interaction of the factors was insignificant, and the leaf area values varied between 11.36 cm2 and 31.57 cm^2. While it was seen in the study that there was a decrease in leaf area due to increasing sewage sludge doses, Türkmen et al. (2001) reported that leaf area increased, compared to the control, depending on the increasing sewage sludge doses supplied to the cucumber plant. Akoğlu (2013) reported that boron toxicity, which causes various metabolic and physiological interactions on plants above a certain dose, can negatively affect growth and development.

Seedling dry weight

As seen in Table 2, the effects of boron and sewage sludge applications on seedling dry weight were found to be significant. While the highest seedling dry weight (0.29 g) was obtained from the B_2 application, the lowest value (0.24 g) was observed from the B_1 application. Additionally, as a result of the sewage sludge applications, the highest seedling dry weight (0.37 g) was obtained from the SS_0 application, while the lowest dry weight (0.17 g) was obtained from the SS_3 application. It was observed that the effect of the interaction of factors on the seedling dry weight was not significant. While the seedling dry weight values depending on the interaction values of the factors varied between 0.16 - 0.42 g. The data obtained in this study are partially similar to the results reported by Çakır and Çimrin (2018). Başdinç and Çirka (2021), in their study, reported that increasing sewage sludge doses in the Öz Ayşe bean cultivar had a reducing effect on the dry weight of the seedlings compared to the control group. In addition, in many studies conducted with different doses, it was stated that sewage sludge increases the dry weight of the plants, but after certain doses, it negatively affects the dry weight of the plants (Çimrin et al 2000, Qasim et al 2001).

Root dry weight

As seen in Table 2, the effect of boron doses on root dry weight was found to be significant and while the highest root dry weight value (0.11 g) was obtained from the B_2 application, the lowest (0.06 g) was determined from the B_0 application. In the study, the effect of sewage sludge applications on root dry weight was found to be significant. The highest root dry weight (0.16 g) was obtained from the SS_0 application and the lowest values (0.02 and 0.03 g) were obtained from the SS_3 and SS_2 applications (Table 2). In the study, it was determined that the effect of the interaction of boron and sewage sludge applications on root dry weight was significant, and the highest root dry weight (0.29 g) was obtained from the B_2xSS_0 application (Figure 1C). In the study, contrary to the data obtained by Çimrin et al. (2000), the root dry weight decreased with increasing sewage sludge doses.

Some macro-element content of plants

In this study on the cowpea plants, it was determined that different doses of boron and sewage sludge and the interactions of these factors had significant effects on B, P, Ca, K, and Mg content in the plants (Table 3).

After different boron applications, while the highest boron amount (184.55 mg kg^{-1}) was determined in the plants from B3 boron application, the lowest value (41.76 mg kg^{-1}) was obtained from B_0 (Table 3). As seen in Table 3, as a result of sewage sludge applications, the highest boron element value (107.38 mg kg^{-1}) was obtained from the SS_0 application, while the lowest value (62.66 mg kg^{-1}) was obtained from the SS_3 application. As a result of the interaction of the factors, the highest boron

Table 3

The effects of sewage sludge and boron applications on the content of some elements

Applications		B (mg kg^{-1})	P (mg kg^{-1})	Ca (%)	K (%)	Mg (%)
Boron (B) mean	B0	41.76 D	1.128 A	1.894 B	2.461 A	0.828 A
	B1	62.69 C	0.993 C	1.442 D	1.932 C	0.686 B
	B2	70.95 B	0.773 D	1.998 A	2.463 A	0.702 B
	B3	184.55 A	1.037 B	1.739 C	2.345 B	0.806 A
Sewage sludge (SS) mean	SS0	107.38 *A*	0.565 *D*	2.691 *A*	3.118 *A*	1.193 *A*
	SS1	98.28 *B*	0.774 *C*	2.342 *B*	2.540 *B*	0.791 *B*
	SS2	91.62 *C*	1.236 *B*	1.280 *C*	1.976 *C*	0.545 *C*
	SS3	62.66 *D*	1.356 *A*	0.759 *D*	1.566 *D*	0.492 *D*
LSD (%5) B		2.363 *	0.390 *	0.088 *	0.352 *	0.031 *
LSD (%5) SS		2.363 **	0.390 **	0.088 **	0.352 **	0.031 **
LSD (%5) B x SS		1.637 ***	0.684 ***	0.305 ***	0.122 ***	0.108 ***

* There is no statistically significant (5%) difference between the means shown with the same capital and bold letters in the same column.

** There is no statistically significant (5%) difference between the means shown with the same capital and italic letters in the same column.

*** There is a statistically significant (5%) difference between the applications shown in Figure 2A-E.

value (209.95 mg kg^{-1}) was obtained from the B_3xSS_0 application, while the lowest value (25.14 mg kg^{-1}) was obtained from the B_2xSS_3 application (Figure 2A).

As a result of boron applications, while the highest phosphorus amount (1.128 mg kg^{-1}) was determined in the plants from B_0 boron application, the lowest value (0.773 mg kg^{-1}) was obtained from B_2 (Table 3). When the sewage sludge applications were observed, it was seen that the highest phosphorus element value (1.356 mg kg^{-1}) was obtained from the SS_3 application, while the lowest value (0.565 mg kg^{-1}) was obtained from the SS_0 application. As a result of the interaction of the factors, the highest value of phosphorus (1.662 mg kg^{-1}) was taken from B_0xSS_3, and the lowest value (0.414-0.413 mg kg^{-1}) was taken from B_1xSS_0-B_2xSS_1 applications (Figure 2B).

In the study, as a result of sewage sludge applications, the highest calcium value (0.270%) was SS_0, and the lowest value (75.94%) was obtained in the SS_3 application. As a result of boron applications, the highest calcium value (1.998%) was obtained from B_2 and the lowest value (1.739%) from the B_3 application. As a result of the interaction of the factors, the highest value (3.158%) was determined from B_0xSS_0 and the lowest value (0.453%) was monitored from B_1xSS_3 applications (Figure 2C).

As seen in Table 3, as a result of boron applications, the highest potassium values (2.461-2.463%) were obtained from B_0-B_2 applications, and the lowest (1.932%) from B_1 applications. As a result of sewage sludge applica-

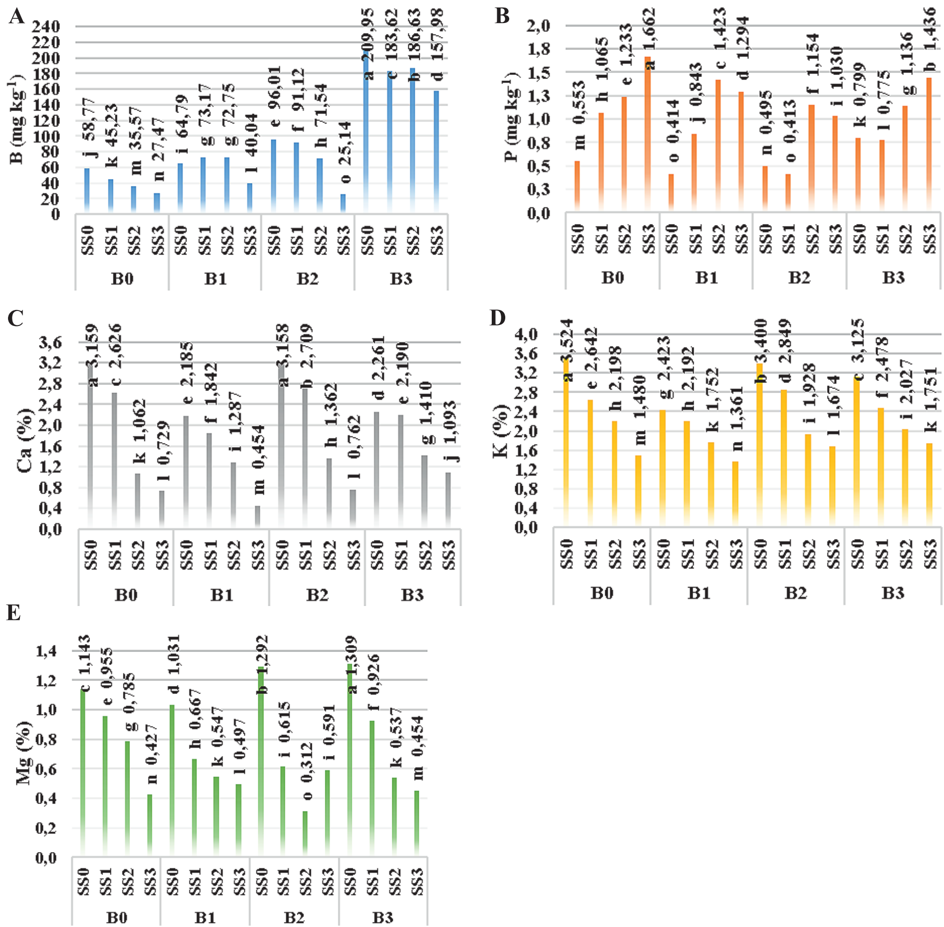

Fig. 2. The effects of boron and sewage sludge applications on observed elements

tions in the study, the highest potassium value (3.118%) was obtained from the SS_0 application, while the lowest value (1.566%) was obtained from the SS_3 application. As a result of the interaction of the factors, the highest potassium value (3.524%) was obtained from the B_0xSS_0 application and the lowest (1.361%) from the B_1xSS_3 application (Figure 2D).

In the study, as a result of different boron applications, the highest magnesium values (0.806%-0.828%) were obtained from B_3-B_0 applications, and the lowest values (0.686% - 0.702%) from B_1-B_2 applications (Table 3). When the study results were examined in terms of sewage sludge, it was determined that the highest magnesium value (1.193%) was obtained from the SS_0 application, and the lowest value (0.492%) was obtained from the SS_3 application (Table 3). As a result of the mutual interaction of the factors, it was determined that the highest magnesium value (1.308%) was obtained from the B_3xSS_0 application and the lowest (0.312%) from the B_2xSS_2 application (Figure 2E).

In a previous study conducted by Lopez-Lefebre et al. (2002) on tobacco plants, it was reported that increasing doses of boron applications increased the phosphorus, potassium, and calcium values and decreased the magnesium value in the plant. In previous studies on strawberries and corn, it was determined that boron uptake in plants had an antagonistic effect on phosphorus content (Adak et al. 2018, Çelik et al. 2019). Gezgin and Hamurcu (2006), investigating the effects of boron on plant nutrition, reported that boron has an antagonistic effect on calcium and magnesium and a synergistic effect on phosphorus and potassium.

CONCLUSION

In the study, it was determined that with increasing boron doses, there was an increase in seedling and root length, seedling and root fresh weight, and seedling and root dry weight of plants, while increasing sludge applications showed decreases in all the examined morphological features. It was determined that there was an increase in the plant nutrients examined in the study, depending on the increasing doses of boron. However, it was observed that while the increase in phosphorus and magnesium values continued after the B3 dose, a decrease occurred in calcium and potassium values. In addition, it was determined that there were decreases in boron, calcium, potassium, and magnesium values and an increase in phosphorus values depending on the increasing sewage sludge doses. It is thought that this study will shed light on similar studies to be done in the future. Conducting such studies in field conditions will allow more realistic results to be obtained. The heavy metals in the sewage sludge used as a solid medium in the research and the pathogens in its structure carry risks in terms of human health. In order to eliminate these risks, it will be more appropriate to use sewage sludge in agriculture after stabilization.

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