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Original Research

Determination of Some Growth Parameters and Chemical Contents of *Glycine max* L. under Lead Stress Condition

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Abstract

The aim of the study was to determine the effects of lead on some growth parameters and chemical contents of soybean (*Glycine max* L.) seedlings. The study was conducted according to the factorial trial in a completely randomized experimental design with six replications. To investigate lead effects on nutrient uptake and metabolism, two soybean varieties were grown under aeroponic conditions and stressed with lead sulphate ($PbSO_4$) at five concentrations in a fully controlled aeroponic climatic cabin. According to the results, Fe, Cu, and Pb contents of the roots and leaves were increased in direct proportions with increasing lead concentrations, and the highest increase was seen in the groups exposed to the highest level of lead. By contrast, total amounts and concentrations of Na in the root, and accumulation of P, Ca, Na, Cd, and Ni in the leaves were reduced. Lead, which was accumulated in a dose-dependent manner in both soybean varieties, reduce the growth of the plant and cause lower uptake of some mineral by plant organs.

Keywords: soybean, $PbSO_4$, macro and microelements, aeroponic system

Introduction

In today's world, soil-based heavy metal pollution is accompanied by significant environmental problems [1]. Since the beginning of the industrial revolution, the release of biomass heavy metals has continued to increase significantly. The increase of anthropogenic applications, such as the use of urban wastes, wastewater, and fossil fuels, emissions of waste incineration units, wastes of metal mines and smelting industries, industrial waste disposal, use of agricultural chemicals such as pesticides, herbicides, and fertilizers, cause heavy metal pollution in the natural environment and the ecosystem [2, 3].

In addition to natural pollution, inadequate use of advanced technologies in developing countries and inadequate pollution prevention measures increase industry-based environmental pollution [4]. Heavy metals are a major threat to all living things when they are released into the environment, and the accumulation of heavy metals in organisms via the food chain causes serious illnesses and even deaths in these organisms [2, 5]. For this reason, the negative effects of heavy metals on living organisms should not be ignored

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[6]. When the heavy metals in the soil enter into the structure of the plants, they become harmful to the other living things indirectly by entering into the food chain, causing the plasmas to harden, swell, and shrink, precipitating proteins, collapsing the respiratory intensities and thus the reduction of O_2 consumption is the most dangerous aspect [7]. Some heavy metals are important micro-elements for plants at low doses [8, 9], but high doses prevent most plant species from growing and may cause metabolic disturbances [2, 9]. Although lead is found naturally in all plants, it is not a metal necessary for plant metabolism [10]. Lead is the most important heavy metal that generates environmental pollution because it is spread as a metal or compound and is toxic in all cases. Additionally, lead is the metal that causes the most significant damage to the ecological system with human activities. Lead affects various physiological and biochemical processes and disrupts the natural ecosystem [11]. Like many other elements, lead is an element that has an antagonistic or stimulating effect on some elements. It is known that while it promotes the uptake of lead Ca and K elements by plants, it has an inhibitory effect on Mg uptake [12]. Lead element is not absolutely necessary for plants but is present in the soil at a dose of 15-40 mg kg^{-1} and does not pose human or plant health risks unless the lead concentration in the soil exceeds 150 mg kg^{-1}. However, when exceeding 300 mg kg^{-1}, it is potentially dangerous for human health [13]. Lead entering the plant through plant roots and stomata accumulates in different parts of the plant [14] and can directly affect human health indirectly or through respiration by entering the food chain. The diseases caused by lead are bone, nerve, kidney, and cardiovascular diseases [15]. Therefore, humans need to monitor the ratio of this element in its environment.

The accumulation of lead in the plants and passing them directly on to humans has made it more important to work on the plants. Lead, which is the most important and most frequently encountered heavy metal containing toxic substances, is absorbed from the environment of all plants and accumulated in different organs of plants [10]. The lead element slows down stoma movements as well as adversely affects cell stabilization and cell wall stability, leading to a reduction in leaf area and the amount of biomass, inhibition of chlorophyll biosynthesis, triggering or inhibition in some enzyme activities. For these reasons, the plant affects the water regime. Other than these, the lead element is retained by the roots more than the exiles. At the same time, due to rooting and reducing root development, plants decrease the intake of cations and anions, thus affecting nutrient uptake [10].

The present study was conducted to determine the effects of lead distribution on some important macro and microelements in roots and leaves of soybean (*Glycine max* L.) under aeroponic conditions.

Experimental

The research was carried out according to the Factorial Trial in Completely Randomized Experimental Design with six replications in a fully controlled aeroponic climatic cabin in the Department of Field Crops laboratory, Faculty of Agriculture, Van Yuzuncu Yil University. In the study, Arısoy and Atakişi soybean varieties were used as materials.

Seeds were sterilized using sodium hypochlorite (5%) for 10 minutes, then rinsed with sterilized deionized water (DI-H_2O) three times to remove the remaining disinfectants. . It was then placed in a glass pot with 50% super large perlite (0-0.5 mm) and 50% peat and allowed to germinate at 26ºC for 4-6 days. The pH of the optimum nutrient solution (Hoagland) was maintained constant for the maximum number of elements that can be taken by the plants in the range of 5.5-5.6 [16]. Seeds were irrigated with a Hoagland solution (diluted (1:1) with deionized water) of 50-100 ml of half-strength every two days from the beginning of the first germination. For every treatment, six seedlings were transplanted in an aeroponic cabinet that had six replications in itself. So, the experiment was carried on with ten aeroponic cabinets in a fully controlled laboratory. Lead sulphate, which is poorly soluble in water but more soluble in acidic solutions, was dissolved in the acidic (pH 5.5-5.6) Hoagland nutrient solution at the determined doses (0, 25, 50, 75, and 100 mg L^{-1}). The plants were irrigated with 1/5 Half Hoagland solution containing lead ($PbSO_4$) at doses of 0, 25, 50, 75, and 100 mg L^{-1} for ten days after 25 days of planting.

Analyses of Mineral Elements

Soybean plants were harvested after 35 days, then roots and leaves were separated from each other for the determination of some macro and microelements such as P, K, Ca, Mg, Na, Fe, Cu, Zn, Pb, Cd, Co, and Ni contents. Concentrations of the above elements in the powdered herb samples were determined using the Inductively Coupled Plasma-Atomic Emission Spectroscopic (ICP/AES) apparatus under conditions of AOAC 2000 Official Method 984.27. Phosphorus (P) was determined using the molybdate-vanadate method in conjugation with a UV–Visible spectrophotometer (Shimadzu UV-1201 V) [17]. After harvesting, the sample was dried at 70ºC until the plant samples reached their constant weight, and then 200 mg of dried samples were weighed and added with 6 ml of HNO_3 and 2 ml of H_2O_2, then digested at 200ºC for 45 min in a microwave oven.

Statistical Analyses of Data

Variance analyses of the data obtained from the study were performed according to the Factorial Trial in Randomized Experimental Design with six replications. The results of the analysis of variance were evaluated according to the F test, and the significant differences were compared and grouped according to the LSD multiple comparison test (IBM SPSS 22.0).

Results and Discussion

In a plant, the roots are the organs that are first exposed to Pb ions [18], and the first resistance strategy is to prevent metals from penetrating the root tissues [19]. The roots react swiftly to the bearing of Pb by building a mechanical barrier. In some of the plants, a callose synthesis and storage are between the cell wall and the plasma membrane, and this recently formed structure plays a barrier role against stress factors, including metals [20]. During metal stress, the callose restrains intracellular transport. This can result in inhibiting large amounts of Pb ion flow and also preventing the transport of other molecules. However, callose synthesis is not a generally accepted model in plants in response to Pb. Thus, low-level Pb applications do not inhibit the uptake of small amounts of other metals, as they do not result in an accumulation of callose in the root tissue [21]. In this study, in the light of the above information, the homogenates of two soybean varieties subjected to lead applications at different doses (0, 25, 50, 75, and 100 mg L^{-1}) were analyzed, and the amount of macro and microelements in the roots and leaves were determined.

Phosphorus (P): As a result of the analyses carried out in the homogenates prepared from the roots of plants subjected to different lead doses, significant differences ($P<0.05$) were found between the varieties in terms of phosphorus amounts; thus, the highest P content was measured from Atakişi cultivar as 10.21% (Table 1). As observed in Table 1, the differences among the doses of Pb treated were not statistically significant ($P>0.05$), and the means of phosphorus doses were ranged from 9.00 to 10.31 g kg^{-1}. Lead which is not vitally necessary for plants can be found in the soil up to 15-40 mg kg^{-1}. As known, as long as the lead contained in the soil does not exceed 150 mg kg^{-1}, it does not pose a danger to human and plant health [13]. However, when it exceeds 300 mg kg^{-1}, it is potentially hazardous to the health of humans and many plant varieties. Since lead doses applied in the study did not exceed the toxic limit reported in the literature, it was found that there was no negative effect on the phosphorus accumulation in soybean roots. As seen in Table 1, statistically significant ($P<0.01$) differences were found between the cultivars and among the lead doses. The highest P (8.22 g kg^{-1}) value was obtained from the Arısoy variety, while 6.72 g kg^{-1} P was obtained from the Atakişi variety (Fig. 1a). The lead doses applied in the study adversely affected the accumulated P content in the leaves. Parallel to the increase in lead doses, it was determined that the P content of the leaves decreased. Thus, it was determined that the highest P content in the leaves was obtained from the control plots, while the lowest P content was obtained from the 75 mg L^{-1} lead dose. Güler [22], similar to our findings, found that the effect of increasing doses of lead had significant adverse effects on the P content of aerial parts of corn plants.

Potassium (K): As shown in Table 1, the differences between the cultivars and among the lead doses in terms of K element absorbed in the roots and leaves were not statistically significant ($P>0.05$). K values obtained from the roots and leaves of soybean varieties were found to be 1.07% for roots of both varieties and 2.69% and 2.58 % for leaves of Arısoy and Atakişi varieties, respectively (Table 1). It was determined that the values of the Pb doses were ranged between 0.98-1.15% in roots, while they varied between 2.52-2.83% in leaves. The results of the study were consistent with Durust et al. [13] findings. In the study, it was found that the K content of roots and leaves increased up to a dose of 50 mg L^{-1} and then decreased again (Fig. 1b). However, these increases and decreases were found to be statistically insignificant (Table 1). In his study, İğdelioğlu [23] reported that the K content of leaves was increased in parallel with the increase of Pb doses applied to the rye plant. The results of this study are partially similar to the results of the researcher. But, Güler [22] found that the increased doses of Pb (0, 50, 100, and 150 mg L^{-1}) caused a decrease in the K content in the stem of the corn plant. The effect of heavy metals on plant growth, development and mineral content is closely related to the genetic characteristics of the plants. There are differences in the transport of heavy metals from roots to shoots not only between the different species but also among the same species [24]. The difference between the results obtained in the studies is thought to be due to the different reactions of different plants or genotypes to metal stress.

Calcium (Ca): As a result of the analyses carried out in the homogenates prepared from the roots of plants with different doses of lead, significant differences ($P<0.01$) were found between the varieties, and the highest Ca content (0.44%) was found in Arısoy cultivar (Table 1). While the highest amount of Ca (1.20%) was obtained from the control treatment, the lowest amount of Ca (0.47%) was measured from 50 mg L^{-1} lead application (Table 1). The results of the study are partially in agreement with the findings of Yilmaz et al. [25], which reported a decrease in Ca content due to an increase in lead doses. As seen in Table 1, While the reactions of the varieties to the applied Pb doses were the same ($P>0.05$), it was found that there were statistically significant differences among the applied Pb doses in terms of Ca element accumulated in the leaves. As a result of lead applications, the highest Ca content (11.9 g kg^{-1}) was obtained from control plots, while the lowest Ca content (9.5 g kg^{-1}) was obtained from 100 mg L^{-1}, which was the highest lead dose (Table 1). In Table 1, lead dose applications had a negative effect on the Ca content accumulated in the leaves. Therefore, the amount of Ca accumulated in the leaves decreased

Table 1. Macro and microelements of soybean varieties' leaves treated with lead at different doses.

VS		Pb Doses	Roots										Leaves									
			P (%)		K (%)	Ca (%)		Mg (%)	Na (%)		Fe (ppm)		P (%)		K (%)	Ca (%)		Mg (%)	Na (%)		Fe (ppm)	
Varieties III	**Arısoy**	Control	9.71		1.10	0.70		0.97	0.50		272.11	c	8.98		2.35	1.07		0.43	0.13		35.29	
		D1	8.31		0.99	0.56		0.79	0.42		310.43	b	8.87		2.69	1.05		0.46	0.16		35.85	
		D2	9.07		1.10	0.51		0.79	0.44		297.38	bc	8.32		2.75	0.95		0.43	0.12		37.14	
		D3	8.25		0.98	0.54		0.74	0.41		256.72	d	7.10		2.93	1.11		0.50	0.11		35.12	
		D4	10.06		1.16	0.57		0.82	0.41		217.23	e	7.84		2.73	0.93		0.50	0.12		37.92	
		Mean I	**9.08**	**B**	**1.07**	**0.58**	**A**	**0.82**	**0.44**	**B**	**270.77**	**A**	**8.22**	**A**	**2.69**	**1.02**		**0.46**	**0.13**	**A**	**36.26**	**A**
	Atakişi	Control	9.15		1.02	0.52		0.76	0.36		186.91	f	7.31		2.69	1.32		0.51	0.10		32.79	
		D1	10.50		1.19	0.50		0.83	0.52		220.59	e	7.22		2.59	1.18		0.52	0.11		36.21	
		D2	11.11		1.20	0.43		0.74	0.37		207.16	ef	7.01		2.91	1.05		0.46	0.09		34.20	
		D3	9.75		1.12	0.46		0.81	0.36		219.51	e	5.73		2.30	1.08		0.47	0.09		36.30	
		D4	10.56		0.79	0.60		0.78	0.25		364.10	a	6.35		2.41	0.97		0.44	0.05		37.05	
		Mean I	**10.21**	**A**	**1.07**	**0.50**	**B**	**0.79**	**0.37**	**A**	**239.65**	**B**	**6.72**	**B**	**2.58**	**1.12**		**0.48**	**0.09**	**B**	**35.31**	**B**
LSD (0.05)			0.89		0.12	0.05		0.07	0.05		24.69		0.45		0.34	0.11		0.03	0.02		3.34	
Pb doses II		Control	9.43		1.06	0.61	a	0.87	0.43	ab	229.51	c	8.14	a	2.52	1.19	a	0.47	0.12	ab	35.36	c
		D1	9.40		1.09	0.53	ab	0.81	0.47	a	265.51	ab	8.05	a	2.64	1.11	ab	0.49	0.13	a	36.03	ab
		D2	10.09		1.15	0.47	b	0.77	0.41	abc	252.27	b	7.66	ab	2.83	1.00	ab	0.45	0.11	bc	35.67	b
		D3	9.00		1.05	0.50	b	0.78	0.38	bc	238.12	bc	7.10	bc	2.62	1.09	ab	0.48	0.10	bc	35.71	b
		D4	10.31		0.98	0.58	a	0.80	0.33	c	290.66	a	6.42	c	2.57	0.95	b	0.47	0.09	c	36.17	a
		Mean	**9.65**		**1.07**	**0.54**		**0.80**	**0.40**		**255.21**		**7.47**		**2.63**	**1.07**		**0.47**	**0.11**		**35.79**	
LSD (0.05)			**1.40**		**0.19**	**0.08**		**0.11**	**0.08**		**39.04**		**0.71**		**0.54**	**0.18**		**0.05**	**0.02**		**5.27**	
Varieties MS			19.41	*	8.17	0.08	**	0.02	0.06	*	14524.61	*	33.65	**	0.19	0.15		0.01	0.03	**	13.63	
Lead MS			3.48		0.05	0.04	**	0.02	0.03	*	6972.90	*	6.214	**	0.17	0.11	*	0.01	0.01	**	1.24	*

MS: Mean square
VS: Variation sources
:** %5; *:** %1 significant level
I : There is no statistical (P>0.05) difference between the means shown with the same capital letters in the same column.
II : There is no statistical (P>0.05) difference between the means shown with the same lowercase letters in the same column.
III: There is no statistical (P>0.05) difference between the means shown with the same *italic lowercase* letters in the same column.

as the lead dose increased (Fig. 1c). Contrary to our findings, İğdelioğlu [23] stated that increasing Pb doses had a positive effect on Ca accumulation in rye leaves. It can be said that this is due to the difference in metals and plant species that are transported to the roots and leaves through the xylem.

Magnesium (Mg): It was determined that there was no statistically significant ($P>0.05$) difference between the cultivars and among the lead doses in terms of Mg element absorbed in the roots and leaves. The amount of Mg determined from the roots of soybean varieties was found to be 0.82% (Arısoy) and 0.79% (Atakişi), respectively. The values of magnesium content for Pb doses were determined as 0.87, 0.81, 0.77, 0.78 and 0.80%, respectively (Table 1). In Table 1, it was determined that Mg values for soybean varieties were 0.46 g kg^{-1} for Arısoy and 0.48 g kg^{-1} for Atakişi cultivar, and Mg contents of leaves were 0.45-0.49 g kg^{-1} according to lead doses (Fig. 1d). Low-level Pb applications do not inhibit the uptake of other metals, as they do not result in an accumulation of callose that prevents the ingress of metals in the root tissue [21]. İğdelioğlu [23] reported that increasing Pb dose applications had a positive effect on Mg content in rye leaves and that maximum Mg content (0.39 g kg^{-1}) was obtained from the highest Pb dose. But in another previous study, Güler [22] reported that increasing doses of Pb in the corn plant did not produce a significant change in the Mg content detected in the stem of the plant.

Sodium (Na): As a result of the analyzes carried out with the homogenates prepared from the roots and leaves of plants treated with different doses of lead, significant differences ($P<0.05$) were found between the varieties and among the lead doses in terms of Na contents. The highest Na content was observed as 0.58% in the roots and 0.13% in the leaves of the Arısoy variety (Table 1). From Table 1, the highest (0.47%)

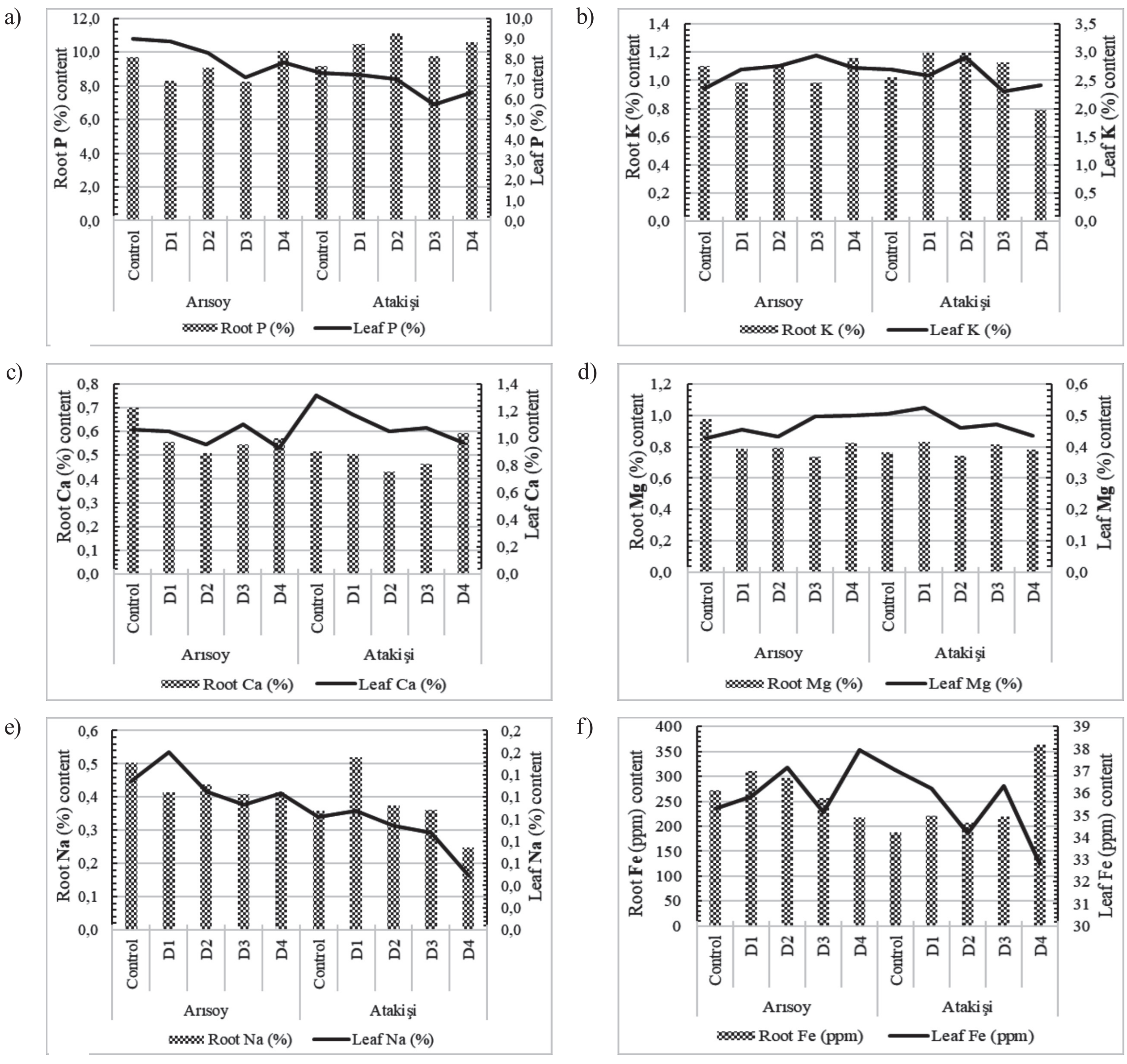

Fig. 1. Chemical components of soybean varieties after lead stress.

and the lowest (0.33%) Na content were obtained from the 25 mg L^{-1} and 100 mg L^{-1} lead applications in the root, while the highest (0.13%) and the lowest (0.09%) of Na content in the leaves were obtained from 25 mg L^{-1} and 100 mg L^{-1} of lead the applications. These results are partially in agreement with the findings of Lamhamdi et al. [26], who reported that high amounts of lead in culture media caused a decrease in sodium. As can be seen from Table 1 and Fig. 1e), the lead doses applied in the study adversely affected the Na content accumulated in the leaves. Similar to the findings obtained in this study, İğdelioğlu [23] reported that increasing Pb doses decreased the Na content detected in the leaf of the rye plant in parallel with the increase of Pb doses.

Iron (Fe): As seen in Table 1, it was determined that there was no statistically significant (P>0.05) difference between the cultivars and among the lead doses in terms of Fe element absorbed in the roots and leaves of soybean cultivars. The highest Fe content was observed as 270.77 ppm in the roots and 36.26 ppm in the leaves of the Arısoy variety (Table 1). From Table 1, the highest (290.66 ppm) and the lowest values (229.51 ppm) of Fe contents of the roots were obtained from the 100 mg L^{-1} and 0 mg L^{-1} lead applications, while the highest (35.17 ppm) and the lowest values (35.36 ppm) of Fe contents of the leaves were obtained from 100 mg L^{-1} and 0 mg L^{-1} of lead the applications. As a result of the study, it was found that the doses of lead increased Fe absorption in soybean roots, contrary to Yilmaz et al. [25] findings, which indicated that increasing lead doses in the roots of eggplant reduced Fe uptake. When the data obtained as a result of the Fe analysis were evaluated statistically, the interactions between the varieties and lead doses had significant (P<0.01) effects on the amount of Fe in the roots of cultivars. The highest amount of Fe (364.10 mg kg^{-1}) was obtained from the 100 mg L^{-1} lead application to the Atakişi variety, while the lowest amount of Fe (186.91 mg kg^{-1}) was measured from the control treatment of the same variety (Table 1). İğdelioğlu [23] reported that increasing the Pb dose, in contrast with the findings of this study, adversely affects the Fe content accumulated in the leaves of the rye plant. Güler [22] stated that due to the Pb applications, there was an irregular change in the Fe content detected in the stem of the plant and that increasing Pb doses adversely affected the Fe ratio compared to control. Lead suppresses plant growth and inhibits the uptake of nutrients into the plant, causing the nutrient requirement within the plant to be met, and this affects the ion distribution in the plant [27].

Copper (Cu): As shown in Table 2, in terms of the Cu element absorbed in the roots, the differences between the varieties were not statistically significant (P>0.05), while in terms of absorption in the leaves were significant (P<0.01). Cu values obtained from the roots and leaves of soybean varieties were found to be 6.04 and 5.97 ppm for roots, while 1.12 and 1.95 ppm for leaves of Arısoy and Atakişi varieties, respectively (Table 1). It was determined that the values of the Pb doses ranged between 0.98-1.15% in roots, while they were varied between 2.52-.83% in leaves. From Table 2 and Fig. 2a), in terms of roots and leaves of both cultivars, it was determined that the differences between Pb doses applied were statistically significant (P<0.01), and the highest amount of accumulated Cu contents (7.76 and 1.90 ppm) of the roots and leaves were obtained from 100 mg L^{-1} lead application. Increasing lead concentrations also caused an increase in the amount of copper absorbed by the roots and leaves. As lead doses increased, relatively increased the roots and leaves Cu content was observed. Welsh and Denny [28] reported that there was a significant positive relationship between lead and Cu concentrations, although they varied according to plant species. İğdelioğlu [23], who has investigated the effect of lead doses on nutrient content in the rye, reported that increasing Pb doses positively affected Cu content in leaves, similar to the results obtained in this study. In another previous study, Güler [22] determined that there was a decrease in Cu concentration parallel to the increase of Pb doses applied in the stem of the corn plant.

Zinc (Zn): According to the results, it was found that there were significant (P<0.01) differences between the varieties in terms of accumulated Zn amounts in the roots. The highest Zn content (36.48 ppm) in the roots was observed in the Arısoy cultivar (Table 2). As shown in Table 2, the relative differences among Pb doses were not statistically significant (P>0.05), and Zn contents of the roots depending on the Pb doses varied as 31.95-35.55 ppm, respectively. It is known that lead applied in high concentrations has a negative effect on Zn uptake of plants and causes Zn deficiency. However, it was reported that it had no toxic effect on plants under low lead concentrations [13]. The effect of lead applications on the Zn element accumulated in leaves of soybean varieties was found to be statistically significant (P<0.05). The highest Zn contents (22.83, 22.95, 23.28, and 22.43 ppm) were obtained from 0, 25, 50, 100 mg L^{-1} lead doses, and the lowest Zn content (19.18 ppm) was observed from 75 mg L^{-1} lead dose (Table 2 and Fig. 2b). İğdelioğlu [23] reported that increasing Pb dose applications had a positive effect on Zn content determined in Rye leaves, but, Güler [22] determined that there is a decrease in parallel with the increase of Pb doses applied in Zn determined in the stem of the corn plant.

Lead (Pb): As seen in Table 2, it was found that there wasn't a significant (P<0.01) difference between the varieties in terms of accumulated Zn amounts in the roots. The amount of Pb obtained from the roots of soybean varieties was determined as 20.62 ppm (Arısoy) and 20.40 ppm (Atakişi), respectively (Table 2). From Table 2, the differences among the Pb doses were found to be statistically significant (P<0.01), and the highest lead amount (39.44 ppm) was obtained from 100 mg L^{-1} lead application, while the lowest lead amount (0.81 ppm) was measured from 0 mg L^{-1} lead. As seen

Table 2. The mean of macro and microelements detected in the root.

VS		Pb Doses	Roots Cu (ppm)		Roots Zn (ppm)		Roots Pb (ppm)		Roots Cd (ppm)	Roots Co (ppm)	Roots Ni (ppm)		Leaves Cu (ppm)		Leaves Zn (ppm)		Leaves Pb (ppm)		Leaves Cd (ppm)		Leaves Co (ppm)	Leaves Ni (ppm)	
Varieties [III]	**Arısoy**	Control	5.86		40.29		1.44		0.29	0.72	2.90		1.20		23.14		3.43	b	0.22		0.11	1.74	
		D1	5.79		40.52		10.25		0.25	0.84	2.67		1.25		24.37		4.23	ab	0.17		0.21	2.68	
		D2	6.73		38.53		21.63		0.24	0.95	2.55		0.99		23.22		3.01	c	0.15		0.16	2.44	
		D3	6.45		33.24		28.37		0.15	0.81	2.65		0.95		18.64		3.50	b	0.15		0.14	2.50	
		D4	5.34		29.82		41.44		0.24	0.66	2.36		1.21		23.02		4.92	a	0.13		0.53	2.37	
		Mean [I]	**6.04**		**36.48**	**A**	**20.62**		**0.23**	**0.79**	**2.63**	**A**	**1.12**	**B**	**22.48**		**3.82**	**A**	**0.16**	**A**	**0.23**	**2.35**	
	Atakişi	Control	4.39		28.76		0.18		0.17	0.76	1.81		1.25		22.51		0.53	f	0.12		0.49	2.53	
		D1	5.65		31.87		9.78		0.27	0.57	2.12		1.85		21.54		1.08	e	0.16		0.26	2.66	
		D2	4.65		26.63		25.47		0.22	0.51	2.27		1.96		23.34		1.61	d	0.11		0.32	2.42	
		D3	5.00		30.66		29.13		0.25	0.76	2.24		2.12		19.72		3.99	b	0.04		0.50	2.55	
		D4	10.17		41.29		37.44		0.28	0.89	2.51		2.58		21.84		4.21	ab	0.09		0.26	2.38	
		Mean [I]	**5.97**		**31.84**	**B**	**20.40**		**0.24**	**0.70**	**2.19**	**B**	**1.95**	**A**	**21.79**		**2.28**	**B**	**0.10**	**B**	**0.36**	**2.51**	
LSD (0.05)			**0.70**		**3.21**		**4.43**		**0.05**	**0.20**	**0.27**		**0.21**		**1.71**		**0.67**		**0.04**		**0.16**	**0.27**	
Pb doses [II]		Control	5.12	b	34.53		0.81	d	0.23	0.74	2.35		1.23	c	22.83	a	1.98	c	0.17	a	0.30	2.14	b
		D1	5.72	b	36.19		10.01	c	0.26	0.70	2.39		1.55	b	22.95	a	2.66	b	0.16	a	0.23	2.67	a
		D2	5.69	b	32.58		23.55	b	0.23	0.73	2.41		1.48	bc	23.28	a	2.31	bc	0.13	ab	0.24	2.43	ab
		D3	5.73	b	31.95		28.75	b	0.20	0.78	2.44		1.54	bc	19.18	b	3.75	ab	0.10	b	0.32	2.53	ab
		D4	7.76	a	35.55		39.44	a	0.26	0.77	2.43		1.90	a	22.43	a	4.57	a	0.11	ab	0.39	2.37	ab
		Mean	**6.00**		**34.16**		**20.51**		**0.23**	**0.75**	**2.41**		**1.54**		**22.13**		**3.05**		**0.13**		**0.30**	**2.43**	
LSD (0.05)			**1.11**		**5.08**		**7.01**		**0.07**	**0.35**	**0.43**		**0.32**		**2.70**		**1.05**		**0.06**		**0.25**	**0.43**	
Varieties MS			0.05		322.21	**	0.76		1.84	0.14	2.86	**	10.37	**	7.14		35.28	**	0.05	**	0.27	0.39	
Lead MS			12.29	**	40.79		2801.20	**	0.01	0.01	0.02		0.69	**	33.80	*	13.91	**	0.01	*	0.05	0.47	*

MS: Mean square
VS: Variation sources
:** %5; *:** %1 significant level
I : There is no statistical (P>0.05) difference between the means shown with the same capital letters in the same column.
II : There is no statistical (P>0.05) difference between the means shown with the same lowercase letters in the same column.
III: There is no statistical (P>0.05) difference between the means shown with the same *italic lowercase* letters in the same column.

in Table 2, statistically significant (P<0.01) differences were found between varieties and lead doses in terms of Pb element content determined in the leaves. The highest Pb (3.82 ppm) value was obtained from the Arısoy cultivar, while the lowest Pb (2.28 ppm) was monitored from the Atakişi cultivar. According to the average values, significant increases in the PB content of the leaves occurred in parallel with the increase in lead doses applied in the study. The highest Pb content (4.57 ppm) of leaves was determined from 100 mg L^{-1} lead dose, while the lowest Pb content (1.98 ppm) was obtained from the control application. The differences in the responses of the varieties to lead doses led to interactions of varieties and lead doses to be significant. In the study, the highest Pb content (4.92 ppm) was obtained from the application of 100 mg L^{-1} lead in the Arısoy cultivar (Fig. 2c). In the previous studies of the subject, İğdelioğlu [23], in his study on rye, stated that Pb content was increased in the leaves parallel to the increase of Pb doses, and the highest Pb content (13.63 ppm) was obtained from the highest Pb dose. Güler [22] reported that as a result of different lead dose (0, 50, 100, and 150 mg L^{-1}) applications, Pb content in the stem of the corn plant showed an increase parallel to the increase in doses.

Cadmium (Cd): In terms of the Cd element absorbed in the roots, the differences between the varieties were not statistically significant (P>0.05), while in terms of absorption in the leaves were significant (P<0.01). CD contents obtained from the roots of soybean varieties were determined as 0.23 ppm (Arısoy) and 0.24 ppm (Atakişi). In the leaves, the highest content was determined as 0.16 ppm from the Arısoy variety (Table 2). As observed in Table 2 and Fig. 2d), the differences among the Pb doses were not statistically significant (P>0.05), and the averages of Cd contents of root obtained from the different doses varied from

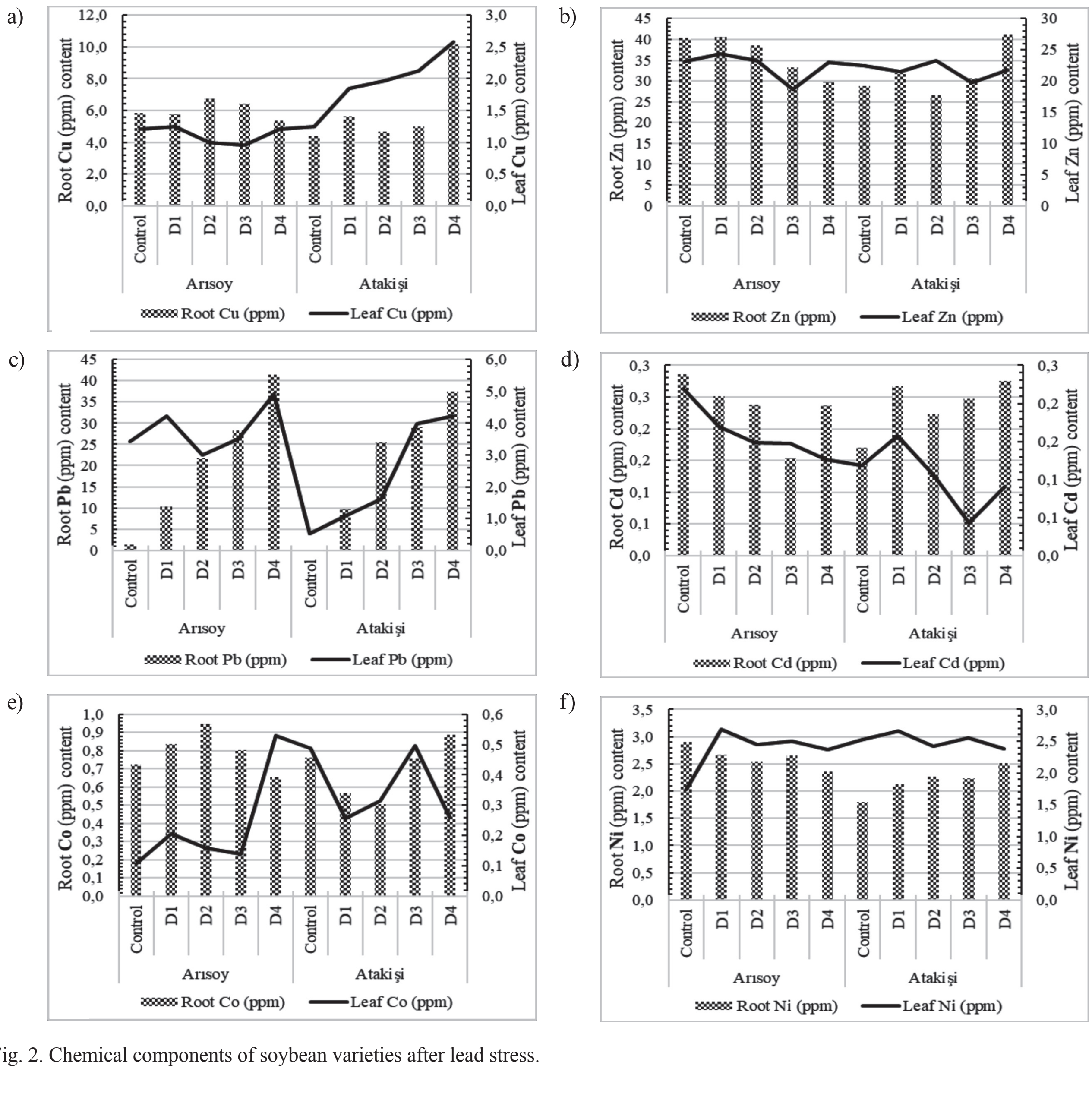

Fig. 2. Chemical components of soybean varieties after lead stress.

0.20 to 0.26 ppm. Based on the applied lead doses, the highest Cd content accumulated in the leaves was obtained from the 0 and 25 mg L^{-1} doses with 0.16 and 0.17 ppm, while the lowest was monitored from 75 mg L^{-1} lead dose as 0.10 ppm. Applications of Pb at low concentrations do not prevent the ingestion of other metals as they do not result in an accumulation of callose that prevents the ingress of metals in the root tissue [21].

Cobalt (Co): According to the results presented in Table 2, the numerical differences between the varieties had no statistical significance (P>0.05). The amounts of Co obtained from the roots were 0.79 ppm (Arısoy) and 0.70 ppm (Atakişi), respectively (Table 2). And also, relative differences among the Pb doses were not statistically significant (P>0.05), and the Co contents determined from the Pb doses in the roots ranged as 0.70-0.78 ppm, respectively. In the study, it was determined that the genotypic difference of cultivars and lead doses had no significant (P>0.05) effect on the accumulation of Co content of leaves. The Co contents obtained from the varieties were 0.23 ppm (Arısoy) and 0.36 ppm (Atakişi). And also, Co values obtained from Pb doses were found to be between 0.23-0.39 ppm (Table 2 and Fig. 2e).

Nickel (Ni): As a result of the analyses carried out in the homogenates prepared from the roots of the varieties, it was determined that there were significant (P<0.01) differences between the varieties in terms of Ni amounts, and the highest Ni content was observed in Arısoy cultivar (2.63 ppm) (Table 2). In Table 2, the relative differences between Pb doses were not statistically significant (P>0.05), and the amounts of Ni obtained from the doses ranged between 2.35-2.44 ppm, respectively. Low rates of Pb weren't found to cause any mechanical obstruction in the root tissue [21], and the results of this research confirm this finding. In the study, it was determined that Pb doses did not prevent the ingress of Ni to the roots.

The effect of lead applications on Ni elements accumulated in leaves was statistically significant (P<0.05). However, there was no statistically significant difference between the varieties used in the study. Ni contents of leaves were determined as 2.35-2.51 ppm in Arısoy and Atakişi varieties. The highest Ni content (2.67 ppm) was obtained from the 25 mg L^{-1} lead dose application, and the lowest Ni content (2.14 ppm) was obtained from the control plots (Table 2 and Fig. 2f). It is known that the uptake of certain metals at high rates inhibits the uptake of other metals. This phenomenon, known as metal antagonism, causes the scarcity of metals (such as Fe, Zn, Cu), which should be taken as micronutrients, reduces the synthesis of molecules containing these metals in the structure, and stops the reactions containing these metals. Metals, when taken up at high concentrations, cause numerous damages at the cellular level, and this situation can be tolerated differently among the different plant organs. Additionally, the lead element adversely affects the plant water regime due to its negative effects on cell turgor, cell wall stability, stomata, and leaf area. Since Pb held by the roots reduces the root growth and thus reduces the cation and anion uptake of the plants. Therefore, it has negative effects on nutrient intake [10].

Conclusion

Today, environmental pollution has become one of the most serious problems faced by humanity. Heavy environmental pollution, especially in soil and air, threatens fauna and flora. The accumulation of heavy metals in the soil is not only effective on soil fertility and ecosystem activities but also affects plants, animals, and human health due to the deterioration of the food chain as they affect many metabolic events such as photosynthesis, respiration, growth, and development of the plant. The results clearly showed that the nutrient composition in the roots and leaves of the plants changed as a result of lead exposure. Under lead stress, differences were found in the content of mineral elements identified in the roots and leaves of soybean varieties (Table 1, 2). According to the results, Fe, Cu, and Pb contents of the roots and leaves were increased in direct proportions with increasing lead concentrations, and the highest increase was seen in the groups exposed to the highest level of lead. By contrast, the concentrations of Na in the root, and accumulation of P, Ca, Na, Cd, and Ni in the leaves were reduced significantly. Since this research was carried out in a controlled climate room and soilless environment (stagnant nutrient solution), it would be beneficial to integrate the information obtained with the results obtained from soil and greenhouse and field trials.

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Conflict of Interest

The authors declare no conflict of interest.

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