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Research Article

Influences on to Nutrient Uptake of Lead, Chromium and Cadmium Toxicity in Switchgrass *(Panicum virgatum* L.) Plant and Linear Regression Analyses

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Abstract: Mining, urban or industrial solid, gas and liquid wastes, pesticide and artificial fertilizer use, paint industry and car exhaust gases cause the release of heavy metals to the nature. This heavy metal stress caused by environmental pollutants limits the growth of plants and reduces product yield and quality. At the same time, heavy metal stress interferes uptake, transport, and utilization of plant nutrients by plants. Consequently, this study was performed to evaluate toxicity and tolerance of lead, cadmium and chromium in switchgrass that can adapt to a wide range of habitats and climates. In order to determine the effects of heavy metals on the nutrient uptake, the switchgrass plant *(Panicum virgatum* L.*)* was grown in artificially contaminated soil with different concentrations of Cd, Pb, Cr solutions. The changes in macro- and micro-nutrient contents in the switchgrass as affected by the different concentrations of the applied metals were evaluated. Although chromium, cadmium and lead have phytotoxic effect and are non-essential elements for plants, it was observed that these elements easily absorbed and accumulated in the aboveground parts of switchgrass. In general, it was found that macro- and micro-nutrient concentrations in the switchgrass were significantly or relatively decreased in different doses of Pb, Cd and Cr applications. Only Ca concentrations in the plant increased significantly with the applied different Pb doses, due to the competition of Ca^{2+} and Pb^{2+} for introduction to stem cells. However, the obtained results were interpreted using linear regression and Pearson correlation.

Switchgrass *(Panicum virgatum* L.) Bitkisinde Kurşun, Krom ve Kadmiyum Toksisitesinin Besin Alımı Üzerindeki Etkileri ve Lineer Regresyon Analizleri

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Öz: Madencilik, kentsel veya endüstriyel katı, gaz ve sıvı atıklar, pestisit ve suni gübre kullanımı, boya sanayi ve araba egzoz gazları ağır metallerin doğaya salınmasına neden olur. Çevresel kirleticilerin neden olduğu bu ağır metal stresi, bitkilerin büyümesini sınırlamakta, ürün verimini ve kalitesini düşürmektedir. Aynı zamanda, ağır metal stresi bitki besin maddelerinin bitkiler tarafından alınmasını, taşınmasını ve kullanılmasını engeller. Sonuç olarak, bu çalışma geniş bir habitat ve iklim yelpazesine uyum sağlayabilen switchgrass'taki kurşun, kadmiyum ve kromun toksisitesini ve toleransını değerlendirmek için yapılmıştır. Ağır metallerin besin alımı üzerindeki etkilerini belirlemek amacıyla, Switchgrass (*Panicum virgatum* L.) bitkisi farklı konsantrasyonlarda Cd, Pb, Cr

Anahtar Kelimeler
Kadmiyum,
Krom,
Kurşun,
Mineral besin,
Switchgrass

çözeltileri ile suni olarak kontamine edilmiş toprakta yetiştirilmiştir. Uygulanan metallerin farklı konsantrasyonlarından etkilenen switchgrasstaki makro ve mikro besin içeriklerindeki değişiklikler değerlendirilmiştir. Krom, kadmiyum ve kurşun fitotoksik etkiye sahip ve bitkiler için esansiyel olmayan elementler olmalarına rağmen, bu elementlerin switchgrass bitkisinin toprak üstü kısımlarında kolayca emilip biriktiği gözlenmiştir. Genel olarak, switchgrass bitkisindeki makro ve mikro besin konsantrasyonlarının farklı dozlarda Pb, Cd ve Cr uygulamalarında önemli ölçüde veya nispeten azaldığı bulunmuştur. Ca^{2+} ve Pb^{2+}'nın kök hücrelere giriş için rekabet etmesi nedeniyle, uygulanan farklı Pb dozları ile sadece bitkideki Ca konsantrasyonları önemli ölçüde artmıştır. Bununla birlikte elde edilen sonuçlar lineer regresyon ve Pearson korelasyonu kullanılarak yorumlanmıştır.

1. Introduction

The studies on plants that grow in contaminated agricultural soils with heavy metals have gained momentum in recent years. Transport of heavy metals through food chains has made these studies much more important. Water intake is the most important way for heavy metals to enter the plants. Animals fed with these plants are also exposed to heavy metals. The consumption of animal products and plants polluted with these metals can cause health problems in humans.

Elements with an atomic weight of 20 and above are classified as heavy metals, which are naturally occurring elements and have a relatively high density compared to water (at least 5 times higher than water density) (Tchounwou et al., 2012). Heavy metal threats have continued to increase in ecological and public health fields since they are intensively used in agricultural, industrial, technological, and domestic applications.

Heavy metals, that are abundant in the environment, are iron, zinc, copper, manganese, silver, lead, and nickel. Although mercury, cadmium, chromium, and arsenic are rarely found in environment, even the low concentrations of these metals have toxicological effects. Heavy metals such as Fe, Mn, Cu, Ni, Zn, Mo, and Co are necessary micro-nutrients for animals and plants (Reeves & Baker, 2000; Wintz et al., 2002), since these metals play an important role in the physiological and biochemical functions of animals and plants (Nagajyoti et al., 2010). But at the same time, in plants exposed to high levels of these metals, toxicity symptoms may occur. Therefore, some heavy metals such as Cr, Cd and Pb have phytotoxic effect. Among these metals, Pb has a negative effect on the growth, photosynthesis processes and morphology of plants (Nagajyoti et al., 2010). Negative effects of Cd on mineral nutrition, photosynthetic and respiratory activities, membrane functions, enzyme activities and hormone balance are mentioned (Clysters & Van Assche, 1985; Boussama et al., 1999; Chien & Kao, 2000). Under Cr toxicity stress, it has been reported that ultra-structural modifications in cell membrane and chloroplasts occur, plant growth is reduced, water relations and mineral nutrition are impaired, chlorosis in leaves is persisted, stem cells are damaged, enzymatic activities change and pigment content decrease (Ali et al., 2015; Farooq et al., 2016; Reale et al., 2016).

Heavy metal stress interferes uptake, transport and utilization of plant nutrients by plants. For example, presence of an excess concentration of Pb in soil structure causes imbalance in the intake of mineral nutrients in plants. Most of the effects observed in plants under Pb toxicity occur in nutrient content and internal nutrient ratios as a result of mineral imbalance (Kabata-Pendias & Pendias, 1992). Cadmium contamination in the soil can impair the uptake and migration of mineral nutrients, resulting in reduced growth, so that, there is a negative correlation between the uptake and distribution of fundamental macro/micro-nutrients in several plant species (Kim et al., 2003; Shukla et al., 2003; Adhikari et al., 2006). Excessive Cr concentration may lead to the separation of nutrients from important binding sites, thus reducing the uptake and displacement of essential elements (Mengel & Kirkby, 1987).

Switchgrass *(Panicum virgatum* L.*)*, a characteristic derivative of the Tallgrass Prairie, is a domestic warm seasonal grass and a main element of natural and anthropogenic pastures throughout most of North America (Calles Torrez et al., 2013). Switchgrass can adapt to marginal lands, and tolerates water of soil deficits and low soil nutrient concentrations (Sokhansanj et al., 2009). Switchgrass is defined as a potential bioenergy product for cellulosic ethanol due to its rapid growth rate and nutrient utilization efficiency (Mann et al., 2012). The objective of the present study was to determine how the heavy metal (Cd, Cr, Pb) affects the relative uptake of macro/micro-nutrients in switchgrass.

2. Material and Methods

2.1. Plant materials and heavy metal treatments

The experiment was conducted as three times replicates completely randomized block design, in plastic pots in the greenhouse. The greenhouse was organized for a day/night temperature of 25/20ºC and 16 h light period. The soil used in experiments was dried with air and sieved by using 5-mesh sieve. The soil texture was clay-loamy, organic matter content of the soil was 1.7%, salt content 0.04%, lime content 28%, pH 7.1, total N 0.06%, total P 3.95 mg kg^{-1}, total K 49.61 mg kg^{-1}, Pb 0.026 ppm, Cr 0.377 ppm and Cd 0.0006 ppm.

As the source of soil pollutant, $Pb(NO_3)_2$ for lead, $Cd(NO_3)_2$ for cadmium, $Cr(NO_3)_3$ for chromium were used in the experiment. The solutions of 0, 30, 60, 90, 120 mg kg^{-1} concentrations of Pb; 0, 2.5, 5, 10, 20 mg kg^{-1} concentrations of Cd and 0, 40, 80, 120, 160 mg kg^{-1} concentrations of Cr were prepared for applications. Two kilograms of the soil were weighed for each pot and transferred to the pots. The specified volume of metal solutions was applied to the soils to the pots. Six seeds were planted in each pot and the pots were placed in the greenhouse. After the plantation, DAP (diammonium phosphate), AS (ammonium sulfate) and K_2SO_4 (potassium sulfate) as basic fertilizer were applied in forms of 200 mg kg^{-1} K, 150 mg kg^{-1} P and 300 mg kg^{-1} N to each pot. Then, the plants were watered evenly with distilled water.

2.2. Chemical analyses

The total growth periods for plants were determined as 60 days. The plants were harvested at the end of the growth period. Harvested plants were washed with deionized water and dried up to constant weight at 70ºC in an oven. Dried plant samples were pulverized with grinder and wet-digested in HNO_3:$HClO_4$ (6:2 v/v) solution by microwave digestion (Ethos Easy, Milestone, Italy). Then, the resulting solutions were diluted with deionized water. The macro- (Ca, K, P, Mg) and micro-nutrient (Mn, Zn, Cu, Fe) contents in plant samples were measured by ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) (iCAP 6000 Series, Thermo Fisher, USA).

2.3. Statistical analyses

Data were statistically analyzed with analysis of variance (One-way ANOVA) using the SAS Statistics with Version 9.4 software. Mean comparisons were performed using the Duncan's Multiple Range Test at a 0.05 level of probability. In tables, a statistical analysis was also conducted independently for each heavy metal. Linear regression and Pearson correlation were used between heavy metals and mineral nutrients.

3. Results

3.1. Effect of heavy metals on macro-nutrients uptake

The influences of different doses of Pb, Cr and Cd metals on the macro-nutrients uptake in the switchgrass are demonstrated in the Fig. 1. Pb physically inhibits the adsorption of many ions (K, Mg, Ca, Cu, Fe, Mn, Zn) from plant roots (Godbold & Kettner, 1991). Similar evaluations have been reported in studies conducted in other plants (Päivöke, 2002; Sinha et al., 2006; Wang et al., 2011; Patel et al., 2017). It has been reported in previous study that at low concentrations of Pb, Cd and Cr heavy metals applied in switchgrass, very little regression was observed in the aboveground biomass (plant height, green and dry biomass) compared to the control. At the same time, it was determined that heavy metal accumulation in the plant increased with increasing doses of heavy metals (Pb, Cd, Cr) applied, and the bioavailability index was above 1 at all concentrations of all three heavy metals (Alacabey & Zorer Çelebi, 2020).

In the present study, the concentrations of P and K in aboveground components of switchgrass significantly decreased, while Ca concentrations increased with increasing Pb doses. Because K^+ ions have near-ionic radii with Pb (Pb^{2+}: 132 pm and K^+: 133 pm) (Nightingale, 1959), these two ions may cause competition to pass through the same K channels of the plant (Sharma & Dubey, 2005). It has been reported to compete with Pb^{2+} for entry into Ca^{2+} stem cells. In the presence of Ca^{2+} in the medium, Pb^{2+} intake and toxicity decrease (Kim et al., 2002). The increase in Ca concentration despite increasing Pb doses can be explained by this competition. Mg concentrations increased in plants exposed to 60 mg kg^{-1} Pb dose compared to control group, however, there was no significant change in Mg content in another dose application.

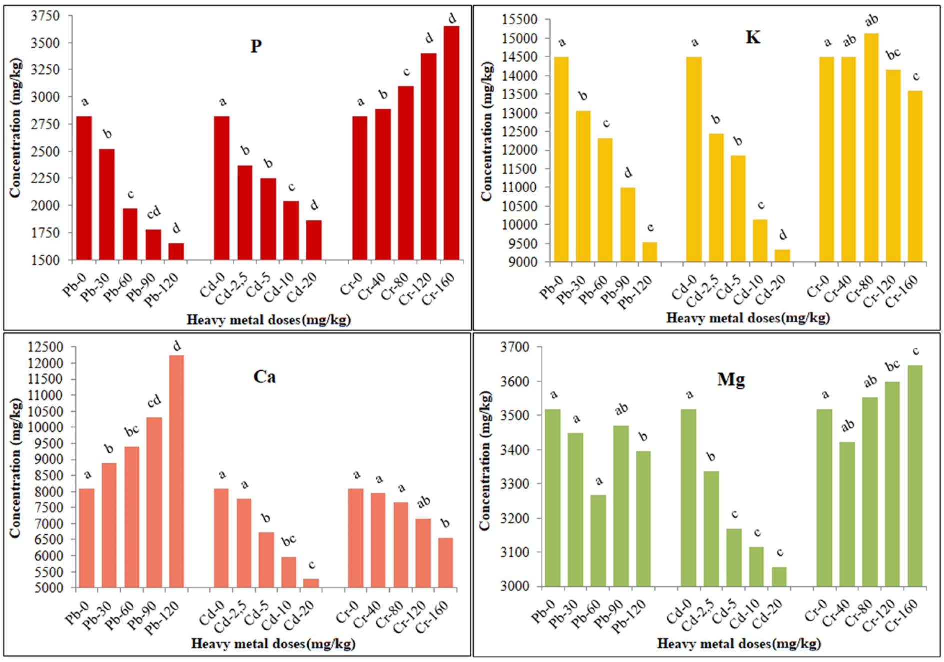

Figure 1. The content of macro-nutrient in switchgrass treated with Pb, Cd and Cr doses.

The macro-nutrient concentrations (Ca, K, P, and Mg) in the aboveground parts of switchgrass significantly decreased in Cd application. The macro-nutrient intake value obtained when the highest Cd dose was applied was found to be approximately 1.5 times higher than the value obtained when the lowest dose was applied. Some studies on macro-nutrient content (Ca, Mg, K) in sunflower plants showed that macro-nutrient concentrations decreased with increasing Cd dose in contaminated soils (Rivelli et al., 2014; Arshad et al., 2016). It has been determined that Cd reduces the intake of necessary nutrients in many plant species (Wahid et al., 2008; Daud et al., 2013; Eren, 2018). Cd and Zn have a chemical similarity with each other due to in the same group of the periodic table. Although Zn is a necessary micro-nutrient for animals and plants, Cd has a toxicity which can lead to breakdown of metabolic processes (Campbell, 2006). In the process of nutrient intake, Cd that acts as Zn is taken into the structure of the plant and prevents the intake of other nutrients. The solubility of $Cd(NO_3)_2$ used in the experiment also increases the intake of Cd to plant tissue. Solubility in water of $Cd(NO_3)_2$ at 20°C (136 g 100 g^{-1}) is greater than the solubility of the macro elements (K:31.6 g 100 g^{-1}, Ca:121.2 g 100 g^{-1}, Mg:69.5 g 100 g^{-1}) and thus causes further dissolution in the water in soil structure. This may be thought to facilitate the absorption of Cd from the soil by plants.

Cr has been implicated in interfering with the absorption or deposition of nutrients such as Ca, Mg, K and P in both air and root parts of plants (Samantaray et al., 1998). It may be related to exposure to excess Cr doses to removal of important nutrients from physiological binding sites. This contrary interaction between mineral nutrients and Cr may be due to interactions in both soil and plant tissues. At the same time, synergistic interactions between Cr and some basic nutrients such as P, Mg and Fe were also observed. The P concentration in switchgrass slightly increased in 160 mg kg^{-1} Cr application as compared to control, but Ca concentrations decreased. It can be said that the addition of Cr inhibits the effect of Ca intake of plants. The concentration of K was slightly increased in the plants exposed to

80 mg kg^{-1} Cr dose compared to the control group, and K concentration was decreased in 160 mg kg^{-1} Cr dose application. However, there was no significant change in K concentration in other Cr dose treatments. The concentration of Mg in switchgrass grown in soils with a dose of 40 mg kg^{-1} Cr decreases compared to the control group, whereas the Mg concentration is increased with increasing Cr doses. However, when compared to the control group, this increase was not significant. The competition of Cr with Ca and K and the reduction intake of these elements of the plant may be due to the fact that $Cr(NO_3)_3$ has a higher solubility (130 g 100 g^{-1}) than these elements (K:31.6 g 100 g^{-1}, Ca:121.2 g 100 g^{-1}). The competition between Cr and Mg is thought to be related to the hydrated ion radius. It is known that as the hydrated radiuses of the ions increase, the adsorption decreases. Since Cr^{3+} has a higher hydrated radius (461 pm) than Mg^{2+} (428 pm) (Nightingale, 1959), it can be said that its adherence is weakened and Mg is leading.

3.2. Effect of heavy metals on micronutrient uptake

Variations in the micro-nutrient concentrations in aboveground of switchgrass with different doses of Pb, Cr and Cd applications are given in Fig. 2. The micro element concentrations, except for Mn, in switchgrass were affected by different doses of Pb applications. Fe concentrations increased in Pb treated plants as compared to Pb untreated plants. The highest Fe concentration was obtained in 90 mg kg^{-1} Pb dose application. The excess of Fe intake by the plant can be explained by the fact that the solubility of Fe^{3+} ions (138 g 100 g^{-1}) is higher than the Pb^{2+} (54.3 g 100 g^{-1}) at same temperature. A result similar to the change in Fe concentration of switchgrass was obtained in another study that was conducted on the content of Fe in leaves of *Vallisneria natans* (Lour.) Hara treated with the different concentrations of Pb (Wang et al., 2011). Zn and Cu concentrations of switchgrass were significantly decreased with increasing Pb concentrations. The effect of Pb application on Zn and Cu uptake is due to the difference between the hydrate radiuses of Pb and these elements. The Pb^{2+} has a lower hydrated radius (401 pm) than Zn^{2+} (430 pm) and Cu^{2+} (419 pm) (Nightingale, 1959), which increases Pb retention in the plant. In a study carried out in *Arachis hypogaea* L. cultivars, changes in Zn and Cu contents showed similar results (Nareshkumar et al., 2014). No significant difference in Mn content of switchgrass was observed in varying Pb doses. Similar results in different plants have been obtained with regard to the change in Mn content (Wang et al., 2011; Wojcik & Tukiendorf, 2014; Kısa et al., 2017). The variation in micro-nutrient contents in different Pb doses suggests that there are different mechanisms for the micro-element uptake of plants under the Pb stress.

Also Fig. 2 showed that Cd toxicity significantly affected Mn, Cu, Fe and Zn concentrations in aboveground of switchgrass. When compared to the Cd control dose, all of the micro-nutrient concentrations were decreased by the application of different Cd doses in the growth medium.

Excessive Cd application to plant nutrition medium causes imbalance and nutrient deficiency in plants (Rizwan et al., 2016). Due to the small hydrated radius of Cd^{2+} (Cd^{2+}: 426 pm, Fe^{3+}: 457 pm, Mn^{2+}: 438 pm, Zn^{2+}: 430 pm) (Nightingale, 1959), the retention of Cd by the plant is more preferred than Fe^{3+}, Zn^{2+} and Mn^{2+} and therefore the adsorption of these elements is reduced. It can be considered that the effect reducing the uptake of Cu by the plant is the difference in solubility between Cd and Cu. Cd (136 g 100 g^{-1}), which has a higher solubility than Cu (125 g 100 g^{-1}), is more adsorbed by the plant and preferred instead of Cu. In the study conducted seven maize genotypes, the concentration of Zn, Cu, and Mn in roots and shoots significantly decreased by the Cd toxicity (Akhtar et al., 2017). The authors stated that Cd reduces the uptake of these micro-nutrients by changing the permeability of plasma membranes and by competing for the same membrane carriers.

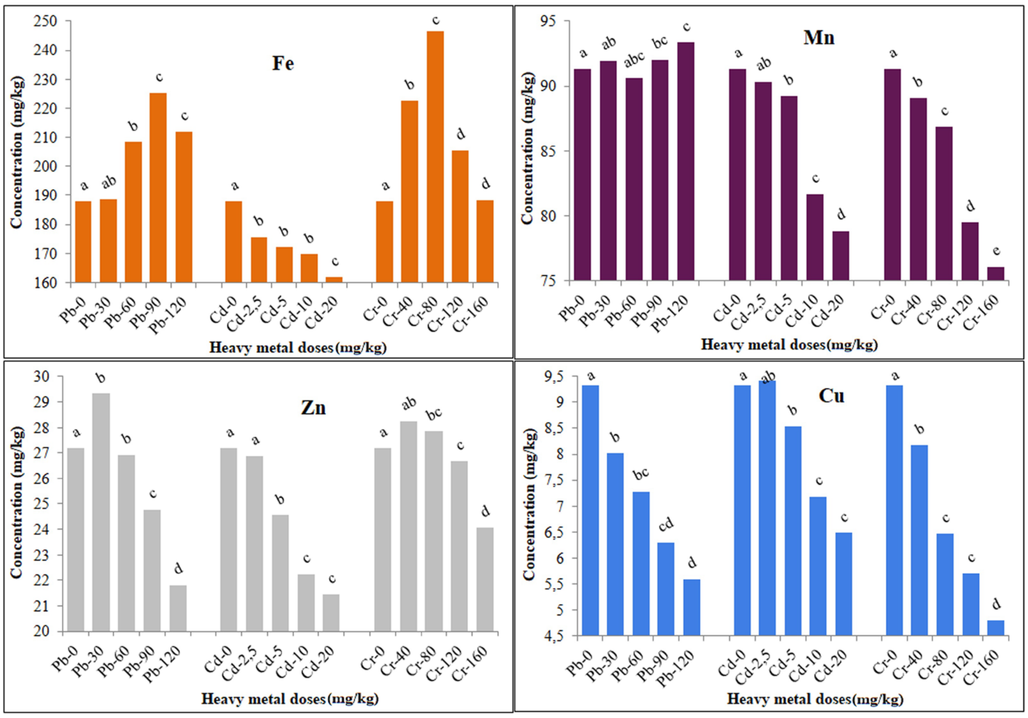

Figure 2. The content of micro-nutrient in switchgrass treated with Pb, Cd and Cr doses.

Mn and Cu concentrations were markedly decreased with increasing Cr concentration compared to control, while changes in Fe and Zn concentrations were considered insignificant (Fig. 2). Cr can reduce the absorption and deposition of important elements such as K, N, Mg, P, Ca, Zn, Fe, Cu, Mn, B and Mo by altering the uptake activity of the plasma membrane due to the competitive binding between common carriers and Cr (Shanker et al., 2005). This reduction in the intake of nutrients in Cr-stressed plants may be due to inhibition of plasma membrane H^+ATPase activity. Because inhibition of plasma membrane H^+ATPase activity may cause a reduction in transport activity of the root plasma membrane and thus reduce the intake of most nutrients (Shanker, 2003).

The Cu concentration in the highest Cr dose was found to be approximately 2 times smaller than the control treatment. Zn concentration increases in the dose of 40 mg kg^{-1} Cr according to the control dose, while the Zn content slightly decreases as the Cr dose increases. It was found that increased Cr dose up to 80 mg kg^{-1} increased Fe concentration compared to the control dose, but when the Cr dose increased from 80 mg kg^{-1} to 120 mg kg^{-1}, Fe concentration was found to decrease to the value of the control dose again. This change in the Fe concentrations with the addition of Cr can be explained by the possible competition in the adsorption regions of the plants, especially the ions having the same charge. At the same time, the fact that the ion radii of Cr^{3+} (64 pm) and Fe^{3+} (60 pm) are close to each other, reinforces this competition effect.

3.3. Linear regression and correlation analyses between heavy metals and mineral nutrients

Simple correlation and linear regression analysis were performed to identify the influence of different heavy metals and their different concentrations in soils on nutrient uptake in switchgrass.

Linear regression analysis was applied to compare the relationships between mineral nutrients and different heavy metal concentrations in switchgrass. The comparison of mineral nutrients and Pb, Cd and Cr are demonstrated in Figs. 3, 4 and 5, respectively. As seen from Fig. 3, there is a significant and negative relationship between Pb and K (r = -0.995, $p<0.01$), Zn (r = -0.833, $p<0.05$), Cu (r = -0.994, $p<0.01$) and P (r = -0.971, $p<0.01$) nutrients. There are similar studies in the literature showing a negative correlation between Pb pollution in the soil and K, P, Zn, Cu (Walker et al., 1997; Päivöke, 2002; Akinci et al., 2010; Wang et al., 2011; Patel et al., 2017). While the relationship between Pb and Mg, Mn is found to be non-significant, the relationship between Pb and Fe, Ca is a significant and positive (r = 0.835, $p<0.05$ for Fe and r = 0.966, $p<0.01$ for Ca). Similarly, some studies in the literature showed a positive correlation between Pb concentration and Ca, Mn content (Cseh et al., 2000; Malkowski et al., 2002; Wang et al., 2011).

It is determined that the relation between Cd and investigated all mineral nutrients is negative (Figure 4.). While the relation between Cd and Ca, Mn, Cu is significant, according to $p<0.01$, the relation between Cd and P, K, Mg, Fe, Zn is significant at $p<0.05$. Similarly, Sikka & Nayyar (2012) found a negative correlation in the content of micronutrients (Mn, Fe, Cu, Zn) in Indian mustard with the application of Cd. and Liu et al. (2011) found a significant negative correlation between Cd and Cu or Zn concentrations in *Lonicera japonica* Thunb.

When investigated Figure 5, it is found that there is a significant and positive relationship between Cr and P (r = 0.980, $p<0.01$), while non-significant relation between Cr and Mg, Fe, Zn, K. The relationship between Cr and Ca, Mn, Cu is found to be significant and negative (r = -0.969, $p<0.01$; r = -0.974, $p<0.01$; r = 0.990, $p<0.01$, respectively).

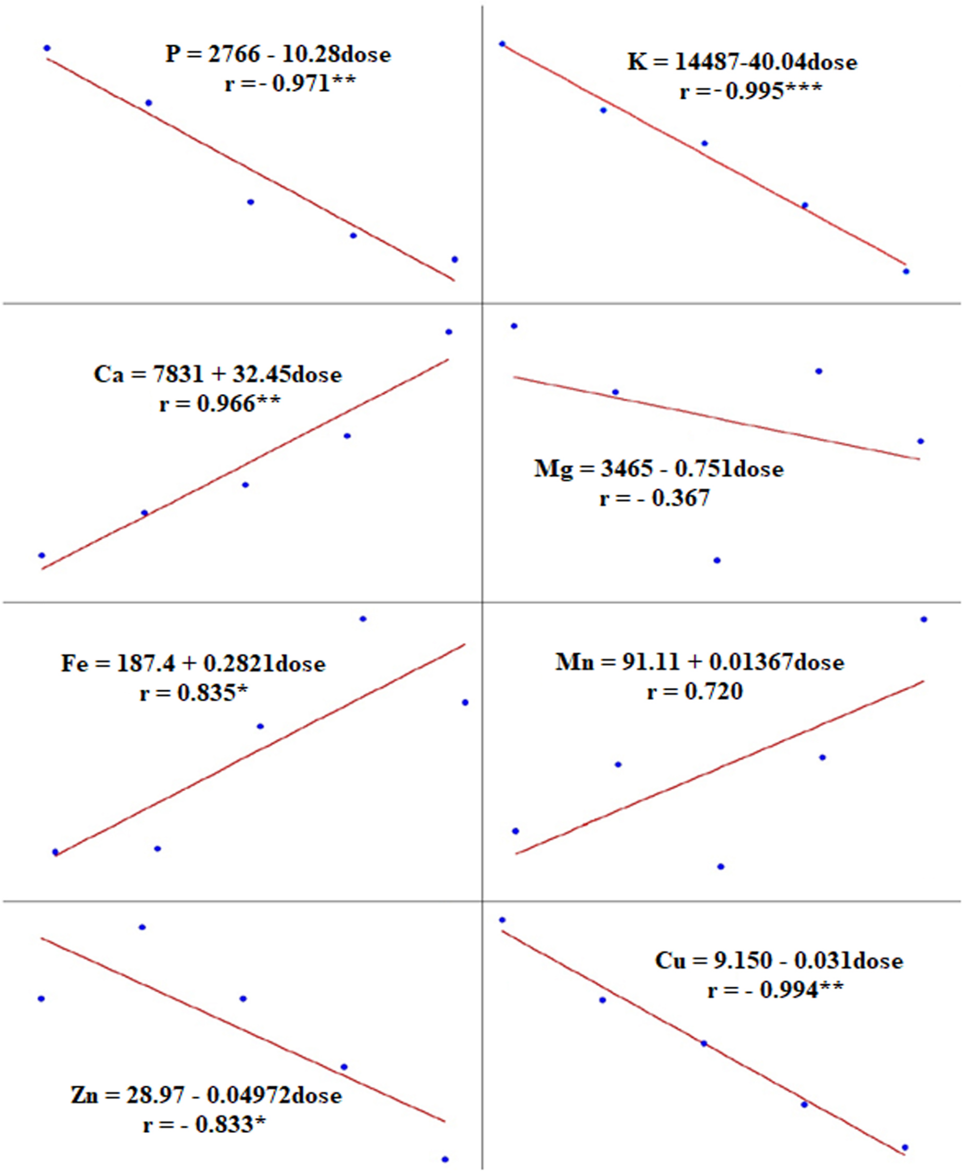

Figure 3. The linear regressions between Pb and macro- and micro-nutrients (x-axis: Pb doses (0, 30, 60, 90, 120 mg kg^{-1}), y-axis: the concentration of each element).

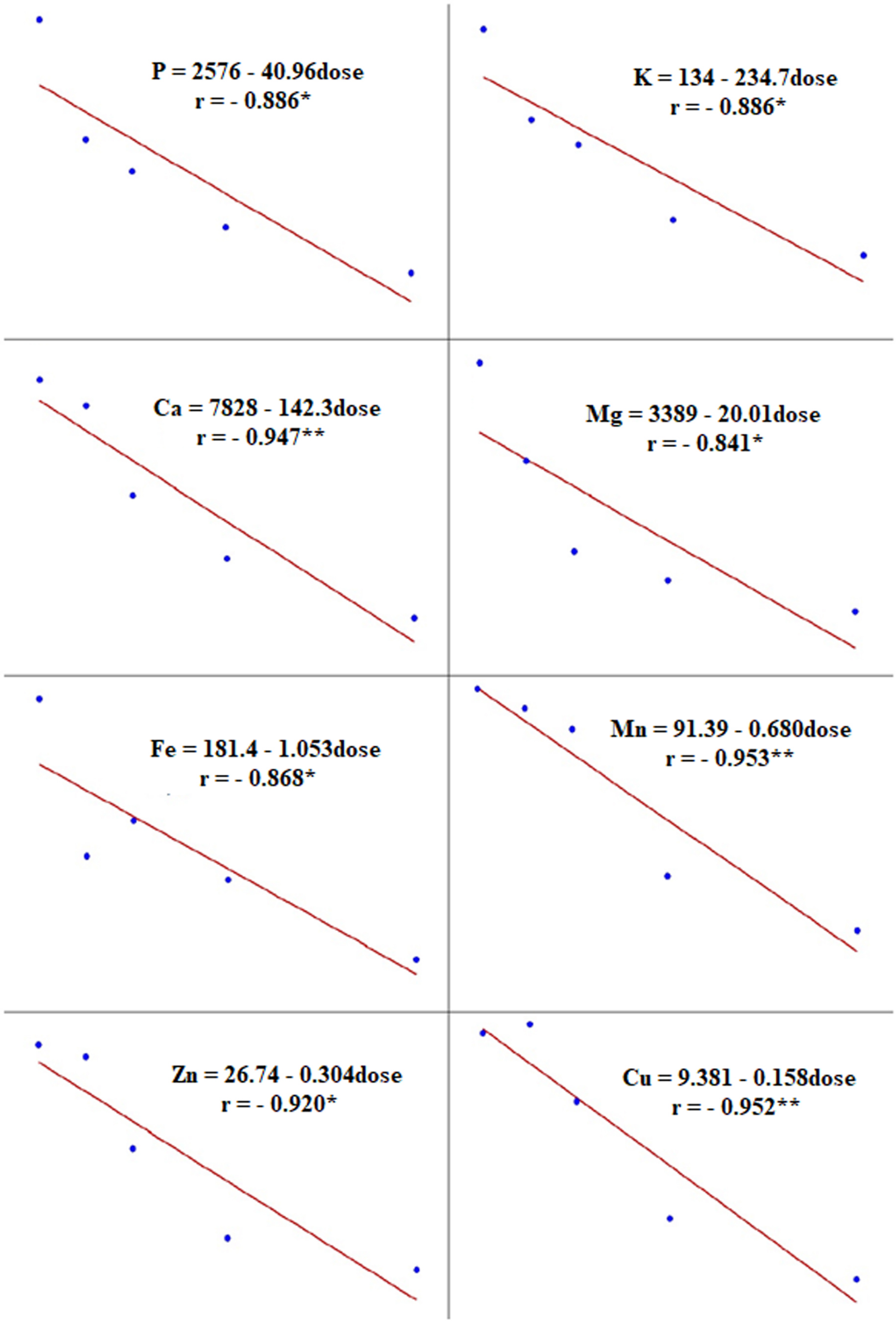

Figure 4. The linear regressions between Cd and macro- and micro-nutrients (x-axis: Cd doses (0, 2.5, 5, 10, 20 mg kg^{-1}), y-axis: the concentration of each element).

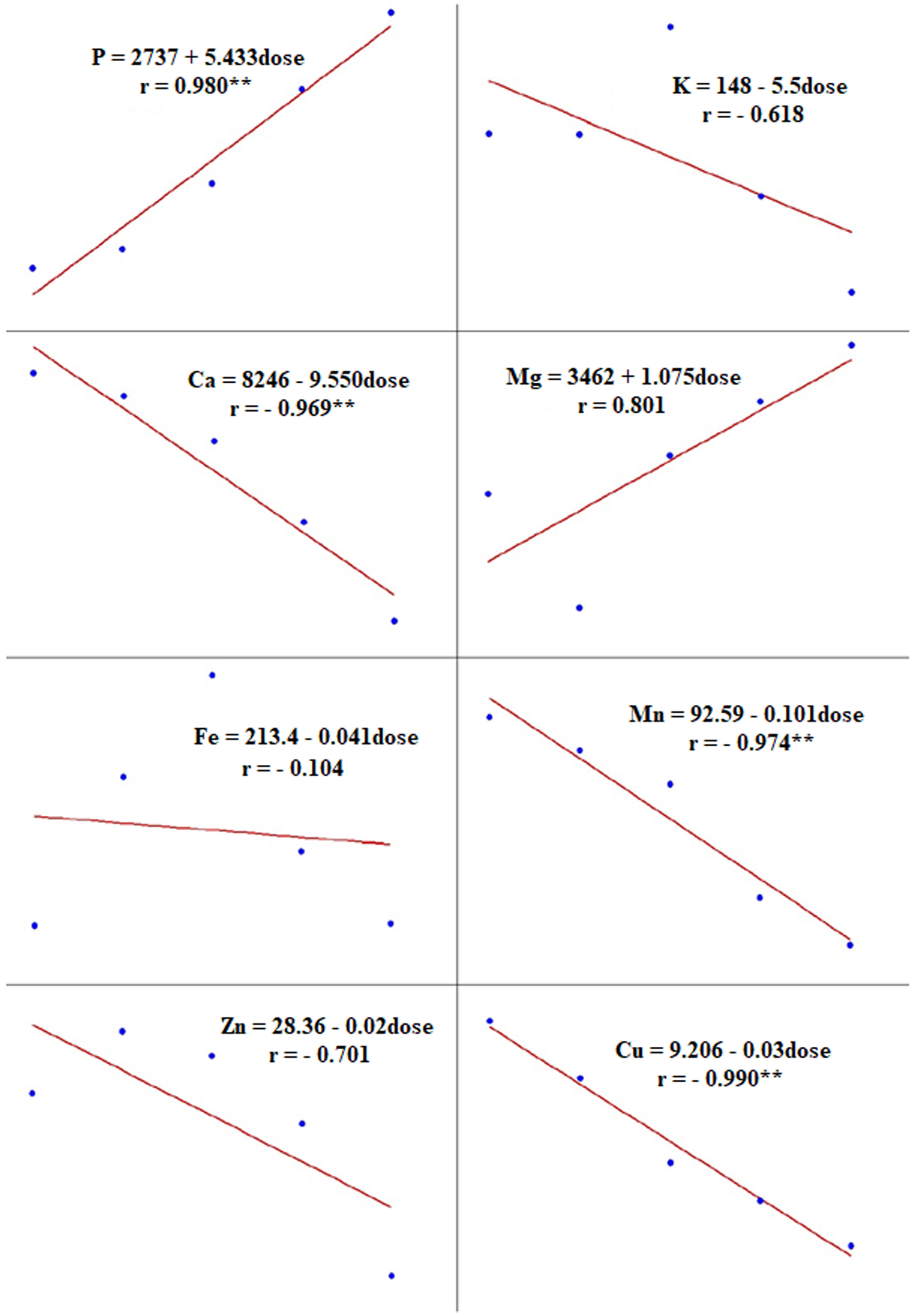

Figure 5. The linear regressions between Cr and macro- and micro-nutrients (x-axis: Cr doses (0, 40, 80, 120, 160 mg kg^{-1}), y-axis: the concentration of each element).

The relationships among plant nutrients in the presence of Pb, Cd, Cr were given as Pearson correlations in Table 1. When used the Pb as a pollutant, it is found in significant relations that the correlation between P and K, Zn, Cu is positive and between P and Fe, Ca is negative. There is a negative correlation between K and Ca, Mn, Fe, while there is a positive correlation between K and Zn, Cu, which both of two correlations K and the other nutrients are significant. The significant correlations between Ca and Fe, Mn and between Ca and Zn, Cu are positive and negative, respectively. Fe and Mn have significant and negative correlation with Zn and Cu. The significant and positive correlation is present between Zn and Cu. However, the correlation between Mg and all nutrients is non-significant.

As seen in correlation analyses, in contaminated soils with Cd, the correlations between all nutrients are found to be significant and positive (Table 1).

In the Cr-media, the correlation between Fe and all elements, except for K and Zn (significant and positive correlation), is non-significant. P has significant and negative correlation with all nutrients with Mg expectation. This correlation is significant and positive. The correlations between K-Mg, Mg-Mn, Mg-Zn, and Mg-Cu are significant and negative, while correlations between K-Zn, K-Mn, Ca-Zn, Ca-Mn, Ca-Cu, Mn-Cu, Mn-Zn and Zn-Cu are significant and positive (Table 1).

Table 1. Pearson correlation coefficients between all nutrients in the presence of Pb, Cd, Cr

Metal	Variable	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Pb	P	1							
	K	0.933**	1						
	Ca	-0.850**	-0.916**	1					
	Mg	0.350	0.220	-0.146	1				
	Fe	-0.766**	-0.666**	0.579*	-0.159	1			
	Mn	-0.358	-0.587*	0.701**	0.266	0.258	1		
	Zn	0.742**	0.818**	-0.818**	0.137	-0.616*	-0.563*	1	
	Cu	0.893**	0.927**	-0.782**	0.313	-0.738**	-0.529*	0.771**	1
Cd	P	1							
	K	0.961**	1						
	Ca	0.811**	0.862**	1					
	Mg	0.872**	0.857**	0.847**	1				
	Fe	0.894**	0.913**	0.708**	0.728**	1			
	Mn	0.847**	0.902**	0.869**	0.770**	0.775**	1		
	Zn	0.885**	0.911**	0.926**	0.854**	0.757**	0.943**	1	
	Cu	0.844**	0.871**	0.863**	0.820**	0.676**	0.941**	0.948**	1
Cr	P	1							
	K	-0.588*	1						
	Ca	-0.781**	0.453	1					
	Mg	0.694**	-0.532*	-0.299	1				
	Fe	-0.266	0.658**	0.123	-0.356	1			
	Mn	-0.960**	0.630*	0.762**	-0.666**	0.298	1		
	Zn	-0.768**	0.702**	0.720**	-0.558*	0.611*	0.797**	1	
	Cu	-0.896**	0.445	0.811**	-0.569*	-0.042	0.913**	0.673**	1

*** p<0.01*
**p<0.05*

4. Conclusion

Pb, Cd and Cr are important heavy metals in terms of toxicity and tolerance evaluation in plants due to the adverse effects on the photosynthetic and enzymatic activities of plants. Pb accumulation in aboveground of switchgrass changed the balance of nutrients by hindering the uptake of P, K, Mg, Zn and Cu and by increasing Ca, Mn and Fe accumulation relatively. The increased concentration of Cd removed the nutrients from the physiologically important binding sites and thus reduced the uptake and transport of the essential nutrients, in other words, Cd replaced all of the nutrients in the plant. With the application of Cr, the intake of nutrients other than P and Mg was prevented by the plant.

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