Assessing phytotoxicity and accumulation of trace elements to Lactuca sativa of a contaminated shooting range soil

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Abstract

Shooting range soil contamination with heavy metals is a common problem around the world. Usually, lead is the main contaminant in the shooting ranges. Extreme concentrations of trace elements create a toxic living environment for various plants. The purpose of this study was to evaluate the effect on lettuce (*Lactuca sativa* L.) grown in contaminated shooting range soil. The results showed that physiological parameters root elongation, shoot length and fresh biomass per plant was negatively affected, especially in the most contaminated site of the shooting range. At the most contaminated shooting range site shoots accumulated higher concentrations of Ni and Zn, roots – Cu, Ni, and Zn. The roots of plants grown in the most contaminated soil accumulated significantly higher concentrations of Cu, Ni and Sb in comparison with control ($p < 0.05$). Accumulation of Cu, Fe, Mn, Ni, Sb and Zn in the roots of the plants grown in the most contaminated site was higher compared to shoots ($p < 0.05$). Bioaccumulation factor of lettuce was lower than 1, only BF of Cu and Ni in plants from most contaminated site was significantly higher compared to control. In terms of translocation factor, the $TF_{soil\ to\ root}$ of Cu and Pb among all plants and Ni in plants grown in the most contaminated site above 1 shows that metals absorbed by *L.sativa* were accumulated in root and lower metal translocation in shoots was determined, except for Mn.

Introduction

Shooting ranges pose an environmental concern due to their contamination with trace elements (Mannine and Tanskanen 1993). The soil of shooting ranges is typically contaminated with lead (Pb), copper (Cu), antimony (Hg), arsenic (As), nickel (Ni), zinc (Zn), silver (Ag) because of these elements are components of the bullets used for shooting. Lead is the main contaminant in the shooting range soil - up to 150 000 mg kg^{-1} concentrations of Pb is reported in the soil of shooting ranges (Sanderson et al. 2014; Barker et al. 2020). Ammunition mostly contains Pb (~ 80 % bullet mass) and smaller traces of As, Sb, Cd, Cu, Ni, Mn and Zn. Cartridges and cases consist mostly of Zn and Ni (Urrutia-Goyes et al. 2017). Antimony is used as a hardening material and constitute 1–2% of a bullet core (Sanderson et al. 2018). The main component of bullet jack usually is Cu ~ 89–95 % (Moon et al. 2011), besides Pb smaller amounts of As, Cd, Sb, Mn are used in used in the manufacture of bullets (Fayiga and Saha 2016).

These contaminants in the shooting range soils are toxic to plants, soil biota, groundwater, and animals (Ma 1989; Carreras et al. 2009; Ahmad and Ashraf 2012; Siebielec and Chaney 2012; Sanderson et al. 2014; Ogawa et al. 2015; Rodríguez-Seijo et al. 2016; Dinake et al. 2018; Johnsen and Aaneby 2019). Lead is the main contaminant in the shooting range soils (Lewis et al. 2001). The mobility of Pb in the ranges strongly depends on soil pH. Mobile forms of Pb can result in contamination of surface and underground waters. Past research has shown the presence of elevated concentrations of Pb in flora growing nearby shooting ranges (Fayiga and Saha 2016). Due to extreme concentrations of Pb in soil, the uptake of nutrient (Na, Ca, K, P, Mg, Zn, Fe, Cu), chlorophyll content, plant growth, biomass, seed germination decrease (Hadi and Aziz 2015; Gul et al. 2020).

Some heavy metals are essential for plant growth, but at high concentrations they become toxic (e.g., Co, Cu, Fe, Mn, Zn) while others (e.g., Cd, Pb, Hg) are toxic even at low concentrations because they have no known physiological functions in plants (Boquete et al. 2021). In the early stage of the plant development the most sensitive indicator of contamination is seed germination. If contaminant does not reach embryo, germination rate might not be affected at lower concentrations heavy metals can even stimulate germination (Moreira et al. 2020). Essential elements create adverse effects on plants only at high doses (Ullah and Muhammad 2020). For example Cu is considered as micronutrient for plants, but at induced Cu stress plants suffer leaf chloroses growth retardation, exposure to Cu leads to oxidative stress (Yadav 2010). Non-essential elements, like lead is very toxic elements for plants, it inhibits plant growth, disrupts nutrient consumption, alters metabolism (Ashraf et al. 2020). The uptake and accumulation of lead varies with plant species and concentration of this element in the environment (Ashraf et al. 2020). Exposed to lead stress, plants exhibit symptoms of poisoning (cytomembrane permeability, disturbance of enzyme activity, mitotic obstruction, DNA damage, changes in physiological processes) (Duan et al. 2020). The plants permanently growing in contaminated sites accumulate large amounts of heavy metals in their tissues (Rehman et al. 2021).

The biomonitoring tests with animals or plants to determine and compare the toxicity of contaminated soils are as possibility to evaluate detrimental effects on the environment. To our knowledge, little scientific research has been done on the environmental impact of contaminated soils from these sectors despite the attempts to use the plants for their phytoremediation abilities (Rodríguez-Seijo et al. 2016) or testing amendments for remediation (Ahmad et al. 2012; Siebielec and Chaney 2012). The aim of the study is to evaluate potential phytotoxicity and trace elements accumulation in *Lactuca sativa* exposed to a shooting range soil.

Materials And Methods

Study site

Soil samples were collected from the small-bore (22.lr calibre) shooting range located in Alytus, Lithuania (54°23'48.1"N, 24°2'41.3"E). The shooting range was opened in 1957, since then it has been used mostly seasonally (April – July). Only small-bore (.22lr caliber) guns are used in this shooting range. The area of range is about 400 m^2 and about 320 m^2 of it is mostly overgrown by grasses. The range consist of 6 shooting positions and the length of shooting area is 50 meters with two target lines at 25 and 50 meters.

Soil sampling and chemical analyses

Soil samples were collected according to distance from the shooting positions to the target lines. Target lines were at the 25 meters and 50 meters lines and soil samples were collected 5, 20, 30 and 45 meters away from the shooting positions. At each representing site 5 subsamples of surface soil were collected and constituted a composite sample. Two areas of shooting range were chosen: to represent less contaminated shooting range site (5–30 m) and more contaminated shooting range site (45 m). The reference area was selected as a grassland site in the relatively unpolluted area (54°25'42.0"N 24°14'04.2"E) and referred as a reference soil. Soil samples were taken from the upper layer of surface soil (10–20 cm) after removing about 2 cm of soil surface layer. Samples were mixed and homogenized and stored at 4°C until analysis.

For chemical analysis, soil was sieved to 2 mm and oven dried at 60°C for 48 h. Soil pH was measured potentiometrically in suspension of soil:water ratio of 1:5 using pH meter (inoLab 720, WTW). Total soil organic matter content was determined by loss on the ignition method. The bulk density of soil was determined by pouring air - dry soil samples in a measured cylinder. Samples were determined by digesting approximately 0.5 g dried soil in 8 mL of HCl, 5 mL of HNO_3, 5 mL of HBr, and 3 mL of HF in a Teflon vessel using a microwave digestion system (Milestone Ethos One, Italy). The total concentrations of elements (Pb, Cu, Fe, Mn, Ni, Sb and Zn) were determined using inductively coupled plasma optical emission spectroscopy (ICP-OES, Perkin-Elmer, Optima 8000). Calibration of trace elements was made by analysing the Quality Control Standard 21 (Perkin Elmer). Precision of analysis was estimated by the coefficient of correlation of four calibration points and was found to be 0.999 for all measured elements

Toxicity study

Lettuce (*Lactuca sativa* L.) plants have been chosen for this study. Phytotoxicity test was carried out according to the OECD guidelines for the testing of chemicals (OECD/OCDE 208 2006). Seeds of lettuce (*Lactuca sativa*) were planted in 200 mL pots filled with 200 g of moist sample soil (sieved to 2 mm). Nine seeds per pot were eventually distributed over the surface of the soil. Distilled water was added daily to maintain 50 % water holding capacity of the soil. The duration of the test was 21 days. The temperature in climate chamber was 20 ± 2°C and the relative humidity – 60 %. Samples were illuminated for 12 h/ photoperiod with photon light density of 180–200 μmol m^{-2} s^{-1}. The plants were treated with shooting range soil. Reference treatment was soil from countryside (54°25'42.0"N 24°14'04.2"E). In each treatment there were three pots of replication. Duration of the test was 21 days. Plants were rinsed with distilled water in order to remove soil particles. The fresh mass was weighted and root and shoot length (cm) per plant was measured. Seed germination was observed after 7 days and germination rate (%) was calculated as the number of seeds sprouted divided by the total number of seeds and multiplied by 100.Shoots and roots were separated and dried at 60°C until the constant weight. For heavy metals analyses dry material were homogenized. This was followed by acid digestion of the samples with 8 ml HNO_3 and 2 ml HF. The samples were diluted to 45 ml with distilled water after that the concentration of elements (Pb, Cu, Fe, Mn, Ni, Sb and Zn) was determined using inductively coupled plasma optical emission spectroscopy (ICP-OES, Perkin-Elmer, Optima 8000).

Translocation factor (TF) was calculated to evaluate ability to translocate element from soil to root and from root to shoot. TF was calculated by method suggested by Sun et al. (2017) from soil to root (Eq. (3)) and from root to shoot (Eq. (4)).

$TF_{soil\ to\ root} = C_{root}\ (mg\ kg^{-1}) / C_{soil}\ (mg\ kg^{-1})$ (1)

$TF_{root\ to\ shoot} = C_{shoot}\ (mg\ kg^{-1}) / C_{root}\ (mg\ kg^{-1})$, (2)

where C_{root} is the content of examined element in root, C_{soil} - content of examined element in soil, C_{shoot} - content of examined element in shoot.

In terms of bioaccumulation of heavy metals, we evaluated bioaccumulation factor (BF). Plants with bioaccumulation factor above 1 is reported as hyperaccumulators (Yazdi et al. 2019). Bioaccumulation factor (BF) was calculated (Eq. (5)) by method suggested by Midhat et al. (2019):

$BF = C_{shoot}\ (mg\ kg^{-1}) / C_{soil}\ (mg\ kg^{-1})$ (3)

where C_{shoot} is the content of examined element in root, C_{soil} - content of a tested element in soil.

Statistical analyses

In order to analyse the effects of the study area, data was analysed grouping in three units according to the lead contamination: 1) reference soil; 2) soil from less contaminated area (5–30 m) were combined into one forming medium contaminated study plot, and 3) heavily contaminated area (45 m) of the shooting range. Relationships between concentrations of trace elements and plant parameters as well as differences between TF's and BF's of heavy metals were assessed using Mann-Whitney U test ($p < 0.05$). Spearman correlation was used to identify relationship between heavy metal concentration in soil and in the tissue of plants ($p < 0.05$). The statistical analysis was run by using IBM SPSS Statistics 25.

Results

The results of soil analyses show that the pH of the studied shooting range and control soil is close to neutral, significantly lower pH was in the soil from 45 m distance ($p < 0.05$; Table 1). Soil organic matter content and density did not show any significant differences compared to control ($p > 0.05$). Ammonium content at 5-30 meters area was significantly higher compared to control. Significantly lower phosphorus content was observed in the 45 meters area of shooting range soil compared to control ($p < 0.05$).

Analyses of total trace elements concentration show that shooting range soil contained high concentrations of lead, with maximum contamination at 45 m area of the range (54560 mg kg^{-1}), significantly higher concentration of lead was observed 5-30 and 45 meter areas of shooting range ($p < 0.05$). Concentration of Cu in the shooting range soil was lower compared to control. Fe concentration was over 8000 mg kg^{-1} in the 45 m area of the shooting range, but no significant differences in Fe concentration was observed. The concentration of Mn and Zn in the 5-30 m area was lower compared to control and to 45 m area ($p < 0.05$). Even 528.3 mg kg^{-1} concentration of Sb was determined in the 45 m area of the shooting range. The site of 45 meters will be considered as more contaminated site than 5-30 m, because of higher concentration of Pb, Ni, Sb, and Zn ($p < 0.05$).

Physiological parameters of *Lactuca sativa* exposed to shooting range soil show that seed germination rate was not different between shooting range soil and control (Table 2). Plants grown in contaminated shooting range soil had significantly lower root length compared to the control and the lowest roots had plants exposed to soil from 45 m area ($p<0.05$). Although seed germination in plants grown in the most contaminated site was similar to the control, after few weeks of the experiment differences in growth was seen visibly - the plant of the most contaminated site stop growth was retarded. Analyses of shoot length and fresh biomass clearly show the plants exposed to the most contaminated site had significantly lower shoot length ($p<0.05$) and fresh biomass per plant compared to the reference soil ($p < 0.05$).

Lettuce exposed to contaminated shooting range soil accumulated high concentrations of lead (Fig. 1). Significantly higher concentrations of Pb were observed in shoots of plants grown in the contaminated soil compared to the reference soil, with the highest concentration of 3963.11 mg kg^{-1}. The roots of plants grown in the soils from the shooting range accumulated significantly higher concentration of lead compared to the reference soil. Eight times more lead was accumulated in the plants grown in soil from 5-30 m area and even 687 times more lead was accumulated in plants grown in soil from 45 m area compared to the reference soil (Fig. 2). The roots accumulated significantly more lead compared to shoots ($p<0.05$). The roots of plants grown in the most contaminated site accumulated even 10 times more lead compared to shoots of the same site. The statistically significant correlations between total Pb concentration in soil and Pb concentration in shoots ($r=0.97$, $p<0.05$) and roots ($r=0.91$, $p<0.05$) were determined.

No significant differences among all heavy metal concentrations in the shoots of lettuce grown in the soil from 5-30 m site of the range compared to reference shoots was observed ($p > 0.05$; Fig. 2). In shoots of lettuce grown in the most contaminated site of the shooting range significantly higher concentrations of Cu, Fe, Mn, Ni, Sb and Zn compared to control shoots were observed. In shoots of plants grown in the most contaminated study site significantly higher concentration of Cu, Fe, Mn, Sb and Zn compared to shoots of plants grown in soil from 5-30 meters area were observed ($p<0.05$). The roots of lettuce grown in the soil from 5-30 meters area of the range accumulated significantly higher concentration of Cu, Fe, Ni ($p < 0.05$) compared to control (Fig. 2). The roots of *L.sativa* grown in the most contaminated range soil accumulated significantly higher concentrations of Cu, Fe, Ni, Sb compared to control ($p < 0.05$). The roots of plants grown in 5-30 meters area soil accumulated significantly higher concentrations of Cu, Fe, Mn and Zn compared to shoots ($p < 0.05$) of the same plants (Fig. 2). Among plants grown in the soil from the most contaminated site significantly higher concentrations of Cu, Fe, Mn, Ni, Sb and Zn were observed compared to shoots of plants grown in the soil from the same area. A significant correlation between total Ni concentration in soil and Ni concentration in shoot ($r = 0.97$, $p < 0.05$) and root ($r = 0.99$, $p < 0.05$) was determined.

The bioaccumulation factor values in lettuce of all sites were lower than 1 (Table 3). Bioaccumulation factor of Cu in plants grown in the most contaminated shooting range soil was 0.98 and it was significantly higher compared to control ($p<0.05$). Significantly higher than control, but still relatively low BFs of Fe, Mn, Ni, Pb, Zn were also calculated in lettuce from 45 meters area of the shooting range

($p<0.05$). BF values of Pb was very low (0.02 at 5-30 m and 0.04 at 45 m) it could be because of extremely high soil Pb concentrations.

The translocation factor of soil to root of Cu, Fe, Ni, Pb, Zn was significantly higher compared to TF of root to soil in lettuce grown in 5-30 meters area of the range (Fig. 3). The translocation factor of soil to root of Cu, Fe, Ni and Pb was significantly higher compared to translocation factor of root to shoot in lettuces grown in shooting range soil of 45 m area. $TF_{soil\ to\ root}$ of Cu (5-30 and 45 m), Ni (45 m), Pb (5-30 and 45 m) and Zn (5-30 m) were above 1. A strong positive correlation between total Ni concentration in soil and bioconcentration factor of Ni ($r = 0.89$, $p < 0.05$) and $TF_{root\ to\ shoot}$ ($r = 0.97$, $p < 0.05$) was determined. On the contrary, strong negative correlation between total Ni concentration in soil and $TF_{shoot\ to\ root}$ ($r = -0.96$, $p < 0.05$) was determined. Translocation factor of Pb from roots to shoots significantly correlated with total soil Pb concentration ($r = 0.90$, $p < 0.05$; Fig. 3).

Discussion

In this study basic soil analyses reflected site specific shooting range contamination with heavy metals and changes in physicochemical soil properties. The changes in soil properties like pH and organic matter can change heavy metal solubility. For example, some heavy metals have a strong attraction to soil organic matter, it means that the organic matter should be highly efficient in the sorption of heavy metals also binding of heavy metals with organic matter is strongly pH depended process (Lewińska and Karczewska 2019). In our study soil pH at the most contaminated shooting range soil was lower compared to control. This finding is in accordance with our study where pH values of the full-bore military shooting ranges soil ranged from 5.6 to 8.0 (Kumarathilaka et al. 2018, Lewińska and Karczewska 2019). Changes of pH affects migration and distribution of heavy metals (Zhang et al. 2018). Phytoavailability of Pb is pH-dependent, by lowering soil pH the availability of Pb could increase (Gul et al. 2020).We could conclude that other original properties of shooting range soil do not drastically change the solubility of contaminants (heavy metals), because the main soil properties discussed earlier did not change significantly, except pH (Ashworth and Alloway 2008; Lewińska and Karczewska 2019).

As it was expected the major contaminant of shooting range soil was lead (from 386.37 to 54560.13 mg kg^{-1}). Concentrations of lead in shooting range soil exceed limit soil Pb concentration (100 mg kg^{-1}) in Lithuania (HN 60:2004). Similar results were reported in (Rodríguez-Seijo et al. 2016; Kumarathilaka et al. 2018; Lewińska and Karczewska 2019) studies. During our study plant was capable of surviving at higher Pb concentrations, but adverse effects on growth was visible. In general lead as a not essential element negatively affects root, plant growth, inhibits photosynthesis, enzymatic activities and at very high concentrations lead to cell death (Hadi and Aziz 2015). Total concentrations of Cu, Fe, Mn, Ni do not pose an environmental risk as concentrations do not exceed limit concentrations (HN 60:2004). But total concentration of Sb exceeded limit concentration (10 mg kg^{-1}) (HN 60:2004). Pollution with Sb was reported in shooting range areas, it is known that Sb is more mobile compared to Pb, therefore shooting ranges can have bigger long-term environmental problem related to groundwater pollution (Shtangeeva et al. 2011). The suppression of shoot and root biomass under increase of antimony concentration could be a result of Sb accumulation in plant. Under our circumstances both shoot and root systems of plants grown in the most contaminated soil accumulated significantly higher concentration of antimony and growth of these plants were inhibited. Studies show that environmental stressors, like heavy metals, can disturb growth and development of plant (Yazdi et al. 2019). Results from this study revealed that above-ground and below-ground plant growth was negatively affected by heavily contaminated (Pb, Sb) shooting range soil. Numerous of research show that the reduction of root length, in the presence of HM, appears as the reason of metal interference with the process of cell division, which causes chromosomal aberration and abnormal mitosis (Yazdi et al. 2019).

Accumulation of heavy metals in the tissues of exposed plants depend on metal supply and plant species. Plants can absorb HM' through passive transport by water mass flow or through active transport by plasma membrane of root cell (Midhat et al. 2019). During this study lead was the main contaminant in soil. In the most contaminated site of the shooting range roots of *Lactuca sativa* accumulated almost 10 times more Pb compared to shoots. Pb content was also higher in roots compared to leaves of the *Brassica campestris* seedlings (Zhang et al. 2020). In the case of Ni, Zhao et al. (2019) reported higher concentration in roots than shoots our results agrees in most Ni contaminated site Ni concentration in *L. sativa* roots were significantly higher. We discovered the tendency of higher heavy metals accumulation in roots than shoots similar observations reported in (Zhao et al. 2019; Steliga and Kluk 2020) studies. The roots are the main organ of plant for stabilization and collection of nutrients (Steliga and Kluk 2020) and translocation from roots to shoot might be limited by precipitation of heavy metals on the root membrane, and this barrier could control metal mobility from root to shoot (Shtangeeva et al. 2011). In terms of BF from results stand out BF' of Cu and Ni in plants from most contaminated site. At the 5-30 m area of shooting range BF' were very low. However, in *L. sativa* exposed to the most contaminated BF can be put together in the following sequence: Sb<Fe<Pb<Mn<Zn<Ni<Cu, but only BF of Cu, Fe, and Ni were significantly higher. Very low Pb bioaccumulation could be explained by low concentration of soluble Pb in soil. As the pH and organic matter values of studied soil do not drastically change solubility of Pb (Ashworth and Alloway 2008; Lewińska and Karczewska 2019). Similar results reported (Dradrach et al. 2020) with bioaccumulation of As in *Festuca rubra* L. values of TF confirms better translocation from "soil to root" system compared to "root to shoot" at translocation of Cu, Fe, Ni and Pb. $TF_{soil\ to\ root}$ of Cu and Pb (in all test samples) and Ni (45 m) > 1 shows that metals absorbed by *Lactuca sativa* are accumulated in its root tissue first and poorer metal translocation in shoots was visible, except for Mn.

Conclusions

The present study demonstrated physicochemical properties and phytotoxicity of the shooting range soil. The soil of shooting range was site specific with high contamination in Pb and Sb. High concentration of antimony, which is more mobile in the soil than lead, in the most contaminated site of the range revealed that pollution of shooting range still needs better understanding and approaches for remediation of these sites must be considered to avoid its hazardous leaching to the groundwaters. Our results showed that in the most contaminated site the inhibition of tested plant growth was observed. Translocation of heavy metals from root to shoot was suppressed, and to our knowledge this could be caused by very extreme heavy metal concentrations when heavy metals on the root membrane form a barrier that controls metal mobility from root to shoot.

Declarations

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Tables

Table 1. Parameters of soil physicochemical analyses: acidity (pH), organic matter content (OM, (%), soil density (g/cm^3), nutrient and heavy metals content (mg kg^{-1}): NH_4^+, PO_4^{3-}, total concentrations of Cu, Pb, Fe, Mn, Ni, Sb and Zn in the shooting range soil. Values are means ± standard error. Same letters indicate no significant differences between samples (U test, $p < 0.05$).

	Shooting range soil		Reference soil
	5-30 m	45 m	
pH_O	6.9±0.16 ab	6.9±0.01 b	7.1±0.01 a
OM	5.7±0.27 a	7.0±0.16 a	8.1±0.01 a
Soil density	5.2±0.14 a	6.5±0.14 a	4.8±0.15 a
NH_4^+	11.3±1.33 a	15.1±3.68 ab	8.8±0.41 b
PO_4^{3-}	9.8±1.74 a	5.5±0.53 b	8.4±0.21 a
Total Pb	386.4±91.42 a	54560.1±5269.62 b	25.3±4.42 c
Total Cu	14.3±6.66 a	21.6±1.75a	41.0±4.37 b
Total Fe	6276.2±1291.34 a	8042.9±894.82 a	7785.2±206.84 a
Total Mn	187.0±16.32 a	221.7±25.21 b	256.2±11.74 b
Total Ni	5.5±1.64 ab	7.9±0.46 b	3.5±0.05 a
Total Sb	-*	528.3±49.55	-*
Total Zn	167.8±98.64 a	505.9±26.84 b	516.9±27.70 b

* – lower the limit of detection

Table 2. Seed germination (%), root and length (cm) and fresh biomass per plant (g) of lettuce (*Lactuca sativa*) exposed to shooting range soils. Values are means ± standard error. Same letters indicate no significant differences between samples (U test, $p < 0.05$).

	Shooting range soil		Reference soil
	5-30 m	45 m	
Seed germination rate	74.1±9.32 a	74.1±7.41 a	81.5±7.41 a
Root length	3.8±0.09 a	2.9±0.10 b	7.1±0.49 c
Shoot length	10.0±0.17 a	5.2±0.03 b	8.8±0.42 c
Fresh biomass per plant	0.5±0.07 a	0.2±0.01 b	0.6±0.05 a

Table 3. Bioaccumulation factor of Cu, Fe, Mn, Ni, Pb, Sb, Zn for *Lactuca sativa.* Values are means ± standard error. Same letters indicate no significant differences between samples (U test, $p > 0.05$).

	Shooting range soil		Reference soil
	5-30 m	45 m	
Cu	0.08±0.02 a	0.98±0.02 b	0.06±0.02 a
Fe	0.01±0.002 a	0.06±0.01 b	0.01±0.0002 c
Mn	0.11±0.01 a	0.18±0.03 b	0.09±0.01 c
Ni	-*	0.69±0.05 a	0.15±0.09 b
Pb	0.02±0.01 a	0.07±0.01 b	0.04±0.04 a
Sb	-*	*0.04*±0.004	-*
Zn	0.46±0.02 a	0.23±0.01 a	0.11±0.01 b

* – lower the limit of detection

Figures

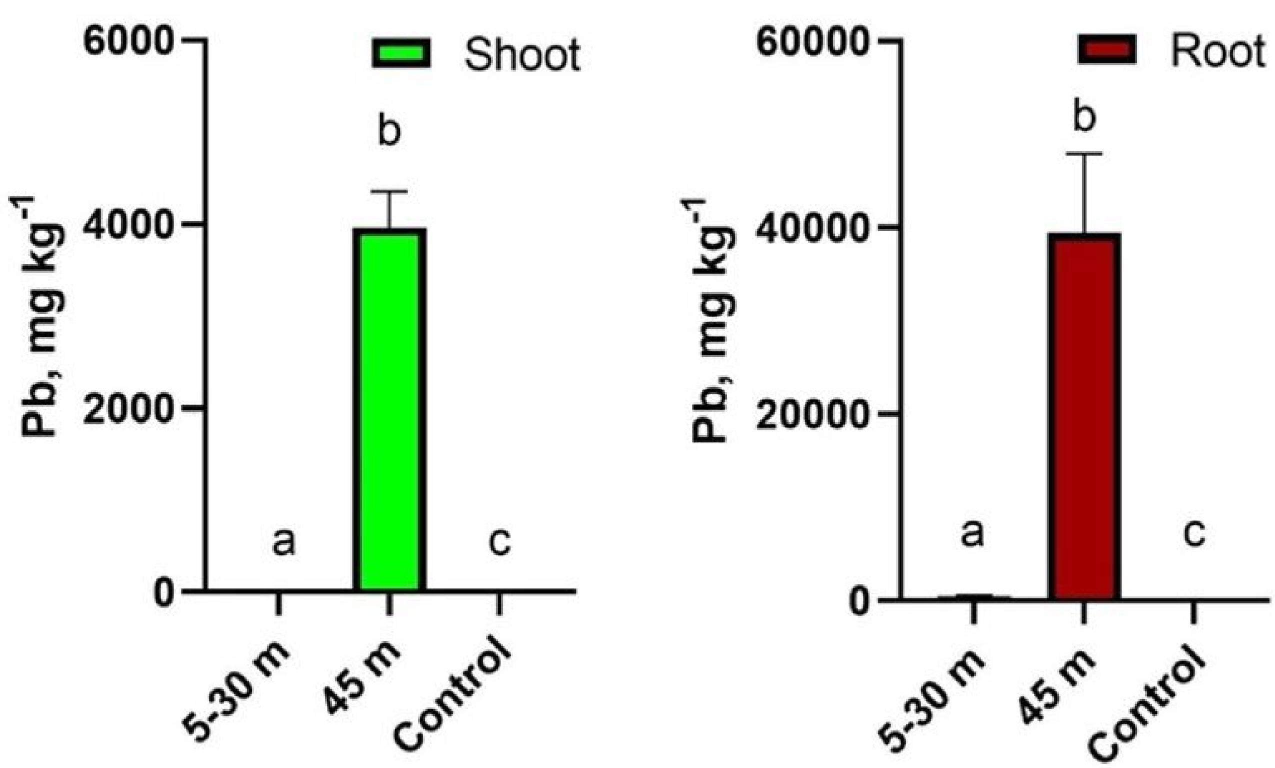

Figure 1

Concentration of lead (mg kg-1) in the shoot and root of Lactuva sativa exposed to shooting range soils. Values are means ± standard error. The different letters indicate significant difference ($p > 0.05$) between the treatments (U test).

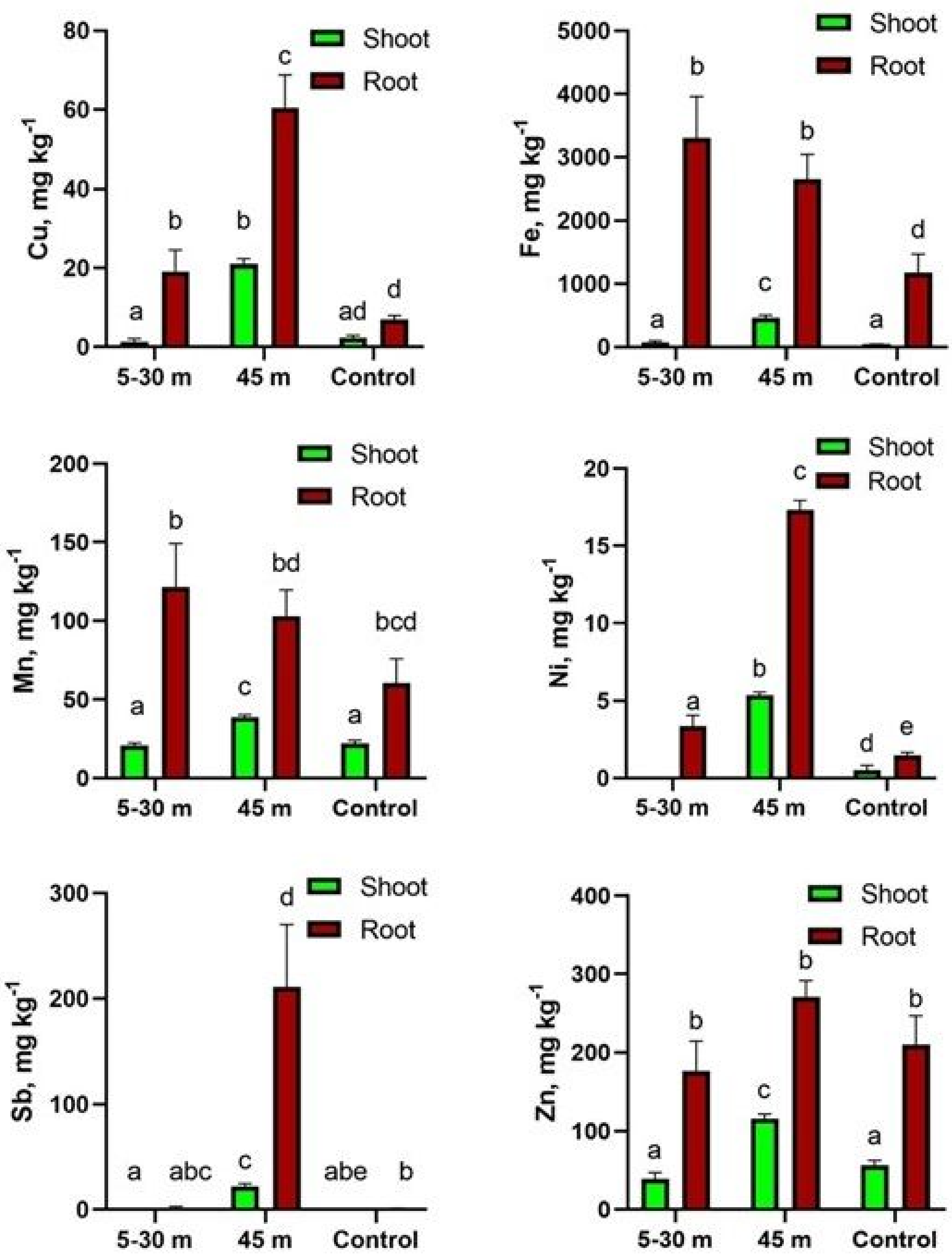

Figure 2

Concentration (mg kg-1) of Cu, Fe, Mn, Ni, Sb and Zn in the shoot and root of Lactuva sativa exposed to the shooting range soil. Values are means ± standard error. Different letters indicate statistically significant difference between samples according to U test ($p < 0.05$).

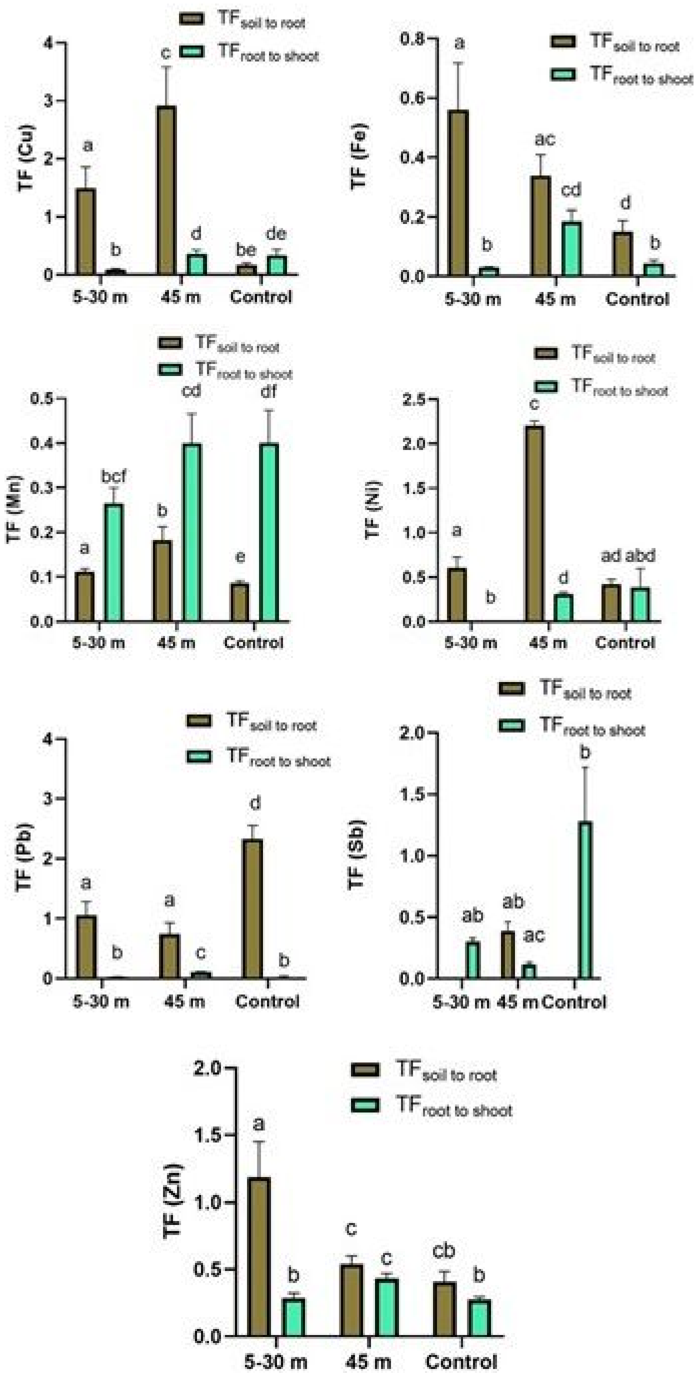

Figure 3

Translocation factor (TF soil to root; TF root to shoot) of Cu, Fe, Mn, Ni, Pb, Sb, Zn of Lactuva sativa exposed to shooting range soils. Values are means ± standard error. Different letters above the bars indicate significant difference between the treatments (U test, $p < 0.05$).