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Lead in Agricultural Soils and Cultivated Pastures Irrigated with River Water Contaminated by Mining Activity

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ABSTRACT

Agricultural soils that have been irrigated with the contaminated water from metallurgical mining activities for more than 70 years constitute an environmental problem as well as a concern for food security and human health. The presence of lead in the soil and cultivated pastures is highly dangerous, due to its toxicity, persistence and accumulation in plants and animals (cattle). This element enters the trophic chain of humans due to the intake of meat, milk and its derivatives. The concentration of lead was determined in the soil and the cultivated pastures with *Lolium x hybridum* Hausskn and *Medicago sativa* L. The soil and pastures samples collected from plots irrigated with river water contaminated with heavy metals at a depth of 0–20 cm. The content of Pb determined by the atomic absorption spectrophotometry. The results showed the lead concentrations in soil in the range of environmental quality standards for soils according to Peruvian regulations. In the soil with *L. x hybridum* and *M. sativa* the average content of lead was 57.17 ± 6.29 $mg.kg^{-1}$ and 57.19 ± 8.99 $mg.kg^{-1}$; in the above-ground tissues were 1.17 ± 0.69 $mg.kg^{-1}$ and 1.62 ± 0.68 $mg.kg^{-1}$, respectively. In addition, no significant differences were observed in the Pb content in the soil and plant tissues. The bioconcentration factor (BCF) in the above-ground tissues of *L. x hybridum* and *M. sativa* was less than one and they were not significant. Therefore, irrigation with long-term contaminated water is not a concern for the farmers in the Mantaro Valley.

Keywords: lead, accumulation, *Lolium x hybridum* (rye grass), *Medicago sativa* (alfalfa), bioconcentration

INTRODUCTION

Lead is extremely toxic and can be easily introduced into the food chain through plants [Hesami et al. 2018, Piechalak et al. 2002, Wierzbicka and Antosiewicz 1993]. It is one of the most dangerous elements in the environment, due to its persistence in the soil from 1000 to 3000 years [ATSDR 2019, Bowen 1979]. It is an environmental threat because it is an important pollutant in the terrestrial and aquatic ecosystems [Sharma and Dubey, 2005]. In the soil solution, it can easily move from the upper to the lower horizons, causing the contamination of groundwater [Alumaa et al. 2002]. Lead is a very toxic metal for plants with a toxicity threshold of less than one μM, almost as much as mercury (Hg) [Kopittke et al. 2010]. Not only does it affect the growth of plants and productivity, but also the food chain, putting the health risk of humans and animals [Khan et al. 2019, Sahi et al. 2002, Xu et al. 2017].

Most contaminated soils contain various pollutants due to the anthropogenic activities, such as the discharge of foundry waste and lead classifies as the second most polluting substance [Liu et al. 2015]. The soil adsorbs lead in different degrees, depending on the content of organic matter, carbonate, clay minerals, oxides of Mn, hydroxides of Fe and Al and mineralogical characteristics [Kabata-Pendias 2011, Sipos et al. 2005]. The mobilization of lead is generally slow, but the increase in acidity, the formation of lead-organic matter complexes can increase its solubility [Kabata-Pendias 2011].

The availability of lead by the plants depends on the soil conditions such as the size of its particles, the capacity of cation exchange, the content of organic matter [Davies 1987].On the other hand, the root surface of the plant, root exudates, mycorrhization and transpiration rate affect the availability and absorption of lead [Davies 1987, Lee et al. 2013]. The absorption of lead is greater in roots than in other parts of plants [Sharma and Dubey 2005]. The absorption of lead and its translocation vary significantly among plant species; the roots of the dicotyledons accumulate significantly higher concentrations of lead than the roots of the monocotyledons [Huang and Cunningham 1996, Jia et al. 2010]. The absorption of Pb by the tissues of the root is mainly intracellular and the metal can accumulate in the vacuoles [Meyers et al. 2008].

In Peru, in the Mantaro Valley (rural sector), the main economic activity is livestock and agriculture, the production of which depends on the water resource of the Mantaro River for the irrigation of their agricultural crops and pastures grown in times of low water. However, this resource is increasingly scarce because the mining and metallurgical activity in the upper Mantaro River basin contributes significantly to the contamination of its surface waters by the discharge of its effluents into the rivers. The use of water contaminated with heavy metals for irrigation of crops for 70 years, consequently brings the concentration of these elements in the soil, in the plants and in the aquatic ecosystems, causing the deterioration of the quality of the soil and water. Considering that, there is still a gap in the knowledge on the Pb content in the soil and the two species grown under irrigation in the Mantaro Valley.

The objective of the study was to determine the concentration of Pb in agricultural soils and cultivated pastures (*M. sativa* and L. x hybridum) irrigated with the river water contaminated with heavy metals.

MATERIAL AND METHODS

The study was carried out in agricultural plots with cultivated pastures irrigated in dry season with the contaminated water from the Mantaro river since 1945 [Ministry of Agriculture 2011]. The source of water pollution involves the discharges of mining and metallurgical effluents in the upper and middle watersheds of the Mantaro River. The area studied is located in the town of Apata, belonging to the province of Jauja, department of Junín; located on the left bank of the Mantaro valley, S11 ° 51'21" and W 75 ° 21'25" at 3332 m (Figure 1). The main economic activity of the population in the field of study is agriculture (maize, potatoes and cultivated pastures) and livestock (cattle rearing).

Seventeen plots with cultivated pastures of different size selected, 10 plots with Lx hybridum (0.361–0.916 ha) and seven plots with M. sativa (0.202–0.338 ha). These species were selected because they are a food source for the milk-producing cattle and their derivatives. The samples in general collected in August 2016. The soil samples collected from the 20 cm of the upper level,

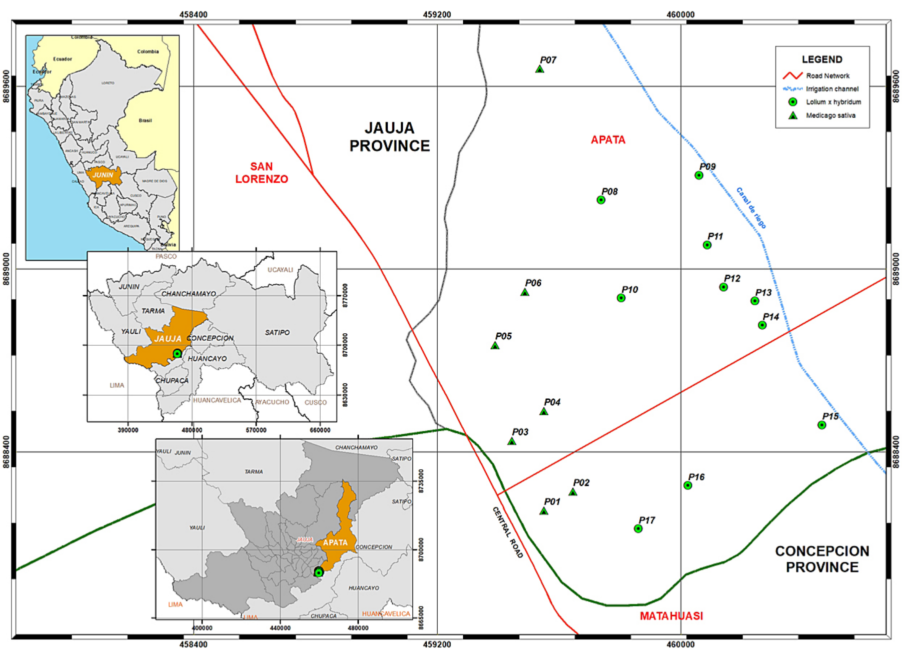

Figure 1. Location map and sampling points

after removing the first layer of the soil surface. Five soil sub-samples were extracted from each plot, which were then mixed and homogenized to extract a composite sample of 1 kg. Each sample composed of soil was air dried, sieved and homogenized. Then, the soil texture was determined [Bouyoucos 1962], the pH was established using the ratio 1: 2.5 soil/H_2O [Thomas 1996], the capacity of cation exchange (CIC) was determined by the saturation method with ammonium acetate [Rhoades 1982] and the content of organic matter through the Walkley-Black method [Walkley and Black 1934].

In order to determine the lead content in the soil, 500 g of soil collected from each plot, dried at room temperature and sieved. The total concentration of lead in the soil determined using 5 g of dry soil the samples subjected to digestion with HNO_3 [APHA, AWWA,WEF 2012]. After digestion, the concentration of lead was determined with the atomic absorption spectrophotometer. From the same soil sampling points as in the previous stage, 500 g of fresh samples of plant tissue of each species (above-ground part of animal consumption) of the same age (4 months) were collected. The leaves and stems samples were washed three times with distilled water, subjected to a drying process in a drying oven at a temperature of 60°C for 48 h until constant weight. Then, the grinding carried out, sifted through a 2 mm mesh screen and a subsequent destruction of the organic matter. In order to determine the content of lead in the plant, 5 g of dry sample weighed, which was subjected to a process of digestion with HNO3 and the concentration of lead was determined by means of atomic absorption spectrophotometry [APHA 1998].

The amount of lead absorbed by the plants irrigated with contaminated water was calculated using the bioconcentration factor (BCF) that several authors use. The relation is equal to BCF = Cplanta /Csuelo where Cplanta is equal to the concentration of the metal in the plant and Csuelo is the concentration of the metal in the soil where the plant grows [Castro et al. 2018, Kicinska 2019]. The means of concentration of lead in the soil and pastures compared using the t test by means of the SPSS statistical package for data processing.

RESULTS AND DISCUSSION

Physical and chemical characteristics of soil with cultivated pastures

More than 80% of the soils have medium textures and in lower proportion moderately thick texture. The soil pH varies from slightly acidic (6.45) to neutral (6.95–7.96) with an electrical conductivity (CE) below one, which indicates that these soils have no salinity problems, organic matter content below 2% and low cation exchange capacity below 15% (Table 1).

Concentration of lead in the soil

The concentration of lead in soil with the culture of *L. x hybridum* varies from 47.65 to 67.02 mg.kg^{-1} of soil, with an average of 57.17 mg.kg^{-1} and with *M. sativa* culture from 43.70 to 67.30 mg.kg^{-1} of soil, with an average concentration of 59.10 mg.kg-1 (Figure 2). Both concentrations are below the Peru's soil environmental quality standards (70 mg.kg^{-1}) (D.S. No. 002–2013-MINAM 2013) [Ministry of the Environment 2013]. No significant differences were detected in the lead content between soils with *L. x hybridum* and *M. sativa*, the presence of cultivated pastures did not influence the concentration of lead in the soil.

Soils had the lead concentrations below the maximum permitted levels, coinciding with the results obtained by [Al-Rashdi & Sulaiman, 2013]; this could attributed to the size of the soil particles. The greater adsorption and persistence of lead occurs in fine textured soils; also, heavy

Table 1. Mean and standard deviation of the chemical-physical parameters of the soil with cultivated pastures

Parameters	Mean ± SD
Sand (%)	47.33 ± 5.16
Silt (%)	24.17 ± 4.91
Clay (%)	28.50 ± 7.71
Textural class	sandy loam – clay loam – sandy clay loam
pH	7.14 ± 0.49
EC (dS/m)	0.29 ± 0.09
OM (%)	1.15 ± 0.26
CEC (meq/100g)	10.54 ± 1.21

SD (standard deviation), EC (electrical conductivity), OM (organic matter), CEC (cation exchange capacity) (n=6)

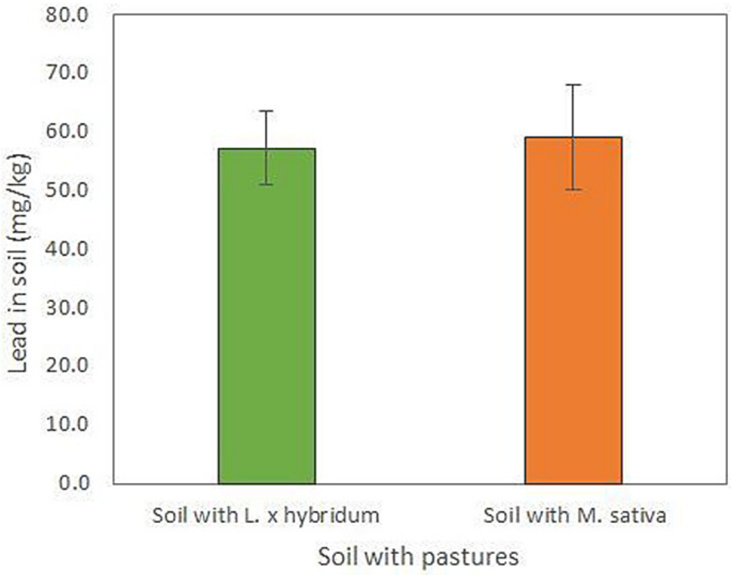

Figure 2. Concentration of lead in the soils with *L.x*

metals such as lead are not immobilized in soils of thick textural classes [Ebrahim et al. 2016]. On the other hand, the stoppage of activities in 75% of the La Oroya Metallurgical Complex operated by the company Doe Run Peru has occurred since 2012. It would have contributed to the reduced contamination of the irrigation water of the crops because the content of lead in the irrigation water in 2014 was 0.08 mg·L^{-1} [Orellana and Erazo 2017] above the environmental quality standards for vegetable irrigation and animal drink.

Concentration of lead in cultivated pastures

The soils in which forage was cultivated showed higher lead values than those found in the plant. The average concentration of lead in *L. x hybridum* and *M. sativa* was 1.17 and 1.62 mg kg^{-1}, respectively. The content of lead in forages was found in the range of 0.13 to 2.35 mg.kg^{-1} for *L. x hybridum* and 0.75 to 2.70 mg kg^{-1} in *M. sativa* (Figure 3). These values are within the limits allowed by the Food and Agriculture Organization of the United, FAO [2003] *M. sativa* recorded higher values of lead than *L. x hybridum*. The concentration of lead was lower in the plant compared to what was found in the soil coinciding these results obtained by Lara-Viveros et al. [2015]. The contribution of heavy metals to the soil occurs every 15 days that is the frequency of irrigation in the Mantaro valley. No significant differences were observed in the accumulation of lead between the pastures studied.

Jadia y Fulekar [2008] reported the lead content in alfalfa of 0.098 mg kg^{-1} lower than the other metals they studied and what was found in this study. Bytyqi y Sherifi [2010] recorded 0.16 – 0.24 mg kg^{-1}. Yahaghi et al. [2019] reported high absorption of soluble lead by *M. sativa* and recommend the addition of bacteria to stimulate the development of the plant under adverse environmental conditions, such as heavy metal contamination. Zhang et al. [2017] reported the lead concentrations in ryegrass *(L. perenne*) shoots f 5.88 ± 34.38 mg kg^{-1} higher than found in this study. Kwiatkowska-Malina and Maciejewska [2013] reported the lead content in *L. multiflorum* from 7.9 to 10.6 mg kg^{-1} that varied significantly under various conditions and interactions of environmental factors.

M. sativa (alfalfa) could successfully extract metals and metalloids, so it would not be advisable to consume them by animals because of the transfer to the food chain [Tabasi et al. 2017]. Lead is not an essential element in the nutrition of plants and is generally present in low concentrations in plant tissues; therefore, the accumulation or hyperaccumulation of lead by plants is an extremely rare event (Baker & Brooks, 1989).

Bioconcentracion factor

The bioconcentration of lead in the aboveground part of the plant tissue is shown in Figure 4. The BCF for *L. x hybridum* and *M. sativa* was less than one (0.0025 – 0.0402). These

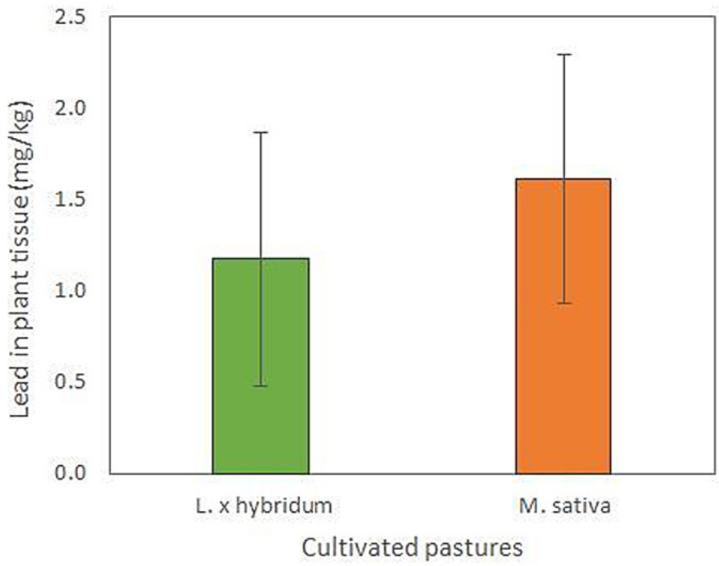

Figure 3. Accumulation of lead in the above-ground tissues of *hybridum* and *M. sativa L.x hybridum* and *M. sativa*

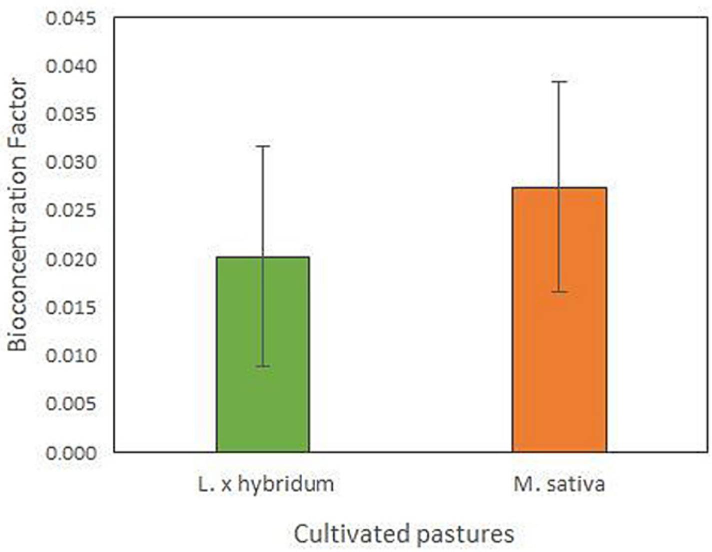

Figure 4. Lead bioconcentration factor (BCF) in the above-ground tissues of *L. x hybridum* and *M. sativa*

values are lower than the ones found by Wang et al. [2015] who reported higher values of BCF in the maturation period of alfalfa and that could be attributed to the physiological characteristics of alfalfa, the characteristics of the soils where it develops, the concentration of heavy metals and environmental conditions.

No significant differences were detected in the bioconcentration of lead in both species; however, *M. sativa* registers higher values. Zhang et al. [2019] in *L. perenne* reported higher BCF (0.004 – 0.19) than found in this study but less than 1; likewise Cao et al. [2016] reported the values of 0.082 in untreated soils. Al-Rashdi y Sulaiman [2013] in *M. sativa* recorded values of 0.58 to 2.13 in the above-ground part of the plant. Elouear et al. [2016] indicates that alfalfa plants could not be feasible for the extraction of lead because the values of BCF were less than one coinciding with the results found.

The results of the study show that *M. sativa* has the ability to retain the maximum concentrations of lead in the roots and to restrict its translocation to shoots and leaves [Aslam et al. 2015]. In legumes, the roots were the main accumulation site [Piechalak et al. 2002]; and the values found are indicative of the lower mobility of the soil to the plant and the species studied are not hyperaccumulators and there is a low risk that lead transferred significantly to the plant.

CONCLUSIONS

The concentrations of lead in the soil with pastures cultivated and irrigated with contaminated water were low; they did not exceed the maximum limits recommended by the environmental quality standards for soil. The accumulation of lead in *L. x hybridum* and *M. sativa* did not exceed the permissible limits. These species are fodder crops of importance for Apata's livestock; they are used as main fodder for cattle. The low values of lead in their tissues do not constitute a risk to animals that consume it. However, the content of other heavy metals should be regularly monitored in order to detect the degree of soil and forage contamination.

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