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Multidisciplinary study of chemical and biological factors related to Pb accumulation in sorghum crops grown in contaminated soils and their toxicological implications

Andrés Blanco [a], María J. Salazar [a], Carolina Vergara Cid [a], Carina Pereyra [b], Lilia R. Cavaglieri [b], Alejandra G. Becerra [c], María L. Pignata [a], Judith H. Rodriguez [a,*]

[a] Multidisciplinary Institute of Plant Biology, Pollution and Bioindicator Section, Faculty of Physical and Natural Sciences, National University of Córdoba, Av. Vélez Sársfield 1611, X5016CGA Córdoba, Argentina

[b] Department of Microbiology and Immunology, National University of Río Cuarto, Ruta 36 km 601, 5800 Río Cuarto, Argentina

[c] Multidisciplinary Institute of Plant Biology, Mycology Section, Faculty of Physical and Natural Sciences, National University of Córdoba, Av. Vélez Sársfield 1611, X5016CGA Córdoba, Argentina

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ABSTRACT

In this study, the content of Pb, the physico-chemical and biological parameters in soils, and the metal transfer to vegetative and reproductive *Sorghum bicolor* plants were evaluated along with their relationship with the toxicological risk of crop consumption. To carry this out, soil and sorghum samples at different growth stages were collected near to a former battery recycling plant. The results showed that the concentrations of Pb in soils at several sites were above the maximum permissible levels. Metal bioavailability was not directly related to the pH, OM% or EC, while no association between metals and the different genera of fungi was observed. Sorghum crops accumulated Pb mainly in the roots in all of the growth stages, and therefore presented low levels of Pb in aerial parts without toxicological risk due to direct consumption. Taken together, our results revealed that sorghum could be employed as a potential phytostabilizator of lead in soils associated with crop production. However, further studies are necessary to extend these findings.

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1. Introduction

Heavy metal pollution in soils is of considerable concern worldwide due to the potential risk to the environment and to human health. Large areas of farmland have been contaminated by metals owing to anthropogenic input from mining, smelting, fossil fuel burning, phosphate fertilizers and sewage sludge (Navarro et al., 2008). Due to the high toxicity of heavy metals, the resulting polluted agricultural soil affects crop growth and the quality of agricultural products, as well as being a serious threat to human health through contamination of the food chain (Salazar et al., 2012; Zhao et al., 2014; Zhuang et al., 2009a). Industrial practices that contribute to heavy metal pollution include lead smelting and secondary lead smelting (recycling of Pb from Pb-containing products) (Cala and Kunimine, 2003; Dahmani-Muller et al., 2000; Fernandez-Turiel et al., 2001; Ramírez, 2008). Many studies have been carried out in industrial areas near to agricultural soils, and have reported Pb concentrations in crops above the European threshold of 0.2 mg kg^{-1} FW (fresh weight) for Pb (Caggiano et al., 2005; González-Miqueo et al., 2010; Honour et al., 2009; Rodriguez et al., 2014; Salazar et al., 2012). In another investigation, Salazar and Pignata (2014) reported high lead concentrations exceeding national and international norms in soils and native plants near to a former battery recycling plant in Córdoba, Argentina. Taking into account that this occurred in an agricultural area cultivated with sorghum, soybeans, wheat and maize, it is important to evaluate the toxicological risk for consumers. Concerning these crops, sorghum has been previously cited as being a potential accumulator of metals in roots in both field and laboratory studies (Al Chami et al., 2015; An, 2006; Salazar and Pignata, 2014; Soudek et al., 2014).

Pollution in soils results in a reduction in the quality of their physical and chemical properties and causes changes in their metal retention capacities (Simon et al., 2000). Metal transfer from soil to plant is a complex process determined by several factors of generally a biological, geochemical or climate nature, with both natural and anthropogenic processes controlling mobility and availability (Kabata-Pendias and Sadurski, 2004).

Numerous studies have indicated that in addition to climatic factors and soil properties, the plant-microorganism interaction is an important factor related to the metal bioavailability of soils (de Souza et al., 1999; Kuffner et al., 2008; Lin et al., 2004), with the rhizosphere being the soil compartment where the interactions among microorganisms, roots and soil modify the nutrient and also the heavy metal availability (Lin et al., 2004). Thus, numerous studies proposed arbuscular mycorrhizal fungi

* Corresponding author.
E-mail address: jrodriguez@com.uncor.edu (J.H. Rodriguez).

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as a good tool for phytoextraction of heavy metals in soils (Redon et al., 2008; Vodnik et al., 2008). Moreover, there are some studies with bacteria and bioremediation of heavy metals, which reviewed the latest studies detailing the most important phenotypes and properties such as peptides and proteins that are used in bioremediation of heavy metals (Valls and de Lorenzo, 2002; Mejaré and Bülow, 2001).

Taking into account the findings mentioned above, it is pertinent to carry out a multidisciplinary study to consider all the chemical, physical and biological factors affecting the bioavailability of toxic metals in soils which can potentially be incorporated into crops. Therefore, the purpose of this study was to evaluate whether physical, chemical and biological factors determine metal mobilization in soils, metal accumulation in sorghum crops and its toxicological risk during the growing season.

2. Material and methods

2.1. Study area and sampling points

The study area was located in Bouwer, a peri-urban commune with a population of approximately 2000 inhabitants, 18 km south of Córdoba city in central Argentina (Fig. 1). The climate is mild, with an annual mean temperature of about 15 °C and an annual rainfall range of 500–900 mm. The soil is an Entic Haplustoll, and this area is characterized by a former battery recycling plant (31°33′34.02″S; 64°11′9.05″W) surrounded by agricultural crops (mostly soybean and associated crops such as sorghum). Bouwer is one of the environmentally most affected areas in the province of Córdoba, being characterized by a waste disposal area, car scrapyards, and a former battery recycling plant that was closed in the year 2005 due to functional problems with lead emissions being c. 35 times higher than the permitted values (Salazar and Pignata, 2014).

The study area is cultivated with *Sorghum bicolor*, which is subjected to zero tillage and has superphosphate fertilizers applied in general in proportions ranging from 50 to 100 kg ha^{-1}.

Fig. 1 shows the location of the sampling sites, which were chosen taking into account the main directions of the winds and the distance to the emission source according to a preliminary study (Salazar and Pignata, 2014).

2.2. Sampling procedure and analysis preparations

Topsoil (rhizosphere and bulk) and crop samples were collected for a full growing season of sorghum for the following different growth stages of plant development: prior to sowing (with only bulk soil fraction being collected), half bloom and maturity (November, 2012; February, 2013; April, 2013, respectively).

Sorghum plants and topsoil samples were collected at the sampling sites following a systematic sampling. Each site was a 3 m^2 square, with 9 sub-sampling points systematically arranged with a 1 m gap between them. At each sampling site, three pools of samples (soils for November, soils and plants for February and April) were collected.

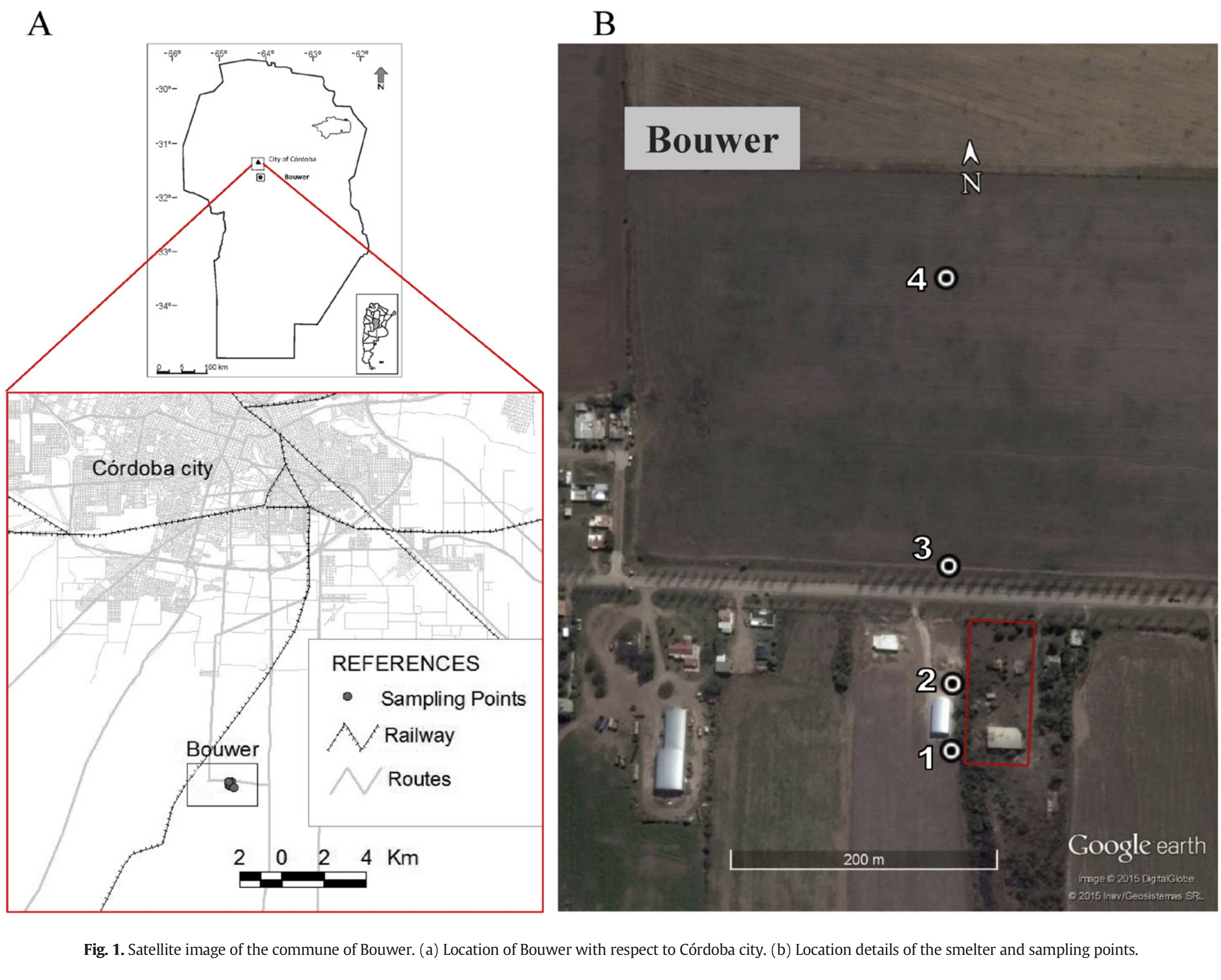

Fig. 1. Satellite image of the commune of Bouwer. (a) Location of Bouwer with respect to Córdoba city. (b) Location details of the smelter and sampling points.

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