Science of the Total Environment 497–498 (2014) 153–162

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Evaluation of the transfer of soil arsenic to maize crops in suburban areas of San Luis Potosi, Mexico

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HIGHLIGHTS

- The soil pH was negatively correlated with the accumulated As in each plant part.
- Fe and Mn had a significant correlation (P = 0.5) with the As translocation factors.
- As(V) was the main species found in soil aqueous leachate and maize crop.
- MTA showed a decrement in As level with distance increment to the irrigation source.
- Inorganic As was the predominant form in edible plant parts for livestock.

ARTICLE INFO

Article history:
Received 9 April 2014
Received in revised form 18 July 2014
Accepted 18 July 2014
Available online 14 August 2014

Editor: Charlotte Poschenrieder

Keyword:
Arsenic species
Corn plant
Agricultural soil
Arsenic phytoavailability
Principal component analysis
Cluster analysis

ABSTRACT

The presence of arsenic (As) in agricultural food products is a matter of concern because it can cause adverse health effects at low concentrations. Agricultural-product intake constitutes a principal source for As exposure in humans. In this study, the contribution of the chemical-soil parameters in As accumulation and translocation in the maize crop from a mining area of San Luis Potosi was evaluated. The total arsenic concentration and arsenic speciation were determined by HG-AFS and IC–HG-AFS, respectively. The data analysis was conducted by cluster analysis (CA) and principal component analysis (PCA). The soil pH presented a negative correlation with the accumulated As in each maize plant part, and parameters such as iron (Fe) and manganese (Mn) presented a higher correlation with the As translocation in maize. Thus, the metabolic stress in maize may induce organic acid exudation leading a higher As bioavailability. A high As inorganic/organic ratio in edible maize plant tissues suggests a substantial risk of poisoning by this metalloid. Careful attention to the chemical changes in the rhizosphere of the agricultural zones that can affect As transfer through the food chain could reduce the As-intoxication risk of maize consumers.

1. Introduction

Arsenic (As) is a metalloid present in various environmental and biological systems (soil, water and foodstuffs), and it is recognized as carcinogenic, causing skin, lung, and bladder cancers (EPA, 2012). This element occurs in the natural environment as either inorganic (As(III) and As(V)) or organic (monomethylarsonic (MMA) and dimethylarsinic (DMA)) species. In general, inorganic species are considered more toxic than organic species. The background As concentrations in soil vary between 0.1 and 40 mg kg^{-1} with an average of 10 mg kg^{-1} (Bai et al., 2008). However, natural and anthropogenic sources, such as mining, industrial activities and pesticide use have contributed to an increase in the As levels in the environment. High As levels have been detected in various parts of the world (Deng et al., 2009; O'Reilly et al., 2010; Watts et al., 2010). Mexico has significant problems of groundwater and soil contamination by As. Several regions in this country possess As levels in the ground water and soil that exceed the allowed maximum limit for agricultural use of 1000 μg L^{-1} and 20 mg kg^{-1} (Rosas et al., 1999), respectively; specifically, a mining district in San Luis Potosi where Ag–Pb–Zn and Au–Cu skarn sulfide ores have been mined for more than 200 yr reported As concentrations of 6765 μg L^{-1} and 1932 mg kg^{-1} in the water and soil, respectively (Razo et al., 2004; Jasso-Pineda et al., 2006; Armienta and Segovia, 2008).

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http://dx.doi.org/10.1016/j.scitotenv.2014.07.072
0048-9697/

The As present in agricultural soil and irrigation water can access plants through their root systems, resulting in phytotoxic effects for some crops. In general, plants are able to tolerate 2 mg kg^{-1} As in soil (Kabata-Pendias and Mukherjee, 2007); however, a high As concentration is toxic for crops, causing necrosis, chlorosis, inhibition of growth and, finally, death (Gulz et al., 2005).

The arsenic concentrations in the edible parts of crops depend on the availability of soil As and the ability of a crop to take up As and to translocate it to the target organs. The As solubility in agricultural soils can vary dramatically from one location to another depending on the soil conditions. Soil parameters such as pH, redox potential, organic matter content, texture, and the concentrations of some elements (aluminum, iron, manganese and phosphorus) can dramatically affect the As solubility (Carbonell Barrachina et al., 1995; Rosas et al., 1999; Zheng et al., 2011).

The transfer of arsenic from soils to the edible plant parts is a key step in the route of As entry into the human food chain. The transfer factors depend not only on the plant species but also on the As concentration and its availability in the soil. The impact on the health of the plants and their consumers caused by exposure to As is primarily associated with the phytoavailability of metalloid species. The phytoavailability of a substance is a function of the abundance, chemical form, and adsorption to soil particles (Traina and Laperche, 1999). There are reports that the soluble total As presents a better correlation with its bioavailability than the total As content (Gulz et al., 2005).

Livestock and humans may be exposed to As toxicity through the plants and vegetables consumed (Khan et al., 2009). Maize is the most widely grown grain crop throughout Mexico (47.2% of the agricultural zone, equivalent to 6.8 million hectares and 17.6 million tons of corn, 2011) (FAOSTAT, 2004), and is the principal consumed cereal, 115 kg per capita (CNMI, 2001), maize is considered to be an excellent provider of digestible carbohydrates and to be rich in protein. In many rural areas, this cereal provides nearly 70 and 50% of caloric and protein intake, respectively (Serna-Saldivar et al., 2008). Additionally, maize is commonly used as a livestock feed. It has been reported that the total arsenic content in the stem and leaf of maize crops in field studies varies from 640 to 3000 μg kg^{-1} (Rosas et al., 1999; Prieto-García et al., 2007; Prabpai et al., 2009; Baig et al., 2010; Marwa et al., 2012; Neidhardt et al., 2012). The intake of livestock fed with contaminated maize silage can represent a risk for human health through the food chain.

In this study, the chemical changes of the rhizosphere, the As accumulation and the As translocation in the maize crop of three sites near to the mining area in San Luis Potosi, Mexico were studied to evaluate the field conditions that could favor As transfer from the soil to the maize plant and represent a human health risk. The total As and As species concentrations in the soil-water–maize system were also determined. Principal component analysis (PCA) and cluster analysis (CA) were adopted to assist in the interpretation of the data that describe the As phytoavailability to maize crops and their potential mobility to grain.

2. Methods/experimental

2.1. Location and sample characteristics

Soil, irrigation water and maize samples were collected from three maize fields near the mining area of San Luis Potosi, Mexico; zones A and B in Matehuala, and zone C in the municipality of Villa de Ramos. The coordinates of the sampling points are described in Table 1. The map in Fig. 1 shows each of the collection points. Several agricultural, rural areas of the state of San Luis Potosi, Mexico (approximately 500 km NE of the city of Mexico) have presented mining activity for over 200 yr. Mineral deposits include galena, pyrite, sphalerite, salts of Cu–Sb, and arsenopyrite (Armienta and Segovia, 2008). The mining waste has contaminated the agricultural zones through irrigation water. The total release of As in the mining areas within this region was estimated at 7.5 ton yr^{-1} (August, 2008–August, 2009) (Martínez-Villegas et al., 2013). Since irrigation water samples has been reported to reach the As concentration of 5.9 mg L^{-1} (Armienta and Segovia, 2008), it is important to understand the As transfer to corn plants in this region.

The sampling agricultural areas are in the Central Plateau and the Sierra Madre Oriental of Mexico and have predominantly a dry temperate and semi-dry climate. The soil types in this region are Phaeozem, Calcisol and Leptosol (INEGI, 2009). Precipitation is scarce in the area, 300–700 mm yr^{-1} (INEGI, 2009), so that the irrigation channels are used most of the year.

The samples were collected from three irrigation areas with crops grown for three months (plant height was 1.2–1.5 m and wet weight was 2.0–3.5 kg). A rectangular systematic sampling was performed in each agricultural zone, which involved the collection of triplicate samples of soil, and maize plants from each farm from six points. Additionally, an irrigation water sample was collected for each sampling site. The distance between sampling points was approximately 4–10 m. At each sampling location, maize root, shoot and grain samples were taken from a single maize plant, followed by collecting 30 g of soil from a 0 to 30 cm depth directly under the sampled plant close to root crop (<20 cm).

Table 1
Coordinates of the sampling points of the agricultural soil, irrigation water and maize crop.

Sample type	Zone A (Matehuala)		Zone B (Matehuala)		Zone C (Villa de Ramos)	
	Point	Coordinate	Point	Coordinate	Point	Coordinate
Agricultural soil and maize crop	MTA-1	N 23° 39′ 57.2″ W 100° 34′ 35.1″	MTB-1	N 23° 43′ 05.2″ W 100° 39′ 20.7″	VR-1	N 22° 49′ 54.2″ W 102° 02′ 53.6″
	MTA-2	N 23° 39′ 56.9″ W 100° 34′ 35.9″	MTB-2	N 23° 43′ 05.0″ W 100° 39′ 20.5″	VR-2	N 22° 49′ 54.2″ W 102° 02′ 32.1″
	MTA-3	N 23° 39′ 57.0″ W 100° 34′ 35.1″	MTB-3	N 23° 43′ 05.2″ W 100° 39′ 20.2″	VR-3	N 22° 49′ 30.8″ W 102° 02′ 15.9″
	MTA-4	N 23° 39′ 56.7″ W 100° 34′ 35.7″	MTB-4	N 23° 43′ 05.4″ W 100° 39′ 20.6″	VR-4	N 22° 49′ 32.4″ W 102° 02′ 19.6″
	MTA-5	N 23° 39′ 56.9″ W 100° 34′ 34.8″	MTB-5	N 23° 43′ 05.4″ W 100° 39′ 20.4″	VR-5	N 22° 49′ 32.1″ W 102° 02′ 18.1″
	MTA-6	N 23° 39′ 56.6″ W 100° 34′ 35.4″	MTB-6	N 23° 43′ 05.5″ W 100° 39′ 20.2″	VR-6	N 22° 49′ 32.2″ W 102° 02′ 17.2″
Irrigation water	MTA-A	N 23° 40′ 20.0″ W 100° 35′ 01.8″	MTB-A	N 23° 43′ 05.2″ W 100° 39′ 20.2″	VR-A	N 22° 49′ 40.9″ W 102° 02′ 18.9″