NU Science Journal 2006; 3(1): 13-19

Effects of Red Clay on Arsenic Mobility in Contaminated Soil, Plant Growth and Plant Arsenic Accumulation

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ABSTRACT

The present study investigates the potential of red clay (RC) as an adsorbent for an immobility of arsenic in contaminated soil (CS) which evaluates the plants growth and the arsenic accumulation in mung beans and maize plants. Growth of mung beans and maize plants on the amended contaminated soil showed significant effect of CR on shoot length, and the weight of shoot and root, especially, CS amended with 2% w/w of red clay. Arsenic concentration in the shoot and root of mung beans and maize were decreased with an increased amount of RC from 0.5 to 2% w/w. The arsenic concentration in shoot and root of both plants for CS amended with RC for all levels were lower than the untreated CS. The arsenic concentration in roots was higher than shoots for both plants.

Keywords: Arsenic, Contaminated soil, Plants growth, Red clay

INTRODUCTION

Inorganic and organic arsenic compounds were used previously as pesticides, plant defoliants, and herbicides. They are also emitted from metal smelters and may accumulate in agricultural and horticultural soils and in plants (Peterson *et al.*, 1981). Otte et al. (1990) studied the uptake of arsenic by using *Urtica dioica* and *Phragmites australis* in outdoor experiments. It was found that arsenic added to the soil to inhibit the growth *Urtica dioica*. *Urtica dioica* and *Phragmites australis* took up increasing amounts of arsenic with increasing arsenic concentration in the soil. According to Burlo et al. (1999), the concentration of arsenic in tomato plants, which growing under soilless culture conditions, increased significantly with increased arsenic concentration in solution and reduced plant growth and fruit yield. Arsenic accumulates in much larger amounts in roots. It has been reported that the percent of water soluble arsenic present was inversely proportional to the iron and aluminum content (Woolson *et al.*, 1973; Roy *et al.*, 1986). An Initial symptom of arsenic toxicity is usually wilting of new-cycle leaves, followed by retardation of root and top growth of the plant (Liebig, 1975). The availability of arsenic to plants is dependent not on the total arsenic concentration of a site, but on the soluble fraction of arsenic present. Methods that were able to permanently reduce the mobility of arsenic in contaminated soils will in turn reduce the toxicity and pollution potential of such soils (Jain *et al*., 1999). Arsenic can be immobilized through adsorption-coprecipitation with various materials. In the soil, iron oxides, and clay minerals have a high fixation capacity for arsenic (Frost and Griffin, 1977; Wilkie and Hering, 1996; Fendrof *et al*., 1997; Manning and Goldberg, 1997; Jain *et al*., 1999).

The contaminated soil (CS) of this study is a by-product of tin-mining activities. It is a highly complex, heterogeneous mixture of sulphide, silicates and oxide with high concentrations of total arsenic (Arrykul *et al*., 1996; Mopoung and Thavornyutikarn, 2004). The CS was obtained from Ron Phibun District, Nakhon Si Thammarat Province, Thailand. The red clay (RC) was obtained from Doi Saket Distric, Chiang Mai Province, Thailand. It contains high quantities of Fe_2O_3 (24.8 % w/w) and Al_2O_3 (23.1 % w/w) (Mopoung and Thavornyutikarn, 2004). Mopoung and Thavornyutikarn (2004) studied adsorption of arsenic by red clay. It was found that the released amounts of arsenic, which leached from red clay, decreased with the change of red clay in CS from 0.5-2.0% w/w.

The objective of this study was to examine what the effect of the addition of RC might have on reducing the mobility of arsenic in contaminated soil. The effects of the different application rates of RC on plant growth, arsenic accumulation in shoot and root of plants were also determined.

MATERIALS AND METHODS

Preparation of red clay and contaminated soil

RC and CS were used in the investigation. RC was air-dried, then crushed and passed through a –80 mesh sieve. The CS samples were collected with a spade from 0-20 cm surface layer at an old mine site in Nakornsrithummarat province (Thailand). The CS sample was air dried and sieved through a 2 mm nylon sieve for all experiments.

Plant growth experiment

The experiments were carried out using the method of Boisson (1999). RC was applied to the CS as an arsenic immobilizing additive on a 0.5, 1.0, and 2% w/w basis. CS (air dried), an additive and a standard nutrient containing 250 mg N (NH_4NO_3), 207 mg K (K_2SO_4), 60 mg Mg ($MgSO_4$), and 109 mg P (NaH_2PO_4) per kg soil dried weight was mixed in a rotate container. The soil mixtures, as well as the untreated CS, were rehydrated to 70 percent of the water holding capacity. The soil mixtures were equilibrated for three weeks under normal atmospheric environmental conditions. Maize (*Zea mays L. cv. Gramineac*) and mung beans (*Vigna radiata cv. Sujata*) were consecutively grown on the equilibrated soils. Seeds were planted after overnight imbibition in 2.0 liter polyethylene pots (4 plants/pot) and then watered daily with distilled water. Each week for six weeks after sowing, shoot length of both plants was determined. After six weeks, shoot and root weight, and root length were determined. After rinsing with distilled water, shoot and root samples were taken for arsenic analysis. Oven-dried plant samples were wet-digestioned over night in 14 NHNO_3 (10 mL) and 70-72% $HClO_4$ (20 mL) , which was followed by a hot digestion (120^{o}C for 2 h) (Helrich, 1990). The solution was filtered through ash free paper and adjusted to 100 mL with deionized water. Blanks of reagents and controlled samples were included in the analytic scheme. The concentration of arsenic was determined by UV-VIS spectrophotometry (Johnson and Pilson, 1972).

The Duncan's New Multiple Range test (DMRT) was evaluated for data of plant growth experiment.

RESULTS AND DISCUSSION

Plant growth

In each week for six weeks after sowing, shoot lengths of plants was determined. For the first three weeks, the shoot length of mung beans and maize for all experiments was not significantly different (Table 1). After the fourth week, the shoot lengths of the mung beans and maize were high, but not significantly different, for CS amended with 0.5- 2.0 percent of RC. The shoot lengths of both plants was low for untreated CS. In the first to third week, the shoot length showed high growth rate but lowered after the fourth week in untreated CS. The fresh weight of shoot and root of both plants on untreated CS were low and they significantly increased in CS amended with 0.5-2.0 percent RC (Table 2). The dried weights of shoot and root of both plants was not significantly different for all experiments but trended to be low for untreated CS. As the analysis of statistics for mung beans and maize showed no significant effect of the content level of RC on root length, but with untreated CS the roots lengthened (Table 2). This may be contributed to the mobility of arsenic to the root of the plants. The distribution of branched-root was inhibited by arsenic, so that the root lengthened (Otte *et al*., 1990). The addition of RC, at the three different levels, to the CS resulted in improved growth of both mung beans and maize. This may be contributed to the content of iron and aluminum oxide in RC which may reduce the mobility of arsenic (Woolson *et al*., 1973; Roy *et al*., 1986).

Table 1 The shoots Length of mung beans and maize plants during the first to the sixth weeks

	Shoot length of mung beans (cm)					
	week					
	1	2	3	4	5	6
Untreated CS	1.53 a	4.05 a	6.73 a	7.94 b	8.76 c	9.00 b
CS + 0.5% RC	1.18 a	3.19 a	6.47 a	8.75 a	10.17 ab	11.60 a
CS + 1.0% RC	1.16 a	2.20 a	5.86 b	8.29 a	9.90 b	10.88 a
CS + 2.0% RC	1.54 a	3.46 a	6.49 a	8.71 a	10.48 a	11.30 a
	Shoot length of maize (cm)					
	week					
	1	2	3	4	5	6
Untreated CS	1.29	2.74	4.81	6.32 b	7.59 b	8.29 b
CS + 0.5% RC	1.07	2.91	4.46	8.71 a	10.44 a	10.98 a
CS + 1.0% RC	1.11	3.05	5.08	8.79 a	10.25 a	10.84 a
CS + 2.0% RC	1.18	2.58	4.26	8.11 ab	9.89 ab	10.79 a

Within a column, mean values followed by a common letter were not significantly different at the 5% (Duncan's New Multiple Range test; DMRT, n = 4)

Table 2 Fresh and dried weight of shoots and root s and roots length of plants

	Mung beans				
	Shoot weight (g)		Root weight (g)		Root length (cm)
	Fresh	Dried	Fresh	Dried	
Untreated CS	4.31 b	2.96 a	3.00 b	0.29 a	16.07 a
CS + 0.5% RC	14.63 a	4.26 a	9.23 a	0.55 a	4.16 b
CS + 1.0% RC	15.83 a	3.07 a	10.91 a	0.73 a	14.86 ab
CS + 2.0% RC	15.44 a	3.79 a	10.22 a	0.57 a	14.23 b
	Shoot length of maize (cm)				
	Shoot weight (g)		Root weight (g)		Root length (cm)
	Fresh	Dried	Fresh	Dried	
Untreated CS	6.71	1.55 a	11.89 b	1.15 a	25.98 a
CS + 0.5% RC	22.14	3.62 a	16.69 a	1.14 a	20.22 b
CS + 1.0% RC	25.31	3.36 a	18.12 a	1.64 a	20.07 b
CS + 2.0% RC	24.11	3.35 a	19.35 a	1.69 a	18.93 b

Within a column, mean values followed by a common letter were not significantly different at the 5% (Duncan's New Multiple Range test; DMRT, n = 4)

Arsenic accumulation in shoot and root

From Table 3, it was found that the arsenic concentration in the shoot of mung beans and maize in untreated CS were high (7.58 and 7.59 mg/kg, respectively). The arsenic concentrations in shoots for amended CS were low and significantly difference from untreated CS. The arsenic concentrations in shoot of mung beans for amended CS were not significantly difference for 1.0 and 2.0 percent of content of RC. The arsenic concentration in the roots of mung beans for untreated CS was highest (136.94 mg/kg). The arsenic concentration in the roots of both plants in amended CS were significantly different for each level of concentration. The addition of all three levels (0.5, 1.0 and 2.0 percent) of RC generally reduced arsenic accumulation in the shoots and roots of both plants if compared to the untreated CS. The differences in the concentrations, suggest that the arsenic concentration in shoots and roots decreased after the addition of red clay with a high content of oxide of iron and aluminum and fine particle size (Mopoung and Thavornyutikarn, 2004).

The arsenic immobility was linearly related to the amounts of oxide of iron and aluminum (Woolson *et al.*, 1973; Roy *et al.*, 1986) with high adsorption capacity. The adsorption of arsenic decreases with the increase in adsorbent particle size. This may be because of the surface area per unit mass available for the adsorption of arsenic, which will be greater for smaller particles (Singh *et al.*, 1996). In both plants, the arsenic accumulated mainly in the root system and only relatively low quantities were translocated to shoots. The results obtained in this experiment compare well with reported results of Burlo et al. (1999). The strategy developed by plants to tolerate the arsenic was avoidance, limiting arsenic transport to shoots and increasing arsenic accumulation in the root system.

Table 3 Concentrations of the total arsenic in the shoots and the roots of plans

	Concentrations of the total arsenic in plants (mg As/kg)			
	Mung beans		Maize	
	Shoot	Root	Shoot	Root
Untreated CS	7.58 a	136.94 a	7.59 a	88.26 a
CS + 0.5% RC	3.07 b	126.86 b	2.33 b	57.74 b
CS + 1.0% RC	1.45 c	71.56 c	1.20 c	35.83 c
CS + 2.0% RC	1.45 c	6.45 d	0.55 d	4.98 d

Within a column, mean values followed by a common letter were not significantly different at the 5% (Duncan’s New Multiple Range test; DMRT, n = 4)

CONCLUSIONS

The growth of mung beans and maize plants improved after addition of RC. The growth (shoot length, and weight of shoot and root) of both plants was significantly effected by red clay. Arsenic concentration in the shoot and root of mung beans and maize were decreased by increasing the content of RC from 0.5 to 2 percent. The uptake of arsenic by both plants on CS amended with RC from 0.5 to 2 percent was lower than untreated CS. The arsenic accumulation in the root was higher than the shoot for both plants and decreased with increased amounts of RC. This data allows us to conclude that the addition of RC led to a decreased concentration of arsenic in the soil solution and therefore to a decreased exposure of plant roots to arsenic. Application of RC might be an appropriate technique in the case of CS in the vicinity of mines which contain high arsenic levels.

ACKNOWLEDGEMENTS

This work was supported by Faculty of Science, Naresuan University, National Research Council of Thailand and Rajamangala University of Technology Lanna, Phitsanulok Campus. Instrumentation used in this project was purchased with partial funding from the Department of Chemistry, Faculty of Science, Naresuan University.

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