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Evaluation of Legume Growth in Arsenic-Polluted Acidic Soils with Various pH Values

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ABSTRACT

In this study, soybeans are grown in soil that has been contaminated with arsenic. Water-quenched slag, BOF slag, and lime conditioner are individually added to soil. Based on observations of plant growth, both soil and plants are analyzed and the vegetation rate and absorption of arsenic are determined. The results indicate arsenic in soil can impact the growth of plants. In soy bean, the root has the highest arsenic concentration, followed by stalk, leaf, legume, and fruit. As the arsenic concentration increases in soil, the vegetation rate of soy bean is reduced.

Keywords: pH; Soils; Amendments; Arsenic; Soybean

1. INTRODUCTION

Taiwan has in recent years suffered complex problems of pollution of the natural environment due to rapid economic development and over-development. These include the pollution of land by heavy metals. This situation concerns may people. In particular some heavy metals at low concentrations have toxic characteristics, and may reside for a long time in the soil. They cannot be easily removed, and are absorbed by plants, entering the food chain. They have cumulative biological effects (bioaccumulation), eventually endangering human health.

Basic oxygen furnace slag and granulated blast-furnace slag are by-products of the production of steel that contains silicates, lime, silicon, aluminum, and other alkali compounds. The acidity of soil and the use of fertilizer that contains calcium, potassium and sodium must meet regulatory requirements regarding the quality of soil and groundwater.

In this study, water-granulated blast-furnace slag, BOF slag and lime conditioner are applied to soil with high cadmium content. The soil is in pots in which soybean are growing. The purpose is to understand how various soil amendments influence the growth of soy beans

1.1 Objectives

The main goals of this study are as follows.

- Assess the removal of arsenic from soil by leguminous after the soil has been amended by the addition of water-granulated blast furnace slag, BOF slag, and lime.
- Record the growth of soy bean, and conduct a soil analysis after the soybeans have been harvested and weighed, to identify the effects of adding water-

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granulated blast-furnace slag, BOF slag and lime on the growth of soybeans.

1.2 Physical and Chemical Properties of Arsenic

Many Organic compounds exist in nature. Their main oxidation states are -3, 0, +3 and +5; four others are less prevalent (Cullen et al, 1989, Oremland et al., 2005). All species can be divided into inorganic arsenic and organic arsenic. The former (inorganic arsenic is composed of mainly inorganic arsenic arsenate (H_3AsO_4, H_2AsO^{4-}, $HAsO_4^{2-}$, AsO_4^{3-}) and arsenite (H_3AsO_3, H_2AsO^{3-}, $HAsO_3^{2-}$, AsO_3^{3-}). Trivalent arsenic is generally more toxic than pentavalent arsenic, and it is also more likely to accumulate in the body. Organic arsenic includes methyl-arsenic (monomethylarsonic acid, MMA) dimethyl arsenic (dimethylarsonic acid, DMA) (Wang et al., 2002).

Inorganic arsenic is produced by anaerobic microorganisms but the reaction is very slow, and generated MMA and DMA are easily reduced to trimethyl arsenic (trimethyl-arsine) and other gases, which are lost into the air. Most inorganic arsenic in soil is pentavalent (Wang et al., 1993). Yuen Guodong (1986) has pointed out that the arsenic with iron, aluminum, magnesium, calcium, nickel and other metals form precipitates. When the water has sulfur compounds present, pH value of less than 5.5, will form a stable solid (AsS, As_2S_3). The solubility with As_2S_3 low (less than 0.05 mg.L-1), and in the reduction of the state, will produce the highly toxic gas with low solubility of arsenic hydride (AsH_3). The soil contained iron and aluminum oxides which have the stronger adsorption ability (Pan, 2007).

1.3 Arsenic Concentration in The Plants

Plants can absorb and accumulate organic or inorganic pollutants in soil and water. Endocrine substances in plant roots and rhizosphere microbes can break down pollutants. The amount of pollutants in contaminated sites involves using plant roots from the contaminated soil, rivers and groundwater to absorb water, nutrients and pollutants. Plants have surface area, to promote the absorption of soil nutrients. However, the root cells of numerous species absorb not only nutrients but also heavy metal compounds.

1.4 Heavy Metals Accumulated in The Plants

Soil pH, the chemical properties of soil and the integrated response of plants to heavy metals that are absorbed by root (Meagher, 2005), released by roots in acidic soils. If pH value is low the H^+ competes with metal ions (to combine with the soil, increasing the solubility of the metal ions in the root (Gu et al., 2005). At pH <5.5, the Mn concentration rapidly increases with pH value (Kramer et al., 2001). When the soil pH value is below 5.0, the Al^{+3} and Mn^{+2} concentrations is accumulated exceed toxic level in the plant.

1.5 Soil Conditioner

1.5.1 BOF

In the refining of molten steel, between molten iron and the raw material sand is added. The temperature of liquid steel is around 1600–1680°C, while that of hot slag is 1000–1200°C. Cooled hot slag is called BOF slag. The chemical constituents of BOF slag, which is stable, are CaO, SiO_2, Al_2O_3, FeO, and MgO.

1.5.2 Water Furnace Slag

Water-granulated blast-furnace slag is cooled using high-pressure water spray, before being dried, magnetically separated, ground, and subjected to a powder selection process. The chemical constituents of silica powder include (SiO_2), alumina (Al_2O_3), calcium oxide (CaO), and magnesium oxide (MgO).

1.5.3 Characteristics of Lime

Adding lime conditioner to soil is usually considered to be the most convenient and economical way to improve acidic soil. The method has many advantages: lime increases soil pH for a long time; reduces the amount of soluble Al in soil, and promotes root growth and nutrient uptake.

2 MATERIALS AND METHODS

2.1 Soil Properties

Old-Pi soil was used in this experiment. Acidic soil is usually red and contains large amounts of Fe and Al oxides. In this study, soil samples were air-dried, ground and sieved. They were stored in plastic containers. Table 1 shows the basic properties of the soil, including its pH, texture, organic carbon content, CEC, and electrical conductivity.

2.2 Pot Experiment

Soybeans called "Tainan II", for the Tainan District Agricultural is high yield and disease resistance. They can be mechanically harvested of soy bean. The research team convened a team to review new crop varieties and hired scholars and experts. They were allowed to register names to promote breeding. narrow-leaf varieties are cultivated in the early spring and summer. The RF400 and PI181569 what has medium height, medium branching. After the seed sow, germination occurs in 33 to 50 days, flowering occurs in 93 to 110 days. According to the Department of Agriculture's manual on soybean crop fertilization, the soil pH must be below 4.6, and the soil must contain 3,000-3,800 (kg/ha) lime and 4,000-5,000 (kg/ha) limestone powder.

2.2.1 Preparation of Contaminated Soil

A total of 74.92 g of arsenic pentoxide in 1L bottles that contained ultra-pure water was added to total concentration of 20 mg/kg (to yield heavy metal pollution control standards) The mixture was slowly added uniformly to 100 kg of soil, alternating between wet and dry over four weeks. The soil properties were determined using 10 g soil samples.

2.2.2 Pre-transplant Soybeans

The pre-transplanted soybeans had a diameter of 35 cm. The pots were about 25cm high and contained mixed soil. To empty pots and pots that contained contaminated soil were applied the following four treatments; treatment A (no conditioner (blank)); treatment B (water-granulated blast furnace slag); treatment C (BOF slag), and treatment D (lime).

The experiment on Tainan's no. 2 soybean was conducted at Ping-Tung. The soil samples were divided into two sets. Two sets of seeds were incubated that each set of seeds corresponded to one set of samples. One week later, Good plants were obtained. Five experiments were performed on each plant. The contents of the pots were fertilized regularly, and plant growth was recorded from Dec 12, 2007 until March 20, 2008, when the plants were harvested.

2.2.3 Soybean Explants Before Processing and After Harvesting

Explants were harvested, rinsed with deionized water, and separated into shoots and roots. Shoots were then divided into leaf stems, and seeds, and stored in sealed brown paper bags. The soybean was dried in an oven for about 2 h at 60°C. The dry weight was determined, and the dry stems were stored in a dry pan. The dry stems were subsequently analyzed.

2.2.4 The Relationship Between Implant Volume of Vegetation and Moisture Content

The volume of plant vegetation, its absorption of heavy metals, and removal efficiency of heavy metals from the soil are closely related to each other (Díaz and Cabido, 1997). The so-called vegetation volume is the ratio of weight (dry weight) to duration of growth (days) of the harvest plant. Moisture content is given by (fresh weight of plant - dry weight of plant) ÷ fresh weight of plant × 100%.

2.2.5 Determination of Amount of Arsenic in The Implant

- To take test samples with a mass of 0.5 ~ 1.0 g were placed in a 300 mL round-bottom flask, to which 10 mL concentrated nitric acid, 2.5 mL concentrated sulfuric acid, and 2.5 mL concentrated perchloric acid were added. The contents were thoroughly mixed by gentle swaying, and the flask was left to stand overnight.
- The soy bean was mounted on the condenser tube to heat in 1,000 W electric stove. The soy bean was boiled for 100 minutes, and 4 mL of formic acid as added dropwise. No red-brown gas was formed. The soy bean was removed from flask, and placed in a cold area.
- The reagent solution was added to the reaction flask with a measured amount of arsenic; 15 mL concentrated hydrochloric acid was added to yield a volume of 50 mL liquid.
- 4. 0.5 mL 10% NaI solution was added. After 15 minutes, 6 mL of 4% NaBH4 was added. Atomic absorption spectrometry was used to determine the arsenic content of soy bean.

3. RESULTS AND DISCUSSION

During incubation, plant buds were grown indoors to eliminate any potential effect of external environmental factors. Soybeans were planted on Dec 12, 2007, and harvested on March 20, 2008, after the plants had flowered. The basic properties of the soil and the arsenic concentrations in the soil and explants (roots, stems, leaves, flowers, and seeds) were determined.

3.1 Basic Properties of Soils

In this study, samples of the old-Pi soil series (at depths of 0–15 cm) were used. The pH range of the acidic soil was 3.84–4.13; the electrical conductivity was 75μS/cm; the organic carbon content was 13 g/kg; and calcium, potassium, and sodium concentrations were 3.35, 1.9, and 5 cmol/kg, respectively (Table 1).

3.2 Growth of Implants

Figures 1, 2 and 3 reveals the growth of soybeans after they had been harvested from the pots. Arsenic contamination of soil significantly and adversely affected growth. The slightly larger amount of arsenic than in the control group affected the growth of the test plants. Soy bean grew best in soil that had been amended with water-granulated blast-furnace slag, followed by so BOF slag, and lime; growth was worst in the unamended soil.

3.3 pH, and Cation Exchange Capacity of Soil

The result in Figures 4-5 provides pH, and CEC of the soils. Soil pH affected plant growth. Adding water-granulated blast-furnace slag and BOF slag to soil increased the absorption capacity of plants that were grown in it by changing the soil pH. The CEC of the soils followed the order soil with BOF slag> soil with water-granulated blast-furnace slag.

Table 1 Basic physical and chemical properties of soil samples

	pH value	Sand (%)	Silt (%)	Clay (%)	Soil texture	Organic carbon (g/kg)	Cation exchange Capacity (cmol(+)/kg soil)
Old Pi soil series	3.84~4.13	14	39	47	Clay	13	3.7

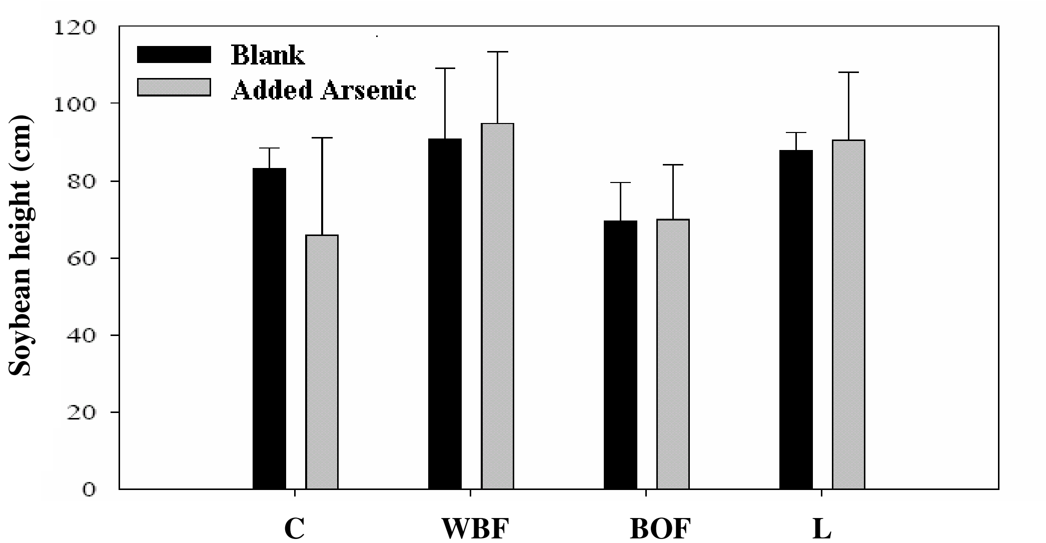

Figure 1 Comparison of soybean height with different soil amendments

Note: C, WBF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

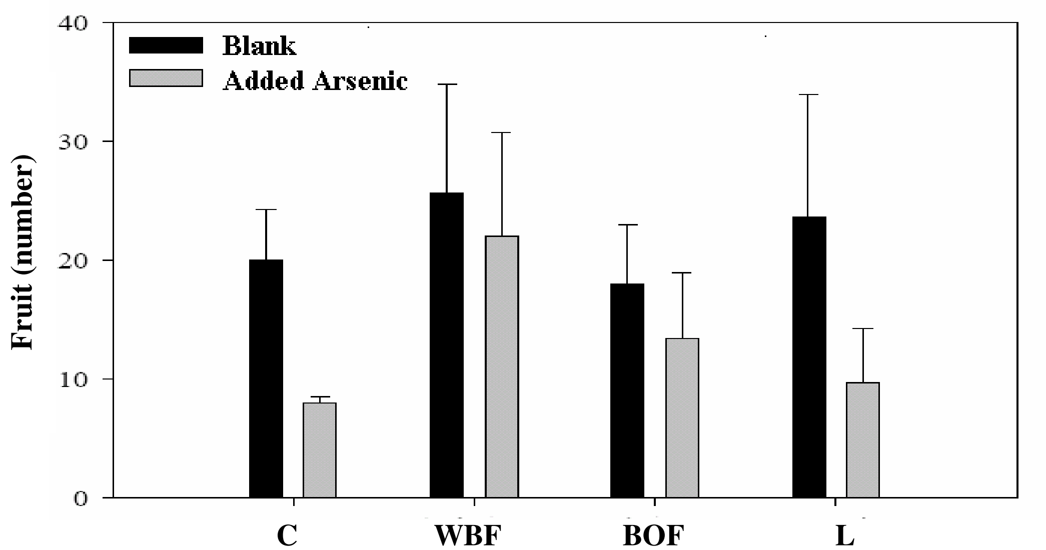

Figure 2 Comparison of soybean fruit number with different soil amendments

Note: C, WBF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

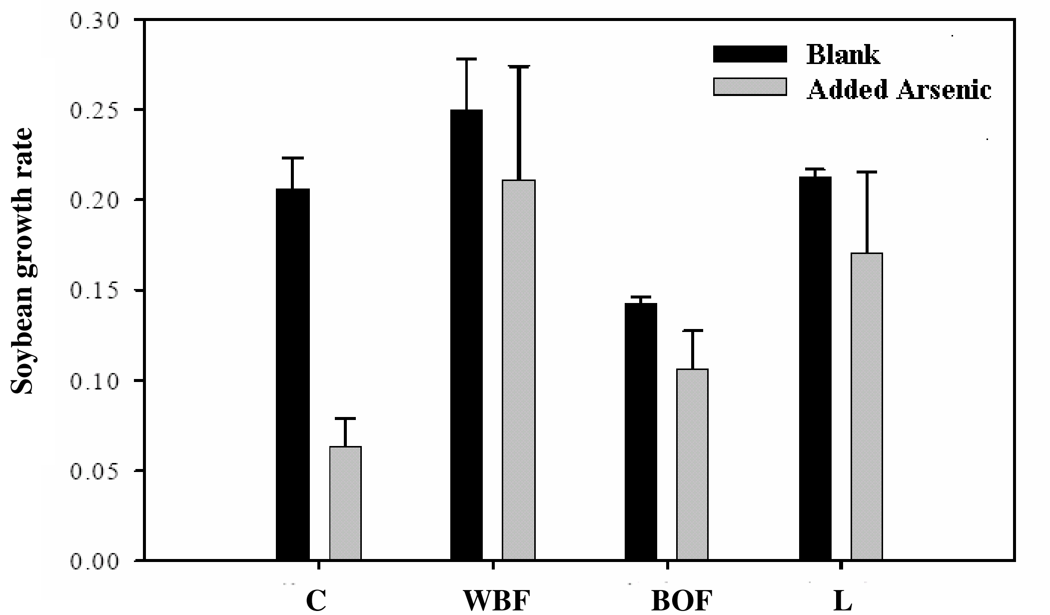

Figure 3 Comparison of soybean grow rate with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

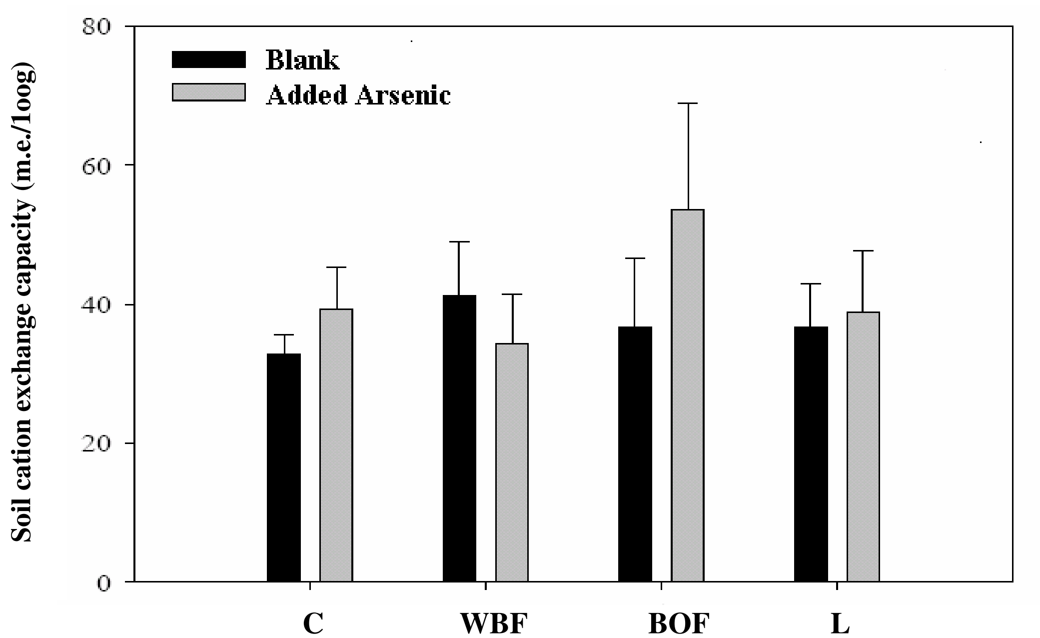

Figure 4 Comparison of soil cation exchange capability with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

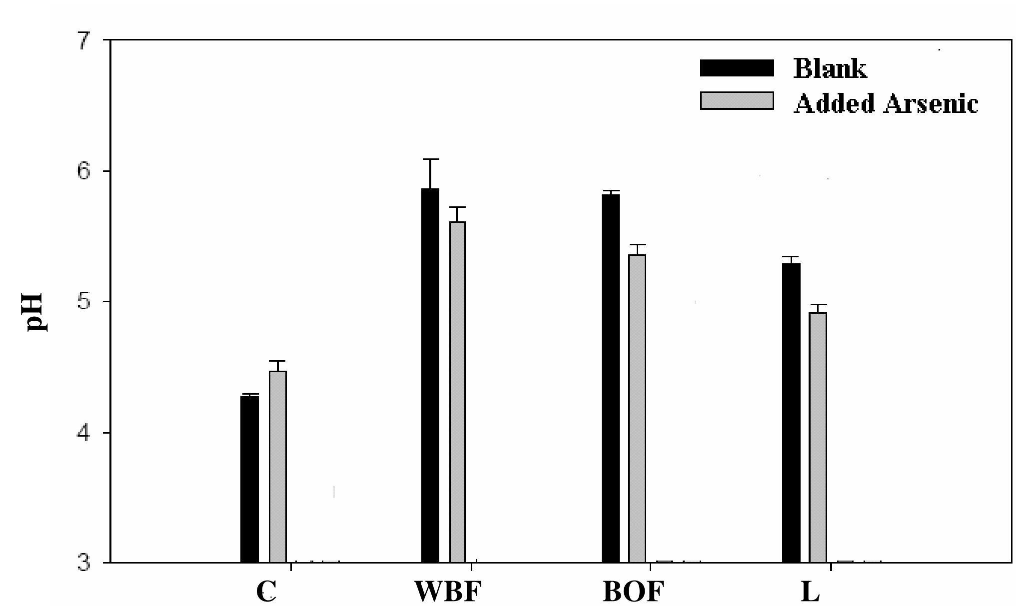

Figure 5 Comparison of soil pH value with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

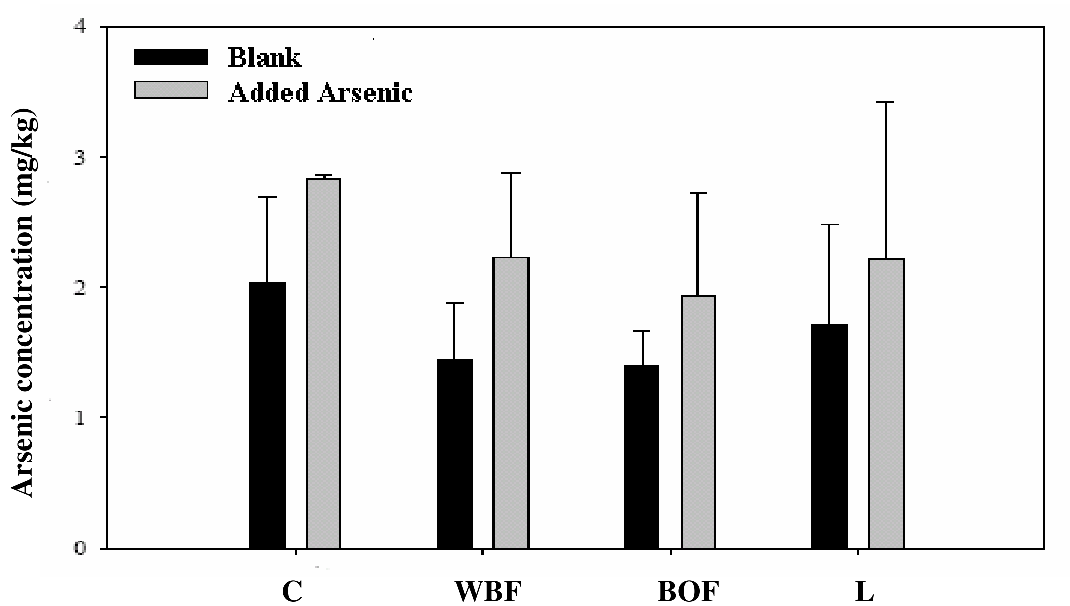

Figure 6 Comparison of arsenic concentration in soybean root with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

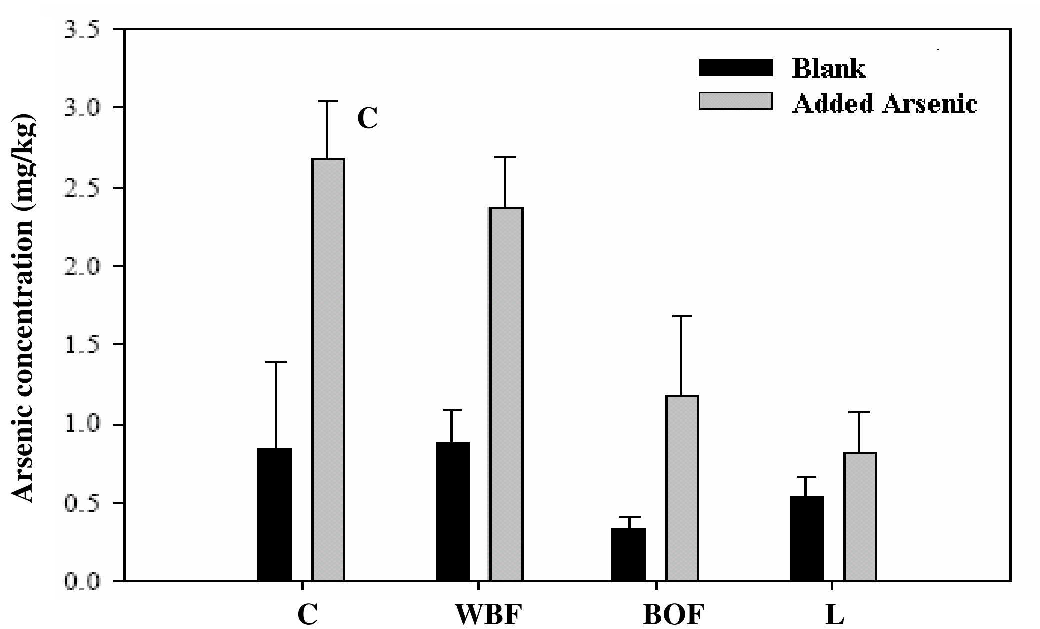

Figure 7 Comparison of arsenic concentration in soybean fruit with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

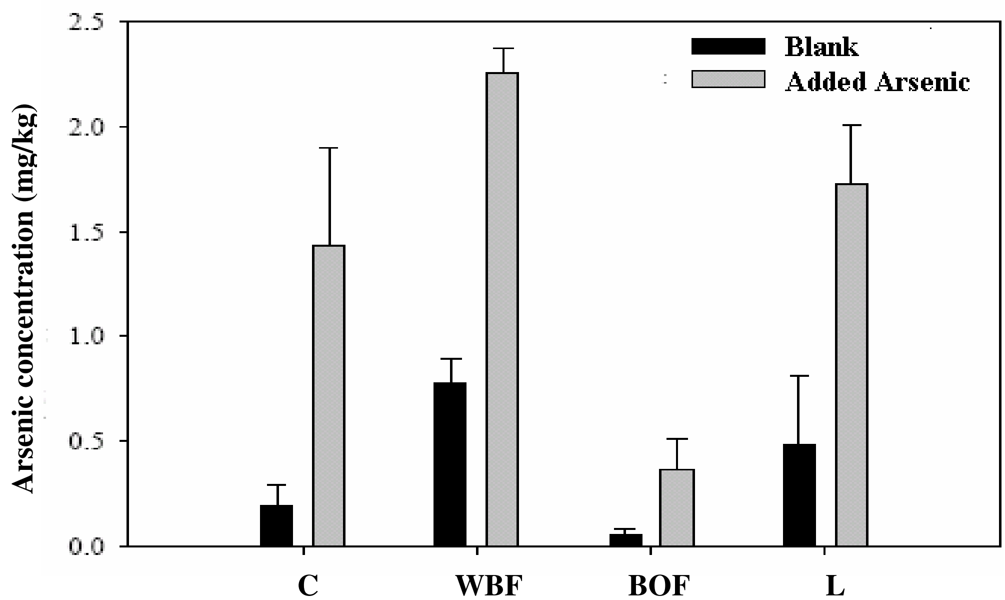

Figure 8 Comparison of arsenic concentration in soybean seed with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime.

3.4 Soil and Arsenic in Implants Parts of Soybean Plants Above Ground and Underground.

Figures 6, 7, and 8 present the in vivo arsenic distribution in soybeans. The arsenic concentration was highest in the main root, followed by the stems and leaves, fruit, and seeds in that order. Statistical results indicated that the arsenic contents in various parts of the soybeans plants were not significantly correlated with soil pH. The arsenic concentration was highest in the soybean roots, which absorbed soy bean directly.

The data indicates the relationship between implant and soil amendments. The additives in the soil promoted the absorption of arsenic. Amending the soil to improve its basic properties and increase the growth of soybean explants increased the absorption of arsenic. The pH value increased and the CEC increased. Addition of BOF to soil yielded the highest absorption of arsenic, followed by addition water-granulated blast-furnace slag, followed by addition of lime conditioner. The soil with no additive absorbed yielded the lowest absorption.

3.5 Bioconcentration Factor and Translocation Factor

Table 2 and Figure 9 show that parts of soybean plants above and parts of the underground are in vivo arsenic distribution. The Bioconcentration Factor and Translocation Factor is 0.27 and 1.64 in soybean with WBF amendments. The WBF contains higher SiO_2, Al_2O_3 and $Fe_2\,O_3$. The additives in the soil promoted the absorption of arsenic. Adding soil amendments to improve the basic properties of the soil and increase the growth of sunflower explants positively affected the absorption of arsenic.

CONCLUSIONS

Soil that was contaminated with arsenic was treated with water-granulated blast-furnace slag, BOF slag, and lime conditioner to examine the effects of different conditions and arsenic adsorption on soy bean growth. Analytical results indicate that the water-quenched slag most helped soybeans to develop, followed by BOF slag and then lime conditioner. Soybeans in soil with added BOF slag absorbed the most arsenic, followed by those grown in soil with added water-quenched slag, followed by those grown in soil with added and lime. Soybeans grown in soil without any amelioration rather than amendment could absorb the least arsenic. The *in vivo* concentration of arsenic in soybean plants was highest in their main roots, followed by their stems and leaves, flowers, and seeds, in that order.

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Table 2 The bioconcentration factor and translocation factor of soybean plant with different soil amendments

	Not added arsenic				Added arsenic			
Soil amendments	Control	WBF	BOF	Lime	Treatment	WBF	BOF	Lime
Bioconcnetration factor	0.18	0.27	0.06	0.12	0.25	0.51	0.06	0.13
Translocation factor	0.79	1.64	0.46	0.85	1.77	3.14	0.74	1.3

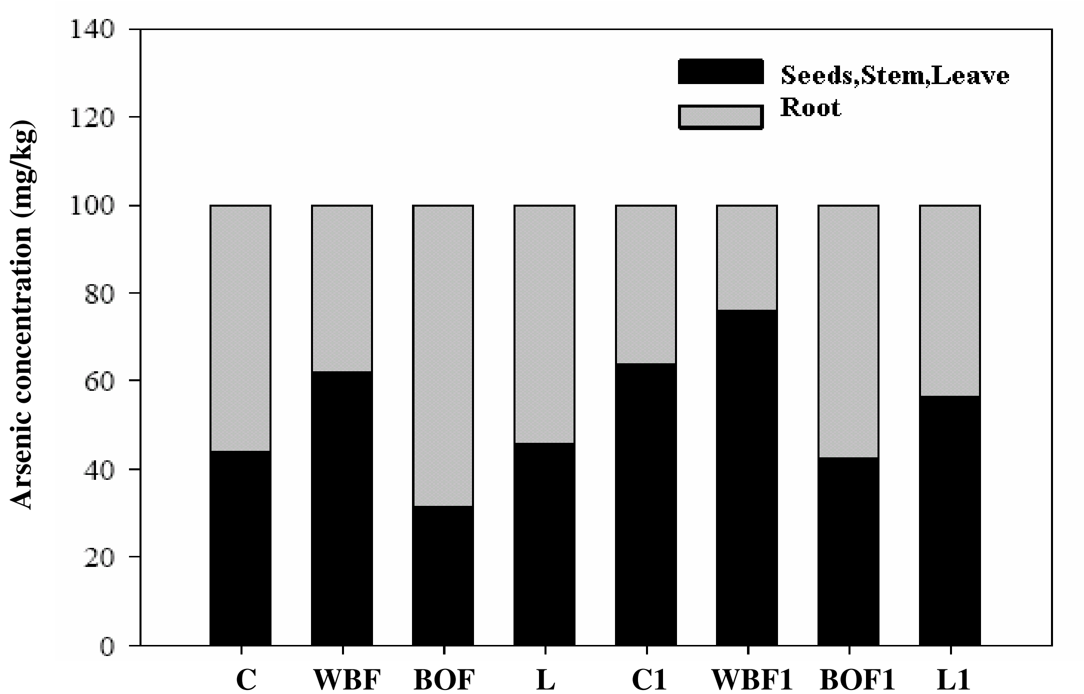

Figure 9 Comparison of arsenic concentration between parts of soybean plants above ground and parts of soybean plants underground with different soil amendments

Note: C, WOF, BOF and L for different soil amendments were the original soil in the control group, water granulated blast furnace slag, BOF slag and lime; C1, WOF1, BOF1 and L 1for different soil amendments were contained arsenic soil in the control group, water granulated blast furnace slag, BOF slag and lime.

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