

# Potentially Toxic Elements

Subjects: **Plant Sciences**

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Potentially toxic element (PTE) pollution is a major abiotic stress, which reduces plant growth and affects food quality by entering the food chain, and ultimately poses hazards to human health.

slag

immobilization

plant

potentially toxic elements

tolerance

## 1. Introduction

With the rapid increase in the world population, similarly to other industries, steel industries are also more concerned about the safe and eco-friendly recycling of their by-products. In the past, steel industries were designed to produce iron and steel of a specific quality and quantity <sup>[1]</sup>. With the rapid growth of industrialization in recent decades, the increased volume of byproducts (slag) produced from iron/steel production has drawn attention to the need for its more effective recycling. <sup>[1]</sup>. Slags are widely used worldwide as a substitute for limestone and offer a cost-effective advantage to farmers. The main aim for researchers and environmentalists is to stop the entry of metals and metalloids into the food chain for better human health <sup>[2][3]</sup>, and in this respect, the use of slags in various fields can help cope with this problem <sup>[2]</sup>. Potentially toxic element (PTE) contamination of soil refers to the excessive deposition of PTEs due to human activities <sup>[3][4][5][6]</sup>. In soil medium, the highest concentrations of PTE plant toxicity are represented by cadmium <sup>[7]</sup>, lead <sup>[7]</sup>, zinc <sup>[8]</sup>, copper <sup>[9]</sup>, nickel <sup>[10]</sup>, vanadium <sup>[11]</sup>, and arsenic <sup>[12]</sup>, etc.

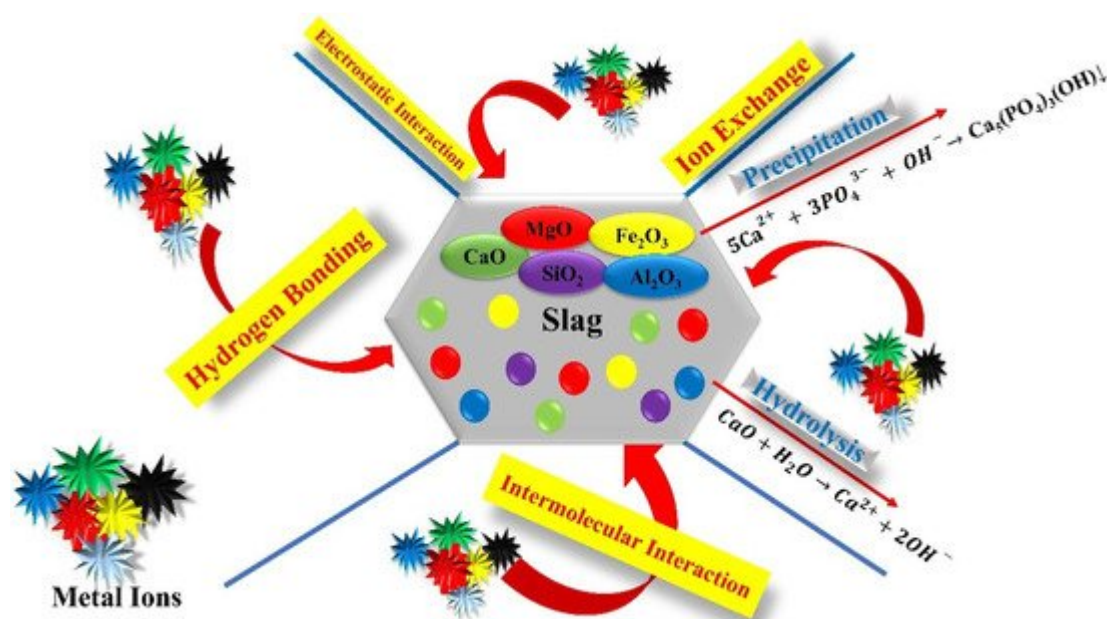
In the current scenario, the need for food is increased, and the use of fertilizers has been increased by humans, resulting in the deterioration of the environment <sup>[13][14][15]</sup>. Highly mobile PTEs can easily enrich the food chain and are highly hazardous to the environment. The remediation of soil becomes very difficult once it becomes polluted with PTEs. Soil cleanup is more complicated than air and water cleanup, according to previous reports <sup>[16]</sup>, because PTEs in the soil form complexes and bonds with clay particles, and it becomes more challenging to break those bonds <sup>[17]</sup>. However, soil contamination in developed countries is considered a severe issue and more attention is paid to its remediation and public health. A wide range of compounds ( $\text{TiO}_2$ ,  $\text{Fe}_3\text{O}_3$ ,  $\text{FeO}$ ,  $\text{Fe}_3\text{O}_4$ ,  $\text{BaO}$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{MnO}$  and  $\text{SiO}_2$ ) and minerals are found on/in the layers of slags produced in various industrial operations <sup>[18][19]</sup>. In 2014, it was observed that each ton of steel produced by the steel industry generates 500 kg of steel slag <sup>[20]</sup>. China utilizes only 25% of steel slag out of 100 million tons produced, the production of steel slag accounting for 24% of the total solid waste produced in China <sup>[21][22]</sup>. Steel slag contains a variety of trace elements on its surface, which makes it an excellent fertilizer for better plant growth. Bearing in mind the importance of these benefits, Japan and Europe use steel slag as a soil amendment agent. Slag is used as a fertilizer and ground shifting agent in Japan and Europe because trace metal elements, such as Cr and V, are not readily released in

slag. [23][24]. Slag fertilizers include slag–silicate fertilizers, slag–phosphate fertilizers, and unique iron matter fertilizers [4]. The presence of  $\text{Ca}^{2+}$  on the surface of steel slag produces stable PTE ions, with the aim to eliminate PTE ions from the contaminated medium.

Moreover, Wen et al. [25] concluded that applying steel slag to PTE acidic mining soils effectively raises the soil's pH, increases soil microbial abundance, and immobilizes PTE ions, providing a desirable plant survival climate. Recently, a variety of studies have reported that there is a great commitment from slag-based fertilizer modification in agriculture to increase crop productivity [26][27], minimize soil acidification [28], and alleviate greenhouse gas (GHG). Slag fertilization's beneficial results focus primarily on the shifts in microbial environments and microbial behaviors. In particular, soil microorganisms play a key role in almost all ecological processes at a system level and provide ecosystem services necessary for preserving soil quality and productivity [29]. Das et al. [1] reported that slag utilization in the PTE-contaminated soil improves crop production by affecting soil pH and greenhouse gas emissions. The fundamental processes of slag–microbial interactions and the importance of soil biota to ecosystem functionality are gradually deceptive.

## 2. Mechanism of Slag Interaction with Potentially Toxic Elements in Soil

Bearing in mind the application benefits of slag-based fertilizers for better crop production in potentially toxic element (PTE)-contaminated soils, it is important to know the different mechanisms slag follows to bind toxic ions at the soil and plant levels (Figure 3). Many studies have mentioned the mechanisms of detoxification of PTEs in plants by slag. However, a better understanding of the mechanism of PTE detoxification in plants from contaminated soils is vital for the practical application of slag. At the soil level, the application of slag may cause the immobilization of PTE, changes in the soil pH, and changes in PTE fractions, and causes an improvement in the soil physicochemical and biological properties of soils. While at the plant level, the application of slag-based fertilizers causes an increase in the antioxidant defense system and causes a reduction in the translocation of PTEs to plant shoots.



**Figure 3.** Proposed mechanism of slag-based fertilizers in the soil.

However, the mechanisms for PTE ion remediation by slag are similar to many other applied amendments in previous studies, such as lime [30], biochar [31][32][33][34], zeolite [35], chitosan [36], the indigenous strain *Bacillus XZM* [37], hydrogen sulfide [38], and sepiolite [39]. The basic PTE ion immobilization on the slag surface was attributed to the presence of silicate, ferrites, and calcium oxides on the surface [40]. Silicate ferrite present on the slag surface releases  $\text{SiO}_4^{4-}$  and  $\text{Fe}_2\text{O}_3$ , and  $\text{OH}^-$  interacts with PTE ions to make them immobile [40]. The presence of hydrogen oxides on the surface of slag has the ability to diffuse into the slag surface [40] due to small masses [41] and then can immobilize PTEs on the slag surface [42]. Moreover, PTEs exchange with the silicate and ferrite present on the slag surface and can be immobilized within the slag matrix [43]. The PTE ions present in the soil solution gradually enter the slag due to the absorption gradient.

Additionally, various metals form complexes with soil organic matter and become immobilized due to increased organic matter after slag addition to the soils. The increase in soil pH might result in the instability of PTE ion concentration in soil solutions. The unstable PTEs in the soil solutions exchange with  $\text{Ca}^{2+}$  in order to be immobilized within the silicate and ferrite fractions [42], while some PTE ions make bonds in soil organic matters. Moreover, various cations and anions are present on the slag surface, which increases the ionic strength and may affect PTE species. However, there are still unresolved areas for further studies to analyze the effects of ionic strength on the immobilization mechanism of PTEs under the slag-based fertilization of acidic polluting soils.

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