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Short Review Paper

Cadmium status in soils: A review on sources and chemistry

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Abstract

Heavy metals entering the food chain through plants occur naturally in the soil. These are seldom toxic for the living organisms until, present in excessive concentrations. The occurrence of cadmium(Cd) in agricultural soils depend upon its concentration in the parent rock from which it weathered, additions from fertilizers and soil conditioners. Cadmium is found to be enriched in sedimentary rocks than in igneous or metamorphic rocks. Anthropogenic sources includes phosphatic fertilizers containing excessive levels of Cd which increases its concentration in surface soils. Mobility of heavy metals due to anthropogenic origin has found to be more than the geogenic ones. Arial deposition of Cd in rural areas is contributed by combustion of fossil fuels, smelting and processing of ores which is comparable to that added to soil from fertilizers and improvements. Bioconcentrations of Cd in plants grown in an elevated level in soil is maximum compared to other heavy metals. The degree of enrichment depend upon the level of Cd present in the soil, the crop species, and the chemical properties of the soil.

Keywords: Cadmium, bioavilability, agricultural soil.

Introduction

An increased cadmium contamination in the soil has been found where land has been used for agricultural practices near industries. The outbreak of Cd poisoning occurred in Japan in the 1950's and 1960's where cadmium concentrations from 200 to 2,000 ppb were found in rice crops which received the effluents from industrial operations contaminated with cadmium[1]. The sources of Cd in soil are natural like sulfide ores of the metal and anthropogenic. Natural sources of Cd contamination includes volcanic activities, forest fires, and weathering of Cd-containing rock[2,3].

The pedogenic processes introduces a very low level of Cd in soil, but major contamination in the soil is through human activities leading to soil contamination. Some anthropogenic contributions to elemental abundances, and their bioavailability in the environment include: occurrence of heavy metals in soil near and far from urban pollution[4]; formation of acid mine drainage[5]; uptake of heavy metals by plants in lab experiments[6]; and uptake of metals by vertebrates in the vicinity of zinc smelters[7], use of phosphatic fertilizers, zinc additives, sewage sludge, manures and arial depositions.

Farming practices incorporates addition of large quantities of fertilizers to supplement the soil with adequate proportion of N, P, and K for crop growth. Although these additives contain trace amounts of heavy metals, but their extensive use significantly increases heavy metal concentrations in the soil[8]. Toxic metals like Cd other heavy metals, metalloid and non-metals gets introduced in the soil upon addition of phosphatic fertilizers[9]. Solid waste is another source for introducing Cd in the soil. E-wastes like batteries, consumer electronics, organic wastes like used motor oils, plastics, household wastes like ceramics, paints, light bulbs etc. introduce Cd contamination to soil.

Cadmium concentration in sedimentary rock has been found to be higher than metamorphic or igneous rocks, and thus the soil weathered from this rock contributes a higher percentage of Cd to the plants. Clay-loam and loamy soil provide a lesser concentration of bioavailable Cd then sandy and silty loam due to their complex forming nature with metals. The absorption of Cd by the plant depends on its various forms, mobility and bio-availability.

The mobility of cadmium is found to depend on the sorption capacity of the soil, it gets strongly binded to organic matter and lesser to the clay minerals[10]. Physico-chemical parameter like pH affects the sorption of Cd by soils and thus its concentration in soil solution[11]. An increased soil pH decreases Cd in solution and make it less available to the plants. At higher pH Cd precipitated in the form of $Cd_3(PO_4)_2$ and/or $CdCO_3$. Mobility of Cd increases under acidic condition in agricultural soil. The threshold value for concentration of Cd in agricultural soils is 5.0 mg/kg. The bioavailability of Cd binded to particulates in soil decreases in the order exchangeable <carbonates <metal <organic complexes <organics <Fe and Mn oxides <mineral lattices[12].

Cadmium accumulation by plants

Cadmium is taken up easily from soils that are sandy, acidic and or low in organic matter by the plant. Cadmium toxicity to the plants for a range of concentrations are mostly unknown. A synergistic relation between zinc and cadmium is frequently associated with higher concentration of Cd in soil. Cadmium gets concentrated in plant parts such as leaves, roots, seeds and fleshy fruits. Leafy vegetables like lettuce, endive and potato tubers grown in unpolluted soil contains higher levels of cadmium than in fruits and cereals[13].

Cadmium has been found in varying range of concentrations among different species of the same plant. Researches conducted during the past have shown that the variations observed are due to differences in soil properties and in the cultivation pattern. Anthropogenic factors like solid waste disposal, differences in the cultivars of a particular crop, and differences in physico-chemical properties of soil profoundly impacted Cd adsorption. Concentration of cadmium in food crops grown in non-contaminated soils varies from 0.01 to 1.0 mg/kg. The vegetables grown on land irrigated by lake water receiving sewage were found to contain cadmium 21 times higher than recommended concentration. Among the plants grown on contaminated soil lettuce, spinach, celery and cabbage accumulated relatively higher concentrations of Cd, while potato tubers, corn, french beans and peas concentrated still lower amounts and a least amount in corn and rice[14,15]. Spinach and Radish accumulated an exceedingly high concentration of Cd (4.0 and 2.5 µg/g) when iriigated by lake water receiving sewage[16].

Factors influencing bioavailability of cadmium

The bioavailability, accumulation, toxicity of metal and impact on various environmental matrices depends on its speciation. The speciation of Cd determines its mobility and thus its availability in water or sediments or soil is confirmed. Soil pH is one of the factors that determines the solubility of metals and hence its availability to the plants, it affects the hydrolysis, solubility as well as surface charge of the metals[17-19]. Among the various organic and inorganic forms like Cd-humate, free Cd^{2+}, $CdCl_2$, $CdCO_3$, CdS or $Cd(OH)_2$, it is the free Cd^{2+} that is being easily absorbed by the plants under acidic conditions. The bioavailability of this exchangeable cation reduces in the presence of organic matter present in the soil due to its complexing ability. Cadmium added to the soil in the form of $CdCl_2$, or CaH_4P_2O increased its concentration in grains or edible part of the vegetables[20].

The amount of Cd uptake by the plants is affected by various factors, such as particle size of the soil; clay particles have sites for specific sorption then sand particles, level of organic matter; due to its high CEC and complexing ability organic matter reduces solubility of metals in soil, pH; a decrease in pH increases H^+ concentration in to the OH and COOH group responsible for adsorption of Cd[21]. Availability of Cd to the plants reduces in its organic, sulfide and residual fraction in soil thus limiting its concentration in crops[22].

Arid climate results in the small soil organic matter, abundant salt and carbonates which makes metal compounds to be in easily available form. The low clay content, organic matter, pH and high levels of oxides of Fe in the tropic soil does not preserve metals in the soil and thus limits the mobility and bioavailability of metals in the tropical regions[23].

Conclusion

Metals can be present in soil by natural geochemical cycling or by anthropogenic processes. Bioaccumulation of Cd in soil and thus by plants and animals in terrestrial environments can be lethal to humans. Additions in the soil from anthropogenic sources tend to be more mobile, hence bioavailable than pedogenic. The availability of Cd in the soil is affected by many factors including total concentration and speciation of metals, mineralogy, pH, redox potential, temperature, total organic content, arid and semi-arid environments.

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