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Studies on the sorption and desorption characteristics of Zn(II) on the surface soils of nuclear power plant sites in India using a radiotracer technique

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Abstract

Zinc adsorption was studied in the soils of three nuclear power plant sites of India. ^{65}Zn was used as a radiotracer to study the sorption characteristics of Zn(II). The sorption of zinc was determined at 25 and 45 °C at pH 7.8 ± 0.2 in the solution of 0.01 M $Ca(NO_3)_2$ as supporting electrolyte. The sorption data was tested both in Freundlich and Langmuir isotherms and could be described satisfactorily. The effect of organic matter and other physico-chemical properties on the uptake of zinc was also studied in all the soil samples. The results showed that the cation exchange capacity, organic matter, pH and clay content were the main contributors to zinc sorption in these soils. The adsorption maximum was found to be higher in the soil on Kakarpara Atomic Power Plant sites soils having high organic matter and clay content. The zinc supply parameters of the soils are also discussed. In the desorption studies, the sequential extraction of the adsorbed zinc from soils showed that the diethylene triamine penta acetic acid extracted maximum amount of adsorbed zinc than $CaCl_2$ and $Mg(NO_3)_2$. The zinc sorption on the soil and amount of zinc retention after extractants desorption shows a positively correlation with vermiculite and smectite mineral content present in the clay fraction of the soil. The amount desorbed by strong base (NaOH) and demineralised water was almost negligible from soils of all the sites, whereas the desorption by strong acid (HNO_3) was 75–96% of the adsorbed zinc.

Keywords: Zinc; Adsorption; Desorption; Radiotracer; Cation exchange capacity

1. Introduction

Zinc is an essential nutrient for the normal healthy growth and reproduction of all higher plants, animals and humans. It forms about 0.004% of earth's crust and ranks 25th in the order of abundance. Zinc is required in small content, but critical concentrations to allow several key plant physiological pathways to function normally. These pathways have important roles in photosynthesis and sugar formation, protein synthesis, fertility and seed production, growth regulation and defense against disease. Deficiencies of zinc occur in many parts of the world on a wide range of soil types but semi-arid areas with calcareous soils, tropical regions with highly weathered soils and sandy-textured soils in several different agro ecological zones tend to be the

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most seriously affected. More than 50% area under cultivation in India are zinc deficient (Singh and Nayyar, 2004).

Adsorption reaction of zinc in soils are important to understand the solid and liquid phase interaction determining the release and fixation of applied zinc and thereby the efficiency of fertilization. The physico-chemical properties play a key role in influencing the process. Because of the heterogeneity of soils, adsorption isotherms are typically different for different soils and elements. Bingham et al. (1964) found that Zn^{2+} can held in the amount excess of the cation exchange capacity (CEC) of soils are retained as zinc hydroxide. Zinc adsorption has been described in various Indian soils by the Langmuir as well as Freundlich adsorption isotherms (Dhane and Shukla, 1995; Adhikari and Rattan, 2002; Patil and Meisheri, 2002).

Zinc adsorption is known to be pH-dependent and is related to CEC of soils (Shuman, 1975, 1986). Zinc sorption by carbonates or precipitation of zinc hydroxide or carbonates may be partly responsible for the zinc unavailability in calcareous soils (Udo et al., 1970; Mcbride, 1994). Fujiyoshi et al. (1998) studied on the sorption of Zn(II) on surface soils using a radiotracer technique and concluded that the organic matter in soils may not always be capable of sorbing zinc to a greater extent. Further, soil organic matter in scavenging Zn(II) ions depends strongly on their kind and physico-chemical properties, such as the degree of degradation and aggregation.

The effects of pH, temperature and soil components on Zn sorption by calcareous soils were studied by Lin and Xue (1987, 1991), the sorption isotherms of Zn on the untreated soils and treated soils to remove $CaCO_3$, organic matters and oxides were respectively determined results. The results of the sequential extraction (Tessier et al., 1979) of Zn(II) sorbed on the soil were reported and it was concluded that at a high pH range the contribution of $CaCO_3$ on Zn sorption was very high by a yellow fluvo-aquic soil and at low pH the contribution became less significant.

The magnitude of zinc deficiency varied widely among soil types and within the various states of India (Singh, 1998). Cropping pattern in the vicinity of the plants at all the three sites selected for the study having wide variation in climatologically condition and annual rain fall pattern. The zinc deficiency in soil shows the symptom in crop like rice, wheat, sugarcane and cotton, which are few of the common crops at these sites, which ultimately affects the crop production. These symptoms of zinc deficiency of zinc some times have been claimed by the local farmers as the effects of NPP operating in the area. This is an effort to estimate the plant available zinc in the soil of the sites and determine the zinc application rate, their frequency of application and supply parameter in area. Therefore, to get the comprehensive knowledge of zinc sorption and desorption in soils this study was conducted with the following objectives:

(1) To evaluate the sorption and desorption (using different extractants) behaviour of zinc in these soils using ^{65}Zn as radiotracer under different physical and chemical conditions.
(2) Studies on the influence of soil properties on the sorption and desorption processes.

2. Materials and methods

Bulk surface soil samples were collected from three nuclear power plant sites of India namely Narora Atomic Power Plant (NAPP), Narora, (Uttar Pradesh), Rajasthan Atomic Power Plant (RAPP), Kota (Rajasthan) and Kakarpara Atomic Power Plant (KAPP), Kakarpara (Gujarat). Soil samples were collected as a representative samples by Environmental Survey Laboratories of respective sites at all nuclear power plant (NPP) as per standard procedure. These samples were analyzed at Environmental Studies Section of Health Physics Division, Bhabha Atomic Research Center, Mumbai. Physico-chemical characteristics of soils are given in Table 1.

These samples were processed, sieved through a 2 mm sieve and analyzed for physico-chemical properties by following the standard procedure (Jackson, 1962). The zinc concentration along with some other elements was also determined after diethylene triamine penta acetic acid (DTPA) extraction. Radiotracer (^{65}Zn carrier free) were procured from Board of Radioactive Isotope and Technology (BRIT), Government of India with isotopic purity of 95 ± 2% in the solution form.

2.1. X-ray diffraction analysis of clay fraction

The soil samples were dispersed in dilute solution (1 g/10 l) of sodium carbonate. The clay in each sample (<2 μm) was separated by combination of wet sieving and sedimentation technique (Jackson, 1962). Magnesium and potassium saturated clays were prepared and parallel oriented specimens of these clays were used for X-ray diffraction (XRD) studies. XRD of the clays, with following treatments were recorded: (i) Mg-clay at 25 °C; (ii) Mg-clay content, glycerol solvated; (iii) K-clay content at 25 °C; (iv) K-clay heated to 300 °C for 2 h; (v) K-clay heated at 550 °C for 2 h; (vi) Mg-saturated after treatment with 4 N HCl and (vii) glycerol solvated after 4 N HCl treatment. Phyllosilicates were identified according to criteria given by Harward et al. (1960) and Carstea et al. (1970). Diffractometer graphs were recorded with a Philips XRD using Ni filter and Cu-Kα radiation were produced at 35 kV and 15 mA.