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Cadmium and Phosphorous Fertilizers: The Issues and the Science

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Abstract

Non-nutritive metals, such as cadmium (Cd), occur naturally in all agricultural soils, in soil amendments (e.g. biosolids), and to varying degrees in phosphorous (P) fertilizers. Its persistence in the environment and its uptake and accumulation in the food chain make Cd a public health concern. The main effect of Cd on human health is kidney disease, and although other adverse effects have been reported (e.g. pulmonary, cardiovascular, and musculoskeletal systems), controversy exists regarding their effects. The only known case of Cd toxicity (i.e. *itai-itai* disease) occurred with subsistence farmers in Japan growing rice on soils contaminated with industrial wastes. Cadmium behaviour in soil and its accumulation by crops is complicated. Numerous factors (e.g. soil pH, organic matter content, salinity, macro and micronutrient fertilizers, crops species and cultivar, and tillage) influence the bioavailability and uptake of Cd by crops. Because fertilization increases the risk of Cd transfer to the food chain, some governments have imposed limits restricting the Cd content of P fertilizers. However, scientific risk assessments have shown that P fertilizer containing Cd is safe and does not pose risk to human health.

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Keywords: non-nutritive metal; *itai-itai* disease; cadmium bioavailability; cadmium risk assessment

1. Introduction

Cadmium is a trace element, a non-nutritive metal regarded as harmful to humans and the environment. It occurs naturally in the earth's crust and oceans and can be added to the soil through natural (e.g. volcanic activity, weathering of Cd-containing rocks, sea spray) and anthropogenic activities (e.g. mining and smelting of zinc (Zn)-bearing ores, fossil fuel combustion, waste incineration, sewage sludge, irrigation waters, manure, and fertilizers derived from phosphate rock) [1] [2]. While not essential to crop growth, or known to be essential to biological systems, agricultural crops will take up and accumulate Cd depending on its availability in the soil and their genetic characteristics [3] [4]. And, depending on its concentration in the soil, Cd can negatively impact soil organisms and soil ecology [5].

2. Health Concerns

2.1 Impacts of cadmium on human health and exposure routes

Public health concerns with Cd are primarily due to its persistence in the environment and its relatively rapid uptake and accumulation in the food chain. Although the health effects of Cd have been studied extensively, controversy exists

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regarding some of the effects. The U.S. Department of Health [6] and the European Commission's Institute of Health and Consumer Protection [7] have recently summarized the health effects of Cd, updating information published by the Organization for Economic Cooperation and Development almost 20 years ago [8]. The main toxic effect of Cd in human health is on the kidney, or renal cortex, but other adverse health effects on pulmonary, cardiovascular, and musculoskeletal systems have been reported, including Cd as a human carcinogen. The nonsmoking general population is mainly exposed to Cd through ingestion of food, and to a lesser extent by air and drinking water. Studies show the average dietary intake of Cd for nonsmokers living in uncontaminated areas is between 10 and 25 µg Cd per day and that average has been declining over the past 30 years [6] [8]. The World Health Organization has established a provisional tolerable weekly intake for Cd at 7 µg/kg body weight, i.e. 60-70 µg Cd per day for an average 60-kg women or 70-kg man [9]. Smoking is a significant source of Cd because tobacco leaves naturally accumulate high levels of Cd [10]. It is estimated that tobacco smokers are exposed to 1.7 µg Cd per cigarette and about 10% is absorbed by the body when smoked.

2.2 Cadmium toxicity and bioavailability in foods

While dietary intake is the primary exposure route for non-smoking adults and children, acute toxicity caused by food consumption is rare [11]. Plants can accumulate high enough concentrations of Cd to become phytotoxic, but risk of food-chain toxicity occurs before phytotoxicity is apparent because of chronic exposure through the food chain. Prolonged exposure to low levels of Cd in air, food and water can lead to its accumulation in the human body in the kidney and bone following oral exposure and kidney and lung following inhalation exposure. Its biological half-life is estimated to range from 6 to 38 years in the kidney and 4 to 19 years in the liver [12].

The adverse effects of Cd on human health were first observed in subsistence rice farmers in Japan in the mid-1950s. They contracted Cd poisoning (*itai-itai* disease) after decades of consuming home-grown rice irrigated with Cd- and Zn-enriched mine wastes. [13]. The disease caused a softening of the bones and kidney failure. Chaney [11] reports that similar Cd kidney disease has been found in other areas in Asia in populations consuming rice grown on contaminated paddy soil, but other documented cases of Cd-induced disease are rare.

The recognition by food authorities and scientists that Cd caused *itai-itai* disease in Japan prompted concern for any potential source of Cd that could introduce Cd into the food chain. Food chain risks from Cd are complicated because bioavailability of Cd in foodstuffs differs greatly. For example, documented cases of people's prolonged consumption of Cd-rich shellfish [14] [15] [16] or garden produce from soils contaminated with Cd and Zn [17] [18] show no evidence of Cd disease. Apparently when Zn accompanies Cd in contaminated soil, it can inhibit both the uptake and bioavailability of Cd [11].

2.3 Other complicating factors

Chaney [11] has thoroughly reviewed the literature demonstrating the complexity of risks from food chain Cd. Some examples he cited from controlled human and animal feeding tests are: increased dietary Zn inhibits Cd absorption while mild iron (Fe) deficiency increases absorption; Cd concentration is higher in whole wheat and bran than white flour, but its absorption from these products is less; and adding Fe to bread wheat reduces Cd retention. Based on the above examples and knowing that polished rice is deficient in Fe, Zn, and calcium (Ca), Reeves and Chaney [19] reported on their research that showed rats fed polished rice diets absorbed 10-fold more Cd than rats fed adequate levels of Fe, Zn, and Ca. They also reported that Cd absorption from sunflower kernels, which have higher levels of Fe, Zn, and Ca than polished rice, was significantly less than that from polished rice. Based on the research reported above and other published studies reviewed, Chaney [11] concluded, "… the science is clear that diet-induced Cd disease is very unusual except for rice subsistence farmers over 50 years old."

The scientific literature shows that under conditions of Fe, Zn and/or Ca deficiency or nutritional stress, Cd adsorption by the intestines is increased [20]. Compared to diets adequate in Fe and Zn, Fe and Zn deficiency can increase Cd retention 15-fold. Rice is generally deficient in Fe, Zn, and Ca for human needs. The bioavailability of Cd in food is related to the nutritional balance of Fe, Zn, and other nutrients. Dietary Fe, Zn, and Ca inhibit absorption and retention of dietary Cd and explain the lack of Cd disease in individuals exposed to extreme soil and food Cd contamination.

3. Cadmium in Soil and Fertilizer

3.1 Cadmium in Soil