Research article

Zinc Deficiency in Agricultural Systems and Its Implication to Human Health

BASU DEV REGMI
Soil Science and Plant Nutrition, School of Earth and Environment,
The University of Westarn Australia, Perth, Australia
Email: basu.regmi@gmail.com

ZED RENGEL
Soil Science and Plant Nutrition, School of Earth and Environment,
The University of Westarn Australia, Perth, Australia

HOSSEIN KHABAZ-SABERI
Soil Science and Plant Nutrition, School of Earth and Environment,
The University of Westarn Australia, Perth, Australia

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Abstract There are more than 3 billion world population are directly or indirectly affected with low zinc (Zn) supply to their food causing up to severe health problems, which is also linked to Zn deficiency in most agricultural soils world-wide. Agricultural technologies contribute to improving nutritionally rich food systems, which plays key role in public health. We therefore review in this paper on the importance of agricultural systems and its role in human health under Zn deficient situation. Several studies have been done to understand the Zn dynamics on crop and plants. There have been much more efforts given to see agronomic, physiological and molecular aspects of Zn in plants and soils. It is however, equally important to look at the human consumption perspective for healthy population. Therefore, this review discusses the role of Zn on soil and crop in view of human nutrition. Agricultural strategies could help to combat such problems in many ways such as breeding Zn efficient genotypes, application of different Zn fertilizers, using high Zn content seed for crop production; and seed priming. The content of Zn in grains and fruits can in some cases be increased through soil or foliar applications of Zn fertilizers. Level of Zn in plant foods could be achieved either by increasing the concentration of compounds which promote their uptake like ascorbic acid, or by decreasing the concentration of compounds which inhibit their absorption of Zn like phytic acid or phenolic compounds. Low cost and easy approaches such as seed priming are also effective measures to load higher Zn in edible parts. Plant breeding and genetic engineering techniques have the greatest potential to increase Zn content in grains, roots and tubers to combat the Zn deficiency world-wide.

Keywords zinc deficiency, agricultural systems, human nutrition

BACKGROUND

Agricultural technologies can be directed towards improving nutritionally-rich food systems, which play an important role in public health. Food systems in many developing countries are now failing to provide adequate quantities of essential nutrients in the people’s diet (Graham and Welch, 1996; Welch and Graham, 2005). Cropping systems promoted by the green revolution have increased the food production but also resulted in reduced food-crop diversity and decreased availability of micronutrients (Welch, 2002; Stein et al., 2007). Micronutrient malnutrition is causing increased rates of chronic diseases (cancer, heart diseases, stroke, diabetes and osteoporosis) in many developing nations; more than 3 billion people are directly affected by the micronutrient deficiencies (Cakmak et al., 1999; Welch, 2002; WHO, 2002; Welch and Graham, 2004).

Unbalanced use of mineral fertilizers and a decrease in the use of organic manure are the main causes of the nutrient deficiency in the regions where the cropping intensity is high (Prasad, 1984; Welch, 1993, 2005). Moreover, agricultural intensification requires an increased nutrient flow towards and greater uptake of nutrients by crops. Until now, micronutrient deficiency has mostly been addressed as a soil and, to a smaller extent, plant problem. Currently, it is being addressed as a human nutrition problem as well. Increasingly, soils and food systems are affected by micronutrients disorders, leading to reduced crop production and malnutrition and diseases in humans and plants (Welch et al., 1982; Welch and Graham, 2004). Conventionally, agriculture is taken as a food-production discipline and was considered a source of human nutrition; hence, in recent years many efforts (Rengel and Graham, 1995a, b; Cakmak et al., 1999; Frossard et al., 2000; Welch and Graham, 2005; Stein et al., 2007) have been made to improve the quality of food for the growing world population, particularly in the developing nations.

Among the micronutrients, zinc (Zn) is the most important for activity of various enzymes and proper growth and development of plants, animals and humans (Alloway, 2004; Welch and Graham, 2004; Singh et al., 2005). Naturally, plant species differ in capacity to grow at low level of soil Zn and to accumulate Zn in the grains. Among different cereal crops, wheat is considered less tolerant to Zn deficiency stress (exhibits significant yield losses due to Zn deficiency) compared to more tolerant species such as peas, carrots and rye (Hacisalihoglu and Kochian, 2003). Several studies (Cakmak et al., 1996; Moussavi-Nik et al., 1997; Erenoglu et al., 1999; Rengel, 1999; Hacisalihoglu et al., 2001; Gonzalez et al., 2007) have investigated different aspects of Zn uptake mechanism. This paper aims at evaluating role of agriculture on Zn nutrition for human being and elucidates the strategies potentially help combating Zn deficiency problems in soil-plant-human continuum.

ZINC IN SOILS

Zinc deficiency in soils and plants is a global micronutrient deficiency problem reported in many countries (Sillanpaa, 1982; Graham and Welch, 2000; Alloway, 2004; Singh et al., 2005). Low availability of Zn in calcareous soils is one of the most widely distributed abiotic stresses in world agriculture, particularly in Turkey, Australia, China and India (Cakmak et al., 1999; Kenbaev and Sade, 2002; Brennan and Bolland, 2006). Zinc deficiency is particularly widespread in cereals growing on calcareous soils (Graham, 1991; Graham et al., 1992; Cakmak et al., 1997; Genc et al., 2006). Zn deficiency is the most important micronutrient deficiency in wheat (Cakmak et al.. 1998; Kabata-Pendias. 2001; Alvarez and Gonzalez. 2006; Bagci et al.. 2007), resulting not only in low production but in the poor nutritional quality of food (Graham and Welch, 1996). In southern Australia more than 18 million hectares of agricultural land are Zn-deficient (Brennan and Bolland, 2006). Similarly, in India alone more than 85 % of the cereal growing area is affected by low Zn. So, availability of Zn appears to be one of the most limiting factors for quality crop production worldwide. Zinc deficiency is common on neutral and calcareous soils, intensively cropped soils, paddy soils and poorly drained soils, sodic and saline soils, peat soils, soils with high available phosphorus and silicon, sandy soils, highly weathered acid and coarse-textured soils (Cakmak et al., 1998; Singh et al., 2005). Factors such as topsoil drying, subsoil constraints, disease interactions and high cost of fertilizer also contribute to zinc deficiency (Sillanpaa, 1982).

ZINC IN PLANTS

Zn is involved in many cellular processes, including activation of enzymes, protein synthesis and membrane stability, but the knowledge of Zn transport in plants is inadequate (Longnecker and Robson, 1993; Marchner, 1995; Grusak et al., 1999; Rengel, 1999; Alloway, 2004). Plants have a natural ability to extract ions from soil and to distribute them between the roots and the shoot. Within a certain concentration range, some heavy metals are essential for the growth of higher plants (Breckle, 1991). In this context, long-distance root-to-shoot transport in the transpiration stream via the xylem as well as the transfer from the xylem to the phloem and the retranslocation via the phloem must be considered as important processes for the redistribution of an element within a plant (Marschner, 1995). Several studies have demonstrated that Zn is easily transported in the phloem of wheat (Pearson and Rengel, 1995; Herren and Feller, 1996; Haslett et al., 2001) and that its redistribution may depend on the plant age and on the Zn content of the source organs (Pearson and Rengel, 1995; Herren and Feller, 1996). Longnecker and Robson (1993) reported that the first pool of Zn in plant is seed and this Zn is mobilized to growing seedling. Moussavi-Nik at al. (1997) also reported that the Zn has a stimulatory effect on crop germination and establishment as well as the final yield, especially in Zn-deficient soils. Wheat seedlings grown from seed with high Zn content produced more tillers and had better growth than seedlings grown from seed with low Zn content (Rengel and Graham, 1995a,b). Seed loading of Zn is affected by plant species and availability of Zn to the parent plant (Longnecker and Robson, 1993). Different species load different amount of Zn into their seeds even when grown in the same environment (Takker et al., 1988; Longnecker and Robson, 1993; Mozafer, 1993; see review by Rengel et al., 1999).

ZINC IN HUMAN NUTRITION AND HEALTH

It is estimated that about one billion people in the world do not eat sufficient food to meet their energy requirements and are consequently undernourished (Stein et al., 2007). Many more people suffer from 'hidden hunger': 150 million are vitamin-A-deficient, almost 2 billion are iodine-deficient, between 4 and 5 billion are iron (Fe) deficient (Hotz and Brown, 2004; Stein et al., 2007) and about 3 billion are Zn-deficient (WHO, 2002; Hotz and Brown, 2004; Stein et al., 2007). Zinc acts as a stabiliser of the structures of membranes and cellular components; in human body, most Zn is in the bone and skeletal muscles (Frossard et al., 2000). In addition to its role in enzyme function (Rivera et al., 1998), Zn also plays a major role in gene expression (Sandstrom, 1997). Zn deficiency in humans reduces growth, sexual maturity and the immune defense system (Frossard et al., 2000; Cunnigham-Rundles et al., 2005). Few studies (Ninh et al., 1996; Ruz, 1997; Rivera et al., 1998) reported that increased growth in Zn-supplemented infants and preschool children have lowered the incidence of diarrhoea and respiratory infections. Meat and seafood are good sources of Zn, and most of the Zn in the developed countries' diet is provided by animal products (Sanstead, 1995). However, in many parts of the developing world, most Zn is provided by cereals and legume seeds. These plant foods are high in phytic acid, which is a potent inhibitor of Zn absorption in the human digestive system (Frossard et al., 2000). Among population children and women are mostly affected with Zn deficiency (White and Broadley, 2005, Stein et al., 2007).

Given the context of growing world population pressure with limited food supply capacity of arable lands and cropping systems, the holistic sustainable improvements in the entire food systems are required to solve the massive problems of malnutrition and increasing chronic diseases in developed and especially developing countries (Welch, 2005). The question is how agriculture can contribute to sustainable solutions to these malnutrition problems. In that context, it is important to understand the dynamics of Zn accumulation in grains and other edible parts, which has an implication for human nutrition.

DISCUSSIONS AND CONCLUSION

Primary source of nutrients supply to human being is from crop and livestock products hence. Agricultural systems have great impact on human health and productivity. Among micronutrients, Zn is most limiting element for crop and animal productivity. Zinc deficiency is prevalent mostly in developing nations, causing the up to severe limitations on physical and intellectual capacity of the people as well as adversely affect their health and well-being (Frossard et al., 2000).

Conventionally, public health has been responsible to address the micronutrient malnutrition, rather than agriculture, despite the same underlying cause: an inadequate intake of balanced diet (Stein et al., 2007). Zinc deficiency has received little public attention, and no systematic interventions are currently in place to control this micronutrient deficiency (IM 2005 as cited in Stein et al., 2007). In recent years, efforts have been initiated in agricultural research and development to increase micronutrients density in edible parts (Cakmak, 2008).

Among different strategies to combat Zn deficiency in soils, application of Zn fertilizers to soil such as ZnSO4 increases the yield of crops Zn-deficient soils (Yilmaz et al., 1997). It also significantly contributes in increased Zn concentration in cereal grains (Graham et al., 1993, Rengel et al., 1999). Similarly, foliar application of Zn fertilizers significantly increased the Zn concentration in seeds (Yilmaz et al., 1997). Harris et al. (2007) found that priming seeds in Zn-containing solutions is a practical way to increase seed Zn prior to sowing and to contribute to better seedling growth. Similarly, priming maize seeds in 1% w/v ZnSO4 solution for 16 h significantly increased seed Zn concentration, and the seedlings derived from these seeds showed greater biomass and significantly greater grain yield (Harris et al., 2007 as cited in Cakmak, 2008). Soil types, growth stage, and genotypes also play key role in efficient use of Zn fertilizers, therefore those factors to be taken into account while applying fertilizers.

Plant breeding techniques to introduce high Zn traits into high yielding crops another promising approach to load the higher Zn content into edible parts of the crops. Efforts to increase the micronutrients density into edible parts have been initiated to develop crop genotypes (Cakmak, 2008). Similarly, genetic engineering and molecular genetics have great role in agricultural research to identify key regulatory steps in the acquisition of Zn by plants. Identifying and transferring of the corresponding genes to agriculturally important crops might allow to increase their nutrient uptake capacity. However, it is important to take into account of diverse soil types and environments, which have impact on plant growth and development.

Bioavailability of minerals for man is critical because mineral absorption by man from plant foods is often low. This appears to be mainly due to the presence of phenolic compounds or phytic acid (Fairweather-Tait and Hurrell, 1996 in stein et al., 2007), which is very strong chelator for Zn and other minerals. Therefore, it is equally important to identifying bioavailability of Zn in plant products by understanding the presence of other inhibitors like phenolic compound and phytates in edible parts or presence of ascorbic acids (which help in absorption of Zn for human being). However, with the increased concentration of Zn would help to increase in absorption proportionately assuming low absorption in the low-Zn plant and high in the high-Zn plant.

CONCLUSION

Agriculture is the mainstay in supplying main sources of nutrition to human being, particularly in developing nations. Large number of population are affected with low Zn supply in their food are living in developing nations, among the most Zn deficient population are children and women. Low cost and easy approaches such as seed priming, soil and foliar application of Zn fertilizers, are effective measures to load higher Zn in edible parts. Similarly with less immediate application but potential approaches are breeding and genetic engineering techniques have the greatest potential to increase Zn content and reducing phytate and phenolic compounds in edible parts to combat the Zn deficiency world-wide.

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