Human health problems related to trace element deficiencies in soil

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Abstract
Human health problems related to deficiency of essential trace elements are discussed. The most extensive problems, affecting one billion people or more worldwide, are associated with inadequate supply of iodine, selenium, and/or zinc. These problems are commonly occurring in, but not limited to, developing countries, and may fortify effects of other health-related problems such as famine and infectious diseases. Future developments in food production to meet the needs of an increasing world population should not neglect the content of essential trace elements in the products.

Key Words
Trace element deficiency, human health, developing countries, iodine, zinc, selenium.

Introduction

Soils can adversely affect human health in several ways. The organism can be affected directly by soil ingestion or inhalation of soil particles, or by contact through wounds. Moreover the soils may contain chemical elements and substances, either naturally or through pollution, that are toxic to humans and animals by excessive intake. On the other hand, many soils may contain too small quantities of essential elements in plant-available form to provide adequate supply to plants, animals, and in the end, man (Deckers and Steinnes 2004). For every essential element there exists a range of safe and adequate human intake. Any supply in excess of this may be toxic. On the other hand intake below this range is likely to cause deficiency problems and in extreme cases death. This range of optimal intake varies among the essential elements and may be considerably narrower for some elements than for others. There is a vast literature on soil pollution with toxic substances and the risk to human health. The most severe case worldwide is probably the excessive lead contamination of urban soils mainly from leaded petrol, which has been shown to significantly affect children´s blood lead levels (Mielke *et al.* 1997). Still problems related to deficiencies in mineral elements are even more widespread and affecting perhaps as much as one third of the population in the world. These problems are generally most abundant in developing countries where people depend largely on locally grown food, often in combination with a general food shortage. Such problems may be expected to continue and even become more serious in a world where a rapidly increasing population depends on food produced on a steadily decreasing agricultural area.

The major mineral elements needed by living organisms, namely sodium, magnesium, phosphorus, sulfur, and chlorine, rarely represent any deficiency problem in humans. However, man and his livestock also depends on a number of elements present in the body only in trace concentrations but still being absolutely necessary for the fulfillment of essential functions in the body. If these elements are not supplied in sufficient amounts through food and drinking water, serious health problems may become evident. This paper, therefore, is concentrated on the essential trace elements. Deficiency problems related to trace elements are also relatively common in agricultural crops. Only exceptionally are these elements added to commercial fertilizers. A soil deficient in one or more essential trace elements may not only reduce the yield of agricultural crops growing on it but also lead to less transfer of the elements to humans or livestock. Trace elements essential to plants but not to humans or animals may thus indirectly affect human health either directly or through the livestock.

Trace element deficiency problems

The elements present only in trace concentrations in the human body but still having a well-defined biochemical function are chromium, cobalt, copper, iodine, iron, manganese, molybdenum, selenium, and zinc. The same elements are also essential to mammals, including most domestic animals. Human health problems related to trace element deficiencies are particularly widespread for iodine, selenium, and zinc, and this paper is therefore focused on those three elements.

Iodine

The span between low and high iodine soils is very large, from about 15 mg/kg in organic-rich soils near the coast (Låg and Steinnes 1976) to less than 1 mg/kg in areas far inland. The major mechanism of iodine transfer from ocean to land reflects preferential volatilization of seawater iodine into the atmosphere (Fuge 2005) and the most likely source seems to be the release of volatile methyl iodide by marine organisms (Yoshida and Muramatsu 1995). The relative role of wet and dry deposition of iodine on land surfaces is not clear (Fuge 2005) and little is known with regard to the quantities of marine iodine carried to areas remote from the sea. Iodine has long been known as an essential element for humans and mammals, where it is a component of the thyroid hormone thyroxene. Insufficient supply of iodine may lead to a series of iodine deficiency disorders (IDD), the most common of which is endemic goiter. Iodine deficiency during pre-natal development and the first year of life can result in endemic creatinism, a disease which causes stunted growth and general development along with brain damage. This brain damage may occur even when there is no obvious physical effect, and probably represents the most widespread current geomedical problem on Earth with as much as 1.6 billion people at risk (Dissanayake 2005). The areas of the world currently most affected by IDD are largely located in developing countries of Africa, Asia, and Latin America (Fuge 2005), mainly in areas located far from the ocean. Even in some affluent countries of Western Europe however it has been suggested that as much as 50-100 million people may be at risk (Delange 1994).

Selenium

Selenium concentrations in soils show extreme geographical variations. This along with a narrow range of safe and adequate intake means that problems have been identified in humans and livestock both in relation to selenium deficiency and excess. In USA there are large areas in the Great Plains where selenium-rich soils are present and some plants may reach levels toxic to livestock. On the other hand the selenium-deficiency related disorder white muscle disease in animals has been commonly observed in several states of the northeast as well as the northwest of USA (Muth and Allaway 1963). China is another country where soils show extremely variable selenium contents geographically (Fordyce 2005), and where significant problems inn humans are evident both in low-selenium and high-selenium districts. Geographically widespread endemic diseases such as Kashin-Beck disease, an endemic osteoarthropathy resulting in chronic arthritis and deformity of the joints, and Keshan disease, a cardiomyopathy whereby the heart muscle is damaged, were both associated with selenium deficiency (Tan and Hou 1989). Rice appeared to concentrate Se more efficiently from the soil in these areas than other local food crops, and people on a rich rice diet showed less selenium deficiency symptoms that people with other eating habits. Recently selenium supplementation to the affected populations has reduced these health problems substantially. It has been indicated that certain iodine deficiency and selenium deficiency problems in humans may be interconnected (Kohrle 1999, Fordyce 2005).

Also in the developed countries the selenium status varies considerably among different populations, depending on the composition of the diet. Around 1970 the incidence of cardiovascular disease in Finland was among the highest in the world, and it was hypothesized that low selenium might be one of the reasons. A large-scale experiment adding selenium to fertilizer was therefore initiated. This led to increased selenium content in bread grain as well as milk, and eventually an increase of serum selenium concentration in the population to the level assumed to be optimal (Hartikainen 2005). Låg and Steinnes (1974; 1978) found that selenium in forest soils of Norway decreased regularly with distance from the ocean from around 1.0 mg/kg near the coast to <0.2 mg/kg in areas shielded from marine influence, suggesting that the marine environment might be a significant source of selenium to coastal terrestrial areas. This seemed surprising considering the extremely low content of selenium in seawater (0.1 µg/L). Cooke and Bruland (1987) however, studying the chemical speciation of dissolved selenium in surface water, observed the formation of volatile organo-selenium compounds, mainly dimethyl selenide, $(CH_3)_2Se$, and hypothesized that out-gassing of dimethyl selenide may be an important removal mechanism for dissolved selenium from aquatic systems. Thus, in a similar way as for iodine, it may seem that biologically driven transport from the ocean to continental areas naturally low in selenium may be a significant factor alleviating selenium deficiency problems.

Zinc

Zinc is an essential trace element required by all living organisms because of its critical roles both as a structural component of proteins and as a cofactor in enzyme catalysis (Leigh Ackland and Michalczyk 2006). According to Alloway (2005) zinc deficiency is the most widespread essential trace element deficiency in the world, perhaps affecting as much as one third of the world´s human population. Large areas of the world have soils that are unable to supply staple crops, such as rice, maize, and wheat, with sufficient zinc. In several countries large proportions of the arable soils are affected by zinc deficiency, such as in India where around 45% of soils are deficient in zinc (Singh 2001). Zinc deficiency in humans was first observed and reported among rural inhabitants of the Middle East in the early 1960's (Nauss and Newberne 1982). Dietary zinc deficiencies are also found in industrialized countries such as USA (Nauss and Newberne 1982) and Sweden (Abdulla *et al.* 1982). Moderate zinc deficiency has been cited as a major etiological factor in the adolescent nutritional dwarfism syndrome in the Middle East, the cardinal features of which are severe delay of sexual maturation and dwarfism (Hambidge *et al.* 1987). Recently it was suggested that fetal Zn deficiency contributes to the pathogenesis in adults (Maret and Sandstead 2008).

Concerns for the future

Regional differences in chromium, copper, iron, iodine, selenium, and zinc in the human diet occur both in developed and developing countries, but their effects are usually more evident in the latter, largely because of malnutrition and reliance on local food products (Oliver 1997). Moreover effects of infectious diseases are likely to be more serious in a population already suffering from imbalances in the diet. The total extent of problems related to trace element deficiencies in developing countries is potentially very large, and further work is required in order to identify the full scale of these problems and eventually solve them. However, the main problem in the 21st century related to human nutrition is obviously the still rapidly increasing population worldwide. At the same time the area of agricultural land is decreasing, due to factors such as urbanization, desertification, and increased soil erosion. During the last few decades the global human population growth has been outpaced by a dramatic increase in amount of food produced per area of land, facilitated by the use of high-yielding crop varieties, chemical fertilizers and pesticides, irrigation, and mechanization (Matson *et al.* 1997). The strong agricultural intensification however has also had several negative effects worldwide (Foley *et al.* 2005), and the production potential of existing agricultural land has been affected by reduced soil fertility in many areas. This development may also have depleted the soil with respect to plant-available forms of essential trace elements. In order to secure the food supply to the next generations it may be necessary to change land-management strategies e.g. by increasing agricultural production per unit land area, per unit fertilizer input, and per unit water consumed. This could be possible e.g. by changing the diversity of crop species and further genetic improvement of key species. There are reasons to believe that the success of such food production changes may be measured mainly in quantitative terms, i.e. in produced tons or calories. It appears important however that the quality of the product, i.e. the distribution of essential nutrients, be given appropriate weight. This also includes the essential trace elements discussed in the present paper, and appears to be particularly important in future projects related to improvement of food production in developing countries.

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