SOIL, FOOD SECURITY AND HUMAN HEALTH

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Keywords: Airborne dust, food security, human health, medicines from soil, soil nutrients, soil and health, soil disease, toxic materials in soil

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Summary

Food security is critical to human health. Food security is achieved when all people have constant access to adequate, safe, and nutritious food that is economically accessible, socially acceptable, and allows for an active and healthy life. The world's population continues to grow rapidly but large areas of cropland have to be abandoned every year due to soil degradation. This combination has lead to a worldwide decrease

in per capita cereal production since the 1980s. The trends of lost croplands and decreased per capita production will need to be stopped or reversed if we are to meet increasing food needs in the future. Building and maintaining soil health will also be critical in the supply of safe and nutritious food for future populations.

Most people recognize that soil plays a significant role in food production, but fewer are aware of the role of soils in food security from a health perspective. Many of the elements that are required for human health come from the soil through either plant or animal products consumed by humans. Some essential elements may also be acquired directly through the voluntary and/or involuntary consumption of soil.

There are also a number of ways that soils can have a detrimental affect on human health. Heavy metals in soil can be taken up by plants and passed on to those who consume them. Ingestion or inhalation of soil particles can expose humans to heavy metals, organic chemicals, and pathogens, and airborne dust can cause direct health problems through irritation of the respiratory passages.
Despite the obvious connections between soils and human health, there has not been a great amount of research done in this area when compared to many other fields of scientific and medical study. More research in this area is essential to protect and enhance human health.

1. Introduction

Many things are likely to come to mind when people think about their health. An active exercise program, wise food choices, good medical care, and proper sanitation are topics that might immediately be thought of. Few people recognize the connection between soils and human health, though soils are actually important to human health. Soils improve human health through the nutrients taken up by plants and animals that eat those plants; nutrients that are needed for adequate nutrition as humans consume the plants or animals. Soils can also act to harm human health if toxic substances or disease-causing organisms enter the human food chain from the soil or by direct contact with the soil or inhalation of dust from the soil. Therefore, soils form an integral link in the holistic view of human health.

1.1. Concept of Food Security

The concept of food security has several facets. These include an appropriate volume of stable food supplies, access to available supplies, food safety, nutritional balance, and social or cultural food preference. This concept of food security has developed over several decades, starting in the 1970s and being constantly and steadily refined through the 2000s. By 2001, the FAO definition of food security had been refined to:

"Food security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."

Basically, food security is seen as being achieved when all people have physical, social, and economic access to adequate, nutritious, and safe food that meets their dietary needs and their food preferences, allowing for an active and healthy lifestyle. This means the concept of human health is intricately linked to the concept of food security and, therefore, soil properties and processes that influence the quantity and quality of food will also be viewed as influencing human health.

1.2. Concept of Human Health

Health was defined as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" by the World Health Assembly in 1948. Note that this definition includes three primary aspects of health: (i) physical, (ii) mental, and (iii) social.

Physical fitness is achieved through proper nutrition in the daily diet and regular exercise. Mental fitness is achieved through emotional and psychological well-being and is also partially dependent on proper nutrition, and social fitness is achieved through the ability to operate comfortably within the expectations of the society the individual lives in. These components of health can also be seen within the food security definition of the FAO, again demonstrating the interrelationship between food security and human health.

1.3. Soils and Human Health in a Historical Perspective

Although we still have much to learn about the exact connections between soils and human health, the idea that soils are important to human health is not necessarily a new one. As far back as approximately 1400 B.C. the Bible depicts Moses as understanding that fertile soil was essential to the well-being of his people. Numbers 13:18-20 (New International Version) reports on the charge Moses gave to the men he sent to explore Canaan. Moses says to them *"See what the land is like and whether the people who live there are strong or weak, few or many. What kind of land do they live in? Is it good or bad?...How is the soil? Is it fertile or poor? Are there trees on it or not? Do your best to bring back some of the fruit of the land."* Note that Moses specifically instructed his men to evaluate the fertility of the soil.

In 400 B.C. the Greek philosopher Hippocrates provided a list of things that should be considered in a proper medical evaluation. Among these items, Hippocrates listed the ground, stating that *"…whether it be naked and deficient in water, or wooded and well watered, and whether it lies in a hollow, confined situation, or is elevated and cold…"* should be addressed.

By the late 1700 and early 1800s, American farmers had recognized that soil properties had some connection to human health. In "Letters from an American Farmer", published in 1792, J. Hector St. John De Crèvecoeur stated *"Men are like plants; the goodness and flavor of the fruit proceeds from the peculiar soil and exposition in which they grow"*. And in "Larding the Lean Earth", published in 2002, S. Stoll noted that North American farmers in the early 1800s recognized a link between an enduring agriculture and an enduring society, leading them to become concerned about the fertility of their soils and to seek ways of improving the soil in order to insure a healthy society.

Continuing into the first half of the 20th Century, a 1940 publication by the International Harvester Company noted that poor soils lead to "stoop-shouldered, poverty-stricken people." Then, in 1947, Sir Albert Howard published his landmark work "The Soil and Health: A Study of Organic Agriculture", a work that took a critical look at modern production agriculture and at the link between soil fertility and health.

Despite these various lines of evidence of some earlier level of understanding that healthy soils are required for healthy people, the scientific study of the relationship between soils and human health is a fairly new undertaking. In his 1997 work "Soil and Human Health: A Review", M.A. Oliver states *"… there is a dearth of quantitative information on the relations between elements in the soil and human health;…there is much speculation and anecdotal evidence."* So, the scientific study of soils and human health is a recent undertaking, but the idea that healthy soils are required for healthy people is not a particularly new one.

1.4. Climate and Soils: Influence on Human Health and Society

Beyond the recognized importance of soils for agricultural production and its influence on humans and civilizations throughout history, there is potentially another, more subtle impact on the broad social health of human communities. Natural soil fertility has a profound influence on what kinds of agricultural activities (i.e. production agriculture, grazing) are undertaken by a society and, if production agriculture is practiced, on what kinds of crops can be grown. The soils also influence the productivity of agricultural efforts, and this in turn affects economic activity and societal stability.

The Saharasia theory focuses on climate and the corresponding soils in an effort to explain the origins of social violence and warfare. Locations with rich, fertile soils and abundant productivity are seen as being among the last places on the planet where warfare developed. On the other hand, in places with frequent long droughts and poor soils, humans fought over scarce resources. This was particularly true in places that were once relatively productive but underwent desertification after human settlement. In these regions, the Saharasia theory argues that the most extremely patriarchal, authoritarian and violent world cultures developed in response to the resource poor conditions created by dry climates and low-fertility soils.

Recall that the third primary aspect of health under the World Health Assembly's definition was social. While research in the area of soils and human health has been fairly limited in general, very little work has been done looking at soils and human health from the perspective of the health of an entire society. This is an area that deserves additional attention.

2. Promotion of Human Health through Soils

There are 14 elements that are essential for plant growth that come from the soil, and many of these elements, such as calcium (Ca), iron (Fe), potassium (K), and others are also essential for human health. Essential soil elements that end up in the human diet are supplied through food from either plants that took the elements up from the soil during growth, or animal products after the animal obtained those essential elements from plants (see also: *Management of Agricultural Land: Chemical and Fertility Aspects*).

Because plants depend on the soil for their nutritional needs, and all higher animals including humans depend directly or indirectly on plants for their nutrition, plants form the base of the food chain and, consequently, a major portion of the nutrients needed for human health originate with the soil. This section will take a closer look at the elemental content of the soil and at some of the ways soil nutrients are taken up and influence human health.

2.1. Soil Elements Necessary for Human Health

The 14 elements in the soil that are essential for plant growth are: nitrogen (N), calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sulfur (S), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), chlorine (Cl), molybdenum (Mo), and sodium (Na). There are additional elements that are needed by some but not all plants such as cobalt (Co), bromine (Br), vanadium (V), silicon (Si), and nickel (Ni). In addition to these soil elements, hydrogen (H), oxygen (O), and carbon (C) are also essential for plant growth but are obtained from air and water (see also: *Soil Chemistry and Soil Fertility*). Most of these elements are also essential for human health as can be seen in the list below.

Eleven elements comprise 99.9% of the atoms found in the human body, subdivided into major and minor elements. Four major elements: H, O, C, and N make up about 99% of the atoms in the body; seven minor elements: Na, K, Ca, Mg, P, S, and Cl make up an additional 0.9% of the atoms in the body. In addition to these major and minor elements, there are approximately 18 additional elements considered essential in small amounts to maintain human life, although the exact number and identity of these elements is not universally agreed on by human health experts. These 18 additional elements, known as trace elements, include: lithium (Li), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), tungsten (W), molybdenum (Mo), silicon (Si), selenium (Se), fluorine (F), iodine (I), arsenic (As), bromine (Br), and tin (Sn).

Element	**Important Sources**
Ca	Kale, collards, mustard greens, broccoli
Cu	Beans, peas, lentils, whole grains, nuts, peanuts, mushrooms, chocolate
I	Vegetables, cereals, fruit
K	Fruits, cereals, vegetables, beans, peas, lentils
Mg	Seeds, nuts, beans, peas, lentils, whole grains, dark green vegetables
Mn	Whole grains, beans, peas, lentils, nuts, tea
Mo	Beans, peas, lentils, dark green leafy vegetables
P	Nuts, beans, peas, lentils, grains
Se	Grain products, nuts, garlic, broccoli (if grown on high-Se soils)
Zn	Nuts, whole grains, beans, peas, lentils

Table 1. Some important plant-tissue sources of elements essential to human life (based on Combs, in Selinus *et al.*, 2005).

Note that of the 29 elements considered essential for human life, 13 are essential plant nutrients obtained from the soil and another five are elements obtained from the soil that are needed by some, but not all, plants. Although the elements Cr, W, Se, F, I, As, and Sn are not considered essential for plant health, these elements are also found in trace amounts in plants that grow in soils containing them. Therefore, soils that provide a healthy, nutrient-rich growth medium for plants will result in plant tissues that contain many of the elements required for human life. In fact, most of the elements necessary for human life are obtained from either plant or animal tissues. Plant tissues are among the most important sources of Ca, P, Mg, K, Cu, Zn, Se, Mn, and Mo in the human diet (Table 1), and these elements are obtained by plants from the soil.

2.2. Health and Nutrient Imbalances in Soil

There are several adverse health affects that can arise from nutrient deficiencies in soils. Iron deficiency is probably the most common example and may affect as many as 5 billion people, with about 2 billion considered anemic. Blood loss to parasites such as hookworms is another major cause of Fe deficiency. Hookworms are a disease-causing organism associated with the soil. The best source of Fe is meat, especially red meat. High reliance on cereal-based diets low in meat, including cereal-based weaning foods for infants, can contribute to Fe deficiency. Low Fe in soils is rarely a problem except in arid regions.

Another soil-related sickness is iodine (I) deficiency, which leads to goiter, severe cognitive and neuromotor deficiencies, and other neuropsychological disorders. The World Health Organization estimates that about one billion people are at risk for iodine deficiency disorders, and has made the elimination of iodine deficiency disorders a priority. Regions known to have soils deficient in iodine are mainly located in the high-altitude interior of continents, although iodine deficiency has been eliminated in many developed countries by introducing iodine supplements to foods such as salt and bread. Most iodine deficiency problems today are found in developing countries, particularly in South America, Africa, and southeast Asia.

A low level of selenium (Se) in soils used to grow grains and other food crops is associated with a Se-deficient diet. Inadequate intake of Se can cause Keshan disease, a heart disease, and Kashin-Beck disease, a disease that results in chronic disabling degenerative osteo-arthrosis. Insufficient Se levels may also be associated with cancer, cardiovascular disease, reproductive problems, muscle diseases, and asthma; in each of these cases research is still ongoing. Places that experience Se deficiency problems in the soil include the mountainous belt of northeast China to the Tibetan Plateau, parts of Africa, and the Pacific Northwest, Great Lakes region, and east coast in the United States.

Zinc deficiency causes stunted growth and hypogonadism. Some foods such as whole grains can be rich in Zn, but low in bio-available Zn which can then lead to Zn shortage in the human organism. Zinc deficient soils are widespread and include about half the world’s soils. Calcareous soils and leached, acidic soils are more likely to be Zn deficient. Copper deficiency has been shown to cause heart disease and has been observed in acidic Histosols, acidic sandy soils, and some alkaline sandy soils.

Soil nutrient deficiencies may occur for a number of reasons. The most obvious reason is that the nutrient simply does not exist in sufficient quantity in the soil to lead to healthy plant growth. But there are also situations in which the nutrient is present in plentiful amounts, but unavailable to plants. For example, zinc (Zn) deficiency commonly occurs in calcareous soils; phosphorus (P) is easily bound by Ca, Al, or Fe depending on the soil pH. In both cases, it is possible to have ample amounts of Zn or P in the soil for nutritional needs, but for inadequate amounts of Zn or P to be taken up by plants due to chemical reactions occurring within the soil binding up these elements (see also: *Land Use Management*).

Another way that nutrient deficiencies may occur is through antagonism, a process by which ions with the same valence will reduce the uptake of another ion. Examples of antagonism include arsenic (As) antagonizing P and strontium (Sr) antagonizing Ca. Some apple orchards in the United States have problems with As antagonism of P uptake because As-containing pesticides have been used in the past. There is also concern that Sr released during the Chernobyl nuclear disaster in 1986 could antagonize Ca uptake, especially in fields in northern Europe where Chernobyl fallout was highest. Because there are several different ways that soil nutrient deficiencies may occur, it is important to determine (i) what kind and (ii) why a deficiency is occurring.

It is also important to note that several elements normally required in small amounts for human health can become toxic when present in high amounts, such as As, Cd, Fe, Zn, Cu, Cr, and others. Therefore, it is important not to over-correct soil nutrient deficiencies. High levels of cadmium (Cd) in the soil, for example, can lead to high levels of Cd in plant tissues and Cd toxicity problems for people who consume plant materials raised in those soils. The itai-itai disease in Japan is a classic example of the problems created by high Cd levels. Mining in the Toyama Prefecture of Japan released Cd into the Jinzu River. The contaminated river water was used for rice irrigation, leading to high Cd levels in the rice and accumulation of Cd in the human body of people who ate the contaminated rice. High Cd levels in human tissues caused itai-itai disease, which is characterized by weak, brittle bones, pain in the legs and spine, coughing, anemia, and kidney failure. These problems eventually lead to the death of the victim. One of the main biologic issues created by high Cd levels in the human body is poor calcium metabolism.

2.3. Animal Products and Soil Nutrient Status

To this point, most of the discussion has focused on the relationship between nutrients in plants and the nutrient status of the soil they grow in. However, the nutrient status of the soil also impacts the nutrition of meat, milk, and other animal products for human consumption. This is because animal feed, whether it is grass, corn, or other plant materials, is grown in the soil. Just as with plants, the nutritional content of these animal products in influences the health of the people who consume them. Table 2 shows some of the most important animal nutrient sources in the human diet.

Nutrient deficiencies do hardly occur in domestic animals raised in the intensive animal husbandry systems in North America, Europe, and other parts of the developed world. The nutrient content in the feed supplied to these animals is usually closely controlled and deficiencies compensated for. However, deficiencies in feed are still common in many developing countries where farmers rely on locally-produced feeds and do not have access to feed supplements.

Deficiencies can also be an issue in organic farming systems in developed countries due to the purposeful avoidance of feed supplements. Careful selection of a variety of feed plants for these organic operations can often overcome the lack of nutrients from feed supplements. Nutrient deficiencies affect animals in similar ways to their effects on humans, which means the symptoms of various deficiencies tend to be similar as well. Any nutrient that is deficient in an animal's diet will also be deficient in products obtained from that animal for human consumption.

Element	**Important Sources**
Ca	Dairy products
Cl	Dairy products, meats, eggs
Cu	Organ meats
Fe	Meats, especially red meat
K	Dairy products, meats
Mo	Organ meats
Na	Dairy products, meats, eggs
P	Meats, eggs, dairy products
Se	Meats from Se-fed livestock
Zn	Meats, organ meats

Table 2. Some important animal-product sources of elements essential to human life(based on Combs, in Selinus *et al*., 2005).

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Biographical Sketch

Eric C. Brevik is an Associate Professor of Geology and Soils at Dickinson State University, North Dakota, USA. Dr. Brevik earned his BS and MA degrees in Geology from the University of North Dakota and his PhD in Soil Science at Iowa State University. He has taught courses in soil science and geology at

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Dr. Brevik is active professionally, having published over 130 peer-reviewed articles, abstracts, and other publications. He is also active both in the United States and internationally in researching the historical and sociological aspects of soil science. He served as the vice chair and then the chair for the Soil Science Society of America's Council for the History, Philosophy, and Sociology of Soil Science from 2004-2006 and currently serves as the webmaster for the same group. As part of his chair duties, he helped organize and chaired a session on Soils and Human Health at the 2006 Soil Science Society of America's meeting in Indianapolis, Indiana, USA. Dr. Brevik is also the current newsletter editor for the International Union of Soil Sciences Council for the History, Philosophy, and Sociology of Soil Science, and he helped organize and chaired a session on the History of Soil Science in Developing Countries at the 2006 World Congress of Soil Science in Philadelphia, Pennsylvania, USA.