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IMPORTANCE OF MICRONUTRIENTS IN AGRICULTURE IN AFRICA AND THEIR IMPACTS ON HEALTH: A REVIEW

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ABSTRACT

Micronutrients deficiency in African soils is assuming alarming rates and may be responsible for the declining yields and quality of crops. These have serious implications on the attainment of the current global agenda: 2030 Agenda for Sustainable Development Goals (SDGs) to end hunger, achieve food security, improve nutrition and promote sustainable agriculture in Africa. These challenges are attributable to: inherent poor soil fertility, use of high analysis NPK fertilizers containing lower quantities of micronutrients, and the increase in cultivation intensity with high-yielding crop cultivars that remove higher quantities of micronutrients from the soil. Micronutrients malnutrition or "Hidden Hunger" is now a massive and rapidly growing public health problem among nearly all poor people in Africa, leading to unproductive work force. Molybdenum deficiency for instance leads to health challenges such as retarded weight gain, decreased food consumption, impaired reproduction, shortened life expectancy, neurological dysfunction, dislocated ocular lenses, and mental retardation. Related deficiency symptoms of micronutrients in plants (Iron, Manganese, Zinc, Copper, Molybdenum, Boron and Cobalt) and in animals (Arsenic, Iodine, Boron, Chromium, Copper, Fluorine, Iron, Manganese, Molybdenum, Nickel, Selenium, Vanadium, Silicon and Zinc) are fully discussed in this paper. To alleviate micronutrients deficiency, the paper identifies the intensification of agriculture through the incorporation of micronutrients fertilizers in African farming systems, molecular alterations of plant genes to improve micronutrients supplies, increasing translocation, remobilization and deposition of micronutrients, improving the bioavailability of micronutrients in plant food and increasing the accumulation of micronutrients and vitamins in edible parts of food crops through the process of bio-fortification.

Keywords: Micronutrients malnutrition; hidden hunger; deficiency symptoms; bio-fortification

INTRODUCTION

The soil remains the main medium in which plants obtain essential nutrients for their growth, development and yield. Humans and animals obtain their nourishment through the plants for their growth, development and reproduction. The soil must therefore be in a good stead to support plants and animals including humans by producing optimally in terms of yield and nourishment. Seventeen elements have been shown to be essential to plants. They are called macronutrients (C, H, O, N, P, K, Ca, Mg and S) and micronutrients or trace elements (B, Fe, Co, Zn, Cu, Mn, Mo, and Cl).

Micronutrients deficiencies in African soils are assuming alarming rates and may be responsible for the declining yields and quality of crops (Hengl *et al*., 2017; Berkhout *et al*., 2019). These have serious implications on the attainment of the current global agenda: 2030 Agenda for Sustainable Development Goals (SDGs) to end hunger, achieve food security, improve nutrition and promote sustainable agriculture in Africa. These disorders are attributable to: inherent poor soil fertility, use of high analysis NPK fertilizers containing lower quantities of micronutrients and the increase in cultivation intensity with high yielding crop cultivars that remove higher quantities of micronutrients from the soil. Current and comprehensive mapping of soil nutrients (macronutrients and micronutrients) in sub-Saharan Africa is credited to Hengl *et al.* (2017). African soils have inherently poor fertility due to the fact that they are very old and lack volcanic rejuvenation (Bationo, 2009) and have been constantly subjected to inappropriate land use, poor management and lack of input utilization leading to continuous nutrient mining and attendant rapid decline in productivity. Global climate change and its effects on soil fertility and productivity also creates new concerns, calling for the application of external inputs and good management for sustainable yield of crops in adequate quantity and quality.

Importantly, the primary source of all nutrients for humans and animals come from agricultural products. Low yield of crops are also associated with micronutrient deficiencies and humans get impacted negatively when their efforts give suboptimal yields against their labour and sweat. If agricultural systems fail to provide enough products containing adequate quantities of all nutrients during all seasons, dysfunctional food systems result that cannot support healthy lives.

It is well established that the micronutrients obtained from the soil are vital components of the diet, therefore managing them in the soil-plant systems is a vital component of sustainable agriculture as soil, plant, animal and human health are closely interrelated. Micronutrient malnutrition also known as “Hidden Hunger” (FAO, IFAD, WFP, 2014) has been recognized as a massive and rapidly growing public health problem among nearly all poor people in many developing nations (Welch and Graham, 2004). It is estimated that more than two billion people worldwide suffer from “hidden hunger” (FAO, 2013) which is a form of malnutrition that occurs when intake or absorption of vitamins and minerals is too low to sustain good health and development in children and normal physical and mental functions in adults. In addition to affecting human health, hidden hunger can curtail socio-economic development, particularly in low and middle income countries (von Grebmer *et al*., 2014).

Why Hidden Hunger?

According to von Grebmer *et al*. (2014), clinical signs of “hidden hunger” affecting the health and development of the larger share of the population is often less obvious except for signs like night blindness due to acute deficiency of Vitamin A and goiter resulting from inadequate iodine intake when deficiencies become acute. “The hidden hunger due to micronutrient deficiencies does not produce hunger as we know it. You might not feel it in the belly, but it strikes at the very core of your health and vitality" (according to Kul C Gautam, former Deputy Executive Director of UNICEF; von Grebmer *et al*., 2014).

Basic Needs of Plants from the Soil

All plants need soils for healthy and luxuriant growth, as well as adequate nutrients essential for good health and reproduction. The soil is the source of 14 out of the 18 essential nutrients needed by plants and apart from nitrogen, the primary source of these essential nutrients is the parent material from which the soil developed (FFD/FPDD, 2011). Nutrients are generally grouped into:

a) Non-mineral nutrients: These are essential nutrient elements supplied by air and/or water, not rocks or minerals (C, H, O, N);
b) Macro- or major nutrients: These are essential nutrients required by plants in relatively large quantities (N, P, K, S, Ca, Mg);
c) Micro- or trace nutrients: These are essential nutrients required by plants in relatively small quantities (Fe, Mn, B, Zn, Cu, Mo, Ni, Cl).

For animals, micronutrients are dietary nutrients, including essential elements and vitamins that are required by humans in very small amounts (Welch and Graham, 2004). They include at least 14 trace elements (As, B, Cr, Cu, F, I, Fe, Mn, Mo, Ni, Se, Si, V and Zn) and 13 vitamins (thiamine, riboflavin, niacin, pantothenic acid, biotin, folic acid, vitamin B6, vitamin B12 vitamin C, vitamin A, vitamin D, vitamin E and vitamin K).

Soil Factors Affecting Availability of Nutrients

The availability of nutrients (macronutrients and micronutrients) is affected by some soil factors such as organic matter, soil texture, soil pH, soil management and climate and spatial variability (SFN, 2006).

Organic matter: Mineral soils are very low in organic matter, and many may be deficient in micronutrients.

Soil texture: Sandy soils are more likely to show micronutrient deficiencies than clay soils.

Soil pH: Micronutrient availability generally decreases as the soil pH increases, with the exception of Mo.

Soil management, climatic and spatial variability: Soil moisture and temperature are important in soil management. Deficiency of one of the macronutrients (N, P, K, or S) may also restrict the ability of the plant roots to explore for other nutrients. For example, P is important for early root formation and growth.

Geographical Distribution of Micronutrient Problems in Africa

In sub-Saharan Africa, comprehensive micronutrients content in the soils have recently been predicted and mapped by Hengl *et al.* (2017) as shown in Fig 1. This relied on data from several sources namely: African Soil Information Service (AfSIS, Ethiopian Soil Information Service (EthioSIS, Nigerian Soil Information Service (NiSIS), Ghana Soil Information Service (GhaSIS). Others included International Fertilizer Development Center (IFDC), One Acre Fund, University of California, Davis, and VitalSigns. The publication is a response to repeated calls for data and monitoring of agricultural systems globally. The usability of the maps has been highlighted to spatially identify regions with deficient or adequate or excess nutrients relative to specific land-use requirements; and pair these with nutrient specific-agronomic interventions required to achieve critical crop thresholds (Hengl *et al.*, 2017).

Earlier work by Kang and Osiname (1985) had mapped and provided examples of common micronutrient deficiencies in sub-Saharan Africa. Micronutrient deficiencies or toxicities in sub-Saharan Africa were first recognized in areas where cash crops were grown. Only in the last few decades has more emphasis been given to the micronutrient status of soils for other crops. The worldwide study by Sillanpaa (1982) provided data on micronutrient concentrations in selected soils of Africa. It illustrated that copper, zinc and molybdenum deficiencies are common in many coarse-textured, acid soils of Ethiopia, Ghana, Malawi, Nigeria, Sierra Leone, Tanzania and Zambia.

Cobalt is required by nitrogen-fixing micro-organisms. It is an essential element for N-fixing legumes. In animal health, lack of cobalt in forage plants can lead to muscular 'wasting' and death in ruminants. In Kenya this deficiency-induced disease is called 'Nakuruitis' (McDowell, 1992). Cobalt deficiencies in grazing ruminants can be prevented or cured by treating pastures with 'cobaltized' fertilizers, or through oral application of heavy pellets (bullets) made of cobalt oxide and iron (McDowell, 1992).

Copper deficiencies are common in many coarse textured acid soils in sub-Saharan Africa. Deficiencies of copper have influenced the growth of wheat on soils derived from volcanic ash and pumice in Kenya and Tanzania (Nyandat and Ochieng, 1976; Kamasho and Singh, 1982) and copper deficiencies are also reported from peat and muck soils in various countries.

Iron deficiencies are rare in sub-Saharan soils due to the large pools of iron in weathered soils. However, areas that have been subjected to bush fires showed iron-deficiencies:

- ✓ Burning resulted in increased soil pH and thereby reduced the plant-availability of iron;
- ✓ The ferrous form is the preferred form of Fe for micronutrient use. Ferric oxides like magnetite are not suitable as micronutrient source.

Sources to successfully overcome iron deficiencies in high pH soils include:

- ✓ Fe-chelates and organic materials, such as manure;
- ✓ Pyrite-enriched manure is a good source of iron on alkaline soils (Bangar *et al*., 1985), and
- ✓ Finely ground basalt and volcanic tuff from a local quarrying operation that contained several percent Fe as Fe II to remedy chlorosis of groundnuts (*Arachis hypogaea*) in calcareous soils (Barak *et al.*, 1983).

Although manganese deficiencies are rare in sub-Saharan Africa, high plant-available Mn can cause toxicities, especially in acid soils. Increasing soil pH specifically through liming can prevent Mn toxicities.

In parts of the world where Mn is deficient in soils, Mn-sulfates, Mn-carbonates or MnO have been applied successfully (Mordtvedt, 1985).

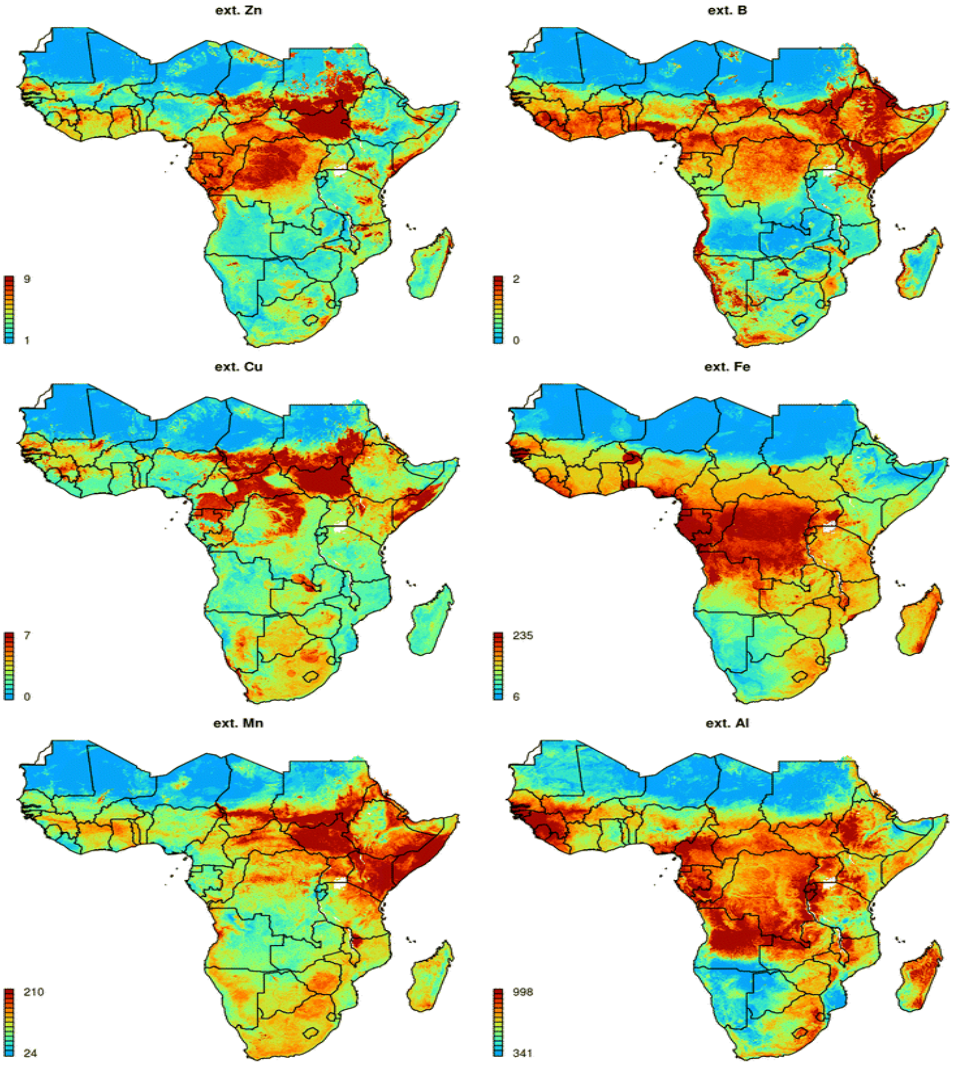

Fig 1: Soil Micronutrients Map of sub-Saharan Africa (Hengl *et al.*, 2017)

Molybdenum, essential for nitrogen fixation through symbiotic micro-organisms, is critical for many leguminous crops. Molybdenum deficiencies have been identified in some groundnut-growing areas of Senegal, northern Ghana, and northern Nigeria (references in Kang and Osiname, 1985).

- ✓ Martin and Fourier (1965) described the positive effects of Mo application on sandy Aeolian sands of West Africa leading to improved groundnut yields, nodulation and nitrogen fixation.
- ✓ Mo deficiencies and related problems can be expected in many parts of Africa, especially for legumes that have high Mo requirements like soybeans and groundnuts.

- ✓ Molybdenum deficiencies have also been observed on acid soils of Zimbabwe where maize is grown.
- ✓ In contrast to deficiencies there are also Mo toxicities, especially in parts of the world with high molybdenum parent materials and poorly drained alkaline soils.
- ✓ Cases of molybdenosis (molybdenum toxicity), a disease in ruminants (stiffness of legs and loss of hair) feeding on forage containing more than 10 to 20 mg Mo kg $^{-1}$, have been reported from North America and from Kenya (McDowell, 1992).

Low zinc concentrations have been found to reduce maize yields in several parts of Africa, for example in Nigeria (Osiname *et al.*, 1973), Zimbabwe and Zambia (Banda and Singh, 1989).

- ✓ Zinc deficiencies are also quite common with the cultivation of rice (Kanwar and Youngdahl, 1985).
- ✓ There is growing evidence that Zn has become gradually deficient in parts of Nigeria's savanna, especially in areas under continuous cultivation and phosphate fertilization (Lombin, 1983; Agbenin, 1998).
- ✓ Zinc is commonly supplied to crops as manufactured zinc sulfate fertilizers, but slowly dissolving zinc oxide has also been used successfully on wheat in South Africa (Dietricksen and Laker, cited in Mortvedt, 1985).

In Nigeria Zinc fertility map has been published by FFD/FPDD, (2011) to aid in soil fertility management and fertilizer use (Fig. 2). A vast majority of the area show sub-optimal Zinc contents for good crop yields and quality.

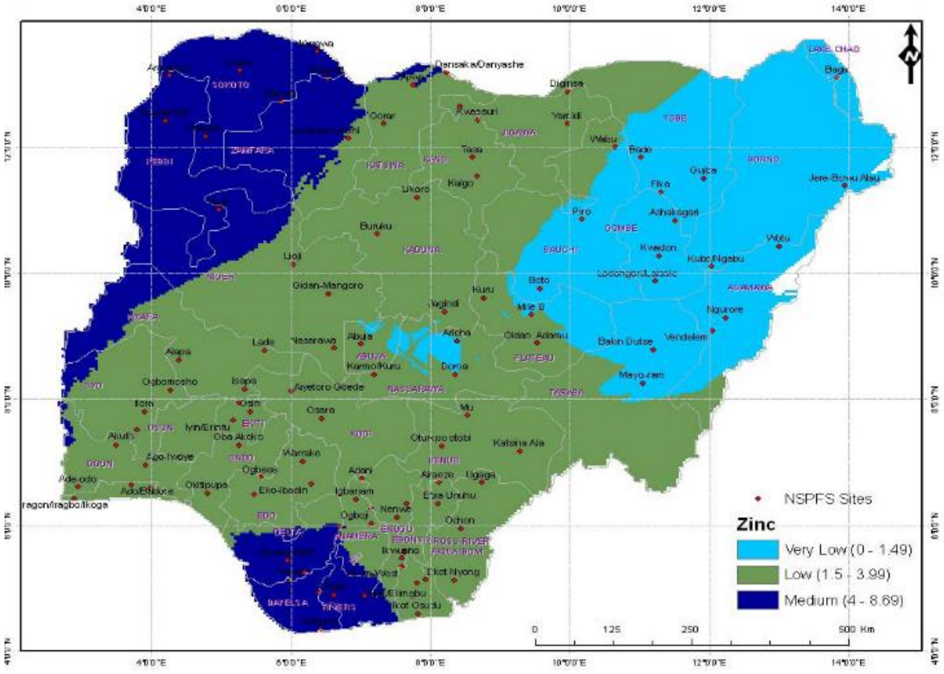

Fig 2: Map of Nigeria showing Zinc fertility status for top soil (FFD/FPDD, 2011)

Figure 3 is a typical map of Nigeria showing Boron fertility status (FFD/FPDD, 2011). A notable part of the country test low in boron requirement of crops. Boron deficiencies have been reported mainly from research on cash crop in the oil palm and cotton-growing areas in West and East Africa (Kang and Osiname, 1985) and their response to boron fertilization has been reported in forestry research. A statistically significant reduction of the incidence of die-back of Eucalyptus species was achieved through boron application (Kadeba, 1990). In Zimbabwe, colemanite and borate fertilizers were applied on cotton and sunflower and were equally effective when incorporated in NPK fertilizers (Rowell and Grant, 1975).

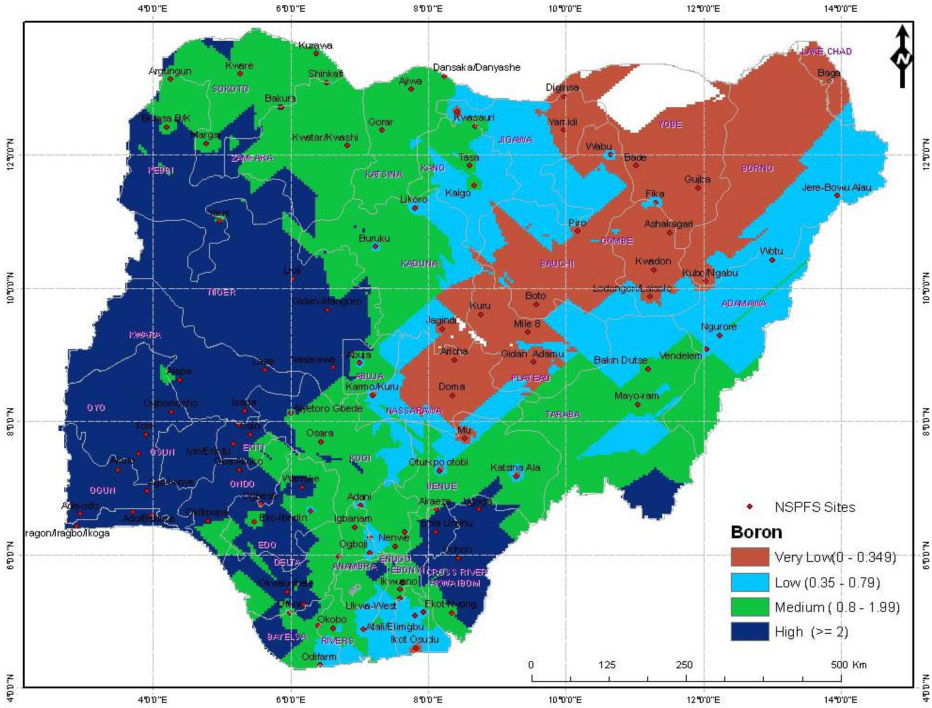

Fig 3: Map of Nigeria showing Boron fertility status for top soil (FFD/FPDD, 2011)

Functions and Deficiencies of Micronutrients in Plants

In agricultural soils, fertility gradient is easily observable in the field as a function of soil and physiographic factors (Ibia *et al*., 2010). Nutrient deficiencies occur when the rate of removal exceeds the reserves in the soil and the annual replenishment through natural processes (NRS, 2012). The increase in cultivation intensity with the increasing demand for higher yields with better quality has resulted in increasing demand for micronutrients.

Moreover, plant productivity has increased along the years due to genetic development and selection of high yielding cultivars. These cultivars with intensive cultivation methods have been found to remove higher quantities of microelements from the soil, leading to deficiencies occurring in many soils.

Table 1: A summary of the functions and deficiency symptoms of micronutrients in plants has been made by FFD/FPDD (2011)

Micronutrient	Functions	Deficiency Symptoms
COPPER (Cu) **Source:** Cu is obtained from the soil (Cu^{++}) and absorbed by the plants through the roots.	It is a constituent of cytochrome oxidase and component of many enzymes - ascorbic acid oxidase, phenolase, lactase, etc It promotes the formation of vitamin A in plants	**In cereals:** Yellowing and curling of the leaf blade, Restricted ear production and poor grain set, Indeterminate tillering. **In citrus:** Die-back of new growth, Exanthema pockets of gum develop between the bark and the wood, The fruit shows brown excrescences.
IRON (Fe) Source: Fe is obtained from the soil (Fe^{++}, Fe^{+++}) and absorbed by the plants through the roots.	It is necessary for the synthesis and maintenance of chlorophyll in plants. It is an essential component of many enzymes. It plays an essential role in nucleic acid metabolism and affects RNA metabolism or chloroplasts.	Typical inter-veinal chlorosis; youngest leaves first affected, points and margins of leaves keep their green colour longest. In severe cases, the entire leaf, veins and inter-veinal areas turn yellow and may eventually become bleached.
ZINC (Zn) **Source:** Zn is obtained from the soil (Zn^{++}) and absorbed by the plants through the roots.	It is involved in the biosynthesis of indole-acetic acid. It is an essential component of a variety of metallo-enzymes such as carbonic anhydrase, alcohol dehydrogenase, etc. It plays a role in nucleic and protein synthesis. It assists the utilization of phosphorus and nitrogen in plants	Deficiency symptoms mostly appear on the 2nd or 3rd fully mature leaves from the top of plants. In maize, from light yellow striping to a broad band of white or yellow tissue with reddish purple veins between the middle and edges of the leaf, occurring mainly in the lower half of the leaf In wheat, a longitudinal band of white or yellow leaf tissue, followed by inter-veinal chlorotic mottling and white to brown necrotic lesions in the middle of the leaf blade and the eventual collapse of the affected leaves near the middle.
MANGANESE (Mn) **Source:** Mn is obtained from the soil (Mn^{++}) and absorbed by the plants through the roots.	It serves as a catalyst in several enzymatic and physiological reactions in plants; a constituent of pyruvate carboxylase. It is involved in plant's respiratory processes. It activates enzymes concerned with the metabolism of nitrogen and synthesis of chlorophyll. It controls the redox potential in plant cells during the phases of light and darkness.	Chlorosis between the veins of young leaves, characterized by the appearance of chlorosis and necrotic spots in the inter-veinal areas. Grayish areas appear near the base of the younger leaves and become yellowish to yellowish-orange.

BORON (B) **Source:** B is obtained from the soil (BO_3^{--}, $B_4O_7^{--}$) and absorbed by the plants through the roots.	It affects the activities of certain enzymes. It has the ability to complex with various polyhydroxy-compounds. It increases permeability in membrane and thereby facilitates carbohydrate transport. It is involved in lignin synthesis and other reactions. It is essential for cell division. It is associated with the uptake of calcium and its utilization by plants. It regulates potassium/calcium ratio in plants. It is essential for protein synthesis	Death of growing plants (shoot tips) The leaves have thick texture, sometimes curling and becoming brittle. Flowers do not form and root growth is stunted. "Brown heart" in root crops characterized by dark spots on the thickest part of the root or splitting at centre. Sensitive plants include tobacco, cotton and legumes.
MOLYBDENUM (Mo) **Source:** Mo is obtained from the soil (MoO_4^{--}) and absorbed by the plants through the roots.	It is associated with nitrogen utilization and nitrogen fixation. It is a constituent of nitrate reductase and nitrogenase. It is required by *Rhizobia* for nitrogen fixation	Chlorotic inter-veinal mottling of the lower leaves, followed by marginal necrosis and infolding of the leaves. In cauliflower, the leaf tissues wither leaving only the midrib and a few small pieces of leaf blade ("whiptail"). Molybdenum deficiency is markedly evident in leguminous plants.

Source: FFD/FPDD, (2011)

Micronutrients Assessment when Deficiencies are Suspected

Soils all over the landscape have varying nutrient supplying power, depending on the amount of total reserves, mobilization and accessibility of the chemically available nutrients to plants. The process of determining the nutrient status of soils or their capacity for prevailing nutrients in order to guide effective fertilizer application can be referred to as **"Soil Fertility Assessment/Evaluation".**

Impact of Climate Change and Soil

Communities around the world are feeling the effects of climate change, but African and Asian communities being the poorest are more vulnerable and the hardest hit. They are the least equipped to recover from the devastation that can result from weather extremes such as storms, floods, eroding coastlines, heat waves, and droughts. Climate change impacts soil nutrients thus affecting fertility and productivity, food security and human health.

Joy (2011) reports that over-cultivated soils will often suffer mineral deficiencies, particularly in systems where nutrients and organic wastes are not returned to the soil. Heavy rains can wash micronutrients below the root systems or into water courses if soils are unprotected, have low organic matter content and poor structure. Agricultural practices can be tuned to improve crop micronutrient uptake, and to reduce leaching from the system. When soils are excessively leached, flooded or submerged, or becomes dry, soil fertility and productivity become impaired nutrients become removed, converted or unavailable. These in turn affect food security.

Changes in temperature and precipitation associated with continued emissions of greenhouse gases will bring changes in land suitability and crop yields. Changes in climate and increases in some extreme weather events, such as floods and droughts, could disrupt stability in the supply of food and people's livelihoods making it more difficult for them to earn a stable income to purchase food.

Climate change can result in substantial decline in labour productivity and inability to cultivate crops and raise animals and may increase poverty and even mortality among the populace. It has the potential to affect different diseases, including respiratory illness and diarrhoea. Decreased water availability and quality in some areas are likely to result in increased health and sanitation problems, such as diarrheal disease. This, together with changes in the patterns of vector-borne disease, has the potential to increase malnutrition by negatively affecting food production and utilization (Vladimir and Gjorgjev, 2012).

Soil Management for Enhanced Fertility and Micronutrient Availability

The soils therefore, need special attention in their management and utilization particularly for agricultural production. Such management requirements for overall soil fertility according to Chude (2011), include:

i) Increased and more efficient mineral fertilizer use;
ii) Exploitation and use of locally available soil amendments;
iii) Maximum recycling of organic products, both from within and from outside the farm (crop residues, animal manures, urban wastes, compost, etc; and
iv) “Improved” land use systems, based on both indigenous and science-based technologies, adaptable to local situations, etc.

Forms of Micronutrients Available for Use in the Soil

SFN (2006) listed several groups or forms of micronutrient fertilizer available for use in soils to include:

Sulphate (salts): The sulphate form of micronutrients such as: Cu, Zn, Fe and Mn represents a water-soluble form that is plant available. Borate is the equivalent plant available form for B. Sulphates are the most commonly used form for field crops. Sulphates can be applied to the soil or foliage.

Oxysulphate: An oxysulphate is an oxide of a micronutrient that has been partially reacted (acidulated) with sulphuric acid. Water solubility of oxysulphates which vary greatly is important when using oxysulphates. In general, the higher the water solubility portion, the better.

Oxide: Oxides are micronutrient elements (Cu, Zn, Fe, and Mn) bonded with oxygen. The bonds with oxygen are very strong, meaning these products are not soluble in water and are not in plant-available form. An oxide of a micronutrient needs to be converted to a plant available form in the soil before being taken up by the plant. For crop response during the growing season, plant available forms (water-soluble forms) of micronutrients need to be used.

Chelate: Chelates are micronutrients such as Cu, Fe, Mn, and Zn held within ring-type compounds. Chelated micronutrients remain in plant-available form longer because the chelated structure slows the micronutrient reaction with soil minerals. Chelated micronutrients can be soil or foliar applied.

Manure: Livestock manure can be a source of micronutrients such as Cu and Zn.

Other forms: Carbonates and nitrates and mixtures with elemental forms are examples of other forms of micronutrients, but are seldom used.

Issues in Animal and Human Health

In animals and humans, micronutrients are dietary nutrients made up of 14 trace elements/ essential elements and 13 vitamins which are required by humans in very small amounts (Welch and Graham, 2004). There is no doubt that agricultural production of staple foods (particularly cereals and starchy tubers) has improved by applying the “green revolution” approaches of developed countries in Africa and Asia. According to UN-ACCSN (1992), what has resulted is massive production and utilization of energy giving foods causing unforeseen nutritional imbalances and problems particularly among pregnant women, infants/children. These have been traceable to low micronutrient intake among others.

Deficiencies and Impacts on Animals and Humans

Deficiency symptoms associated with micronutrients in animal diets have been documented and published (National Research Council, 1989; Nielsen, 1992; World Health Organization, 1996; Welch and Graham, 2004).

These are summarized below:

Arsenic: It is implicated in impaired fertility and increased perinatal mortality, depressed growth, conversion of methionine to its metabolites and methylation of biomolecules.

Boron: It is involved in impaired Ca utilization in bones; more severe signs of vitamin D related rickets; decreased apparent absorption of Ca, Mg and P; impaired mental functions in older women and men (>45 years old).

Chromium: It is implicated in impaired glucose tolerance, impaired growth, elevated serum cholesterol and triglycerides, increased incidence of aortic plaques, corneal lesions, decreased fertility; low sperm count and potentiates insulin action.

Copper: It is involved in hypochromic anaemia, neutropenia, hypopigmentation of hair and skin, impaired bone formation with skeletal fragility and osteoporosis, vascular abnormalities and steely hair. It is a metal cofactor in numerous metalloenzymes, e.g., cytochrome oxidase, caeruloplasmin, superoxide dismutase, etc.

Fluorine: Its status as an essential trace element is debated. It is a beneficial element because of its effects on dental health.

Iodine: It is involved in a wide spectrum of diseases including severe cretinism with mental retardation, enlarged thyroid (goiter). It is an essential constituent of the thyroid hormones.

Iron: Iron deficiency results in erythropoiesis with low iron stores and with work capacity performance impaired. It causes anaemia with reduced hemoglobin levels and small red blood cells. It impairs immune function; it causes apathy; it is responsible for short attention span and reduced learning ability. Iron is a constituent of hemoglobin, myoglobin and a number of enzymes.

Manganese: It is responsible for poor reproductive performance, growth retardation, congenital malformations, abnormal bone and cartilage formation, impaired glucose tolerance. Mn is a metal activator of many enzymes, e.g., decarboxylases, hydrolases, kinases, and transferases. It is a constituent of pyruvate carboxylase and superoxide dismutase in mitochondria.

Molybdenum: It leads to retarded weight gain, decreased food consumption, impaired reproduction, shortened life expectancy, neurological dysfunction, dislocated ocular lenses and mental retardation. It is a cofactor (molybdopterin) in sulfite oxidase and xanthine dehydrogenase.

Nickel: It is responsible for depressed growth and reproductive performance, impaired functioning and body distribution of several nutrients e.g., Ca, Fe, Zn, vitamin B12. It is a cofactor for an enzyme that affects amino acids and odd-chained fatty acids derived from the propionate metabolic pathways.

Selenium: It is responsible for endemic cardiomyopathy (Keshan disease), white muscle disease, endemic osteoarthoropathy (Kashin-Beck disease) with enlargement and deformity of the joints, liver necrosis, exudative diathesis, pancreatic atrophy, growth depression, depressed activity of 5-deiodinase enzymes that produce triiodothyronine (T3) from thyroxine (T4), impaired immune response to viral infections. It is involved in anticarcenogenic activity and it is an essential component of glutathione peroxidase and "selenoprotein-P".

Silicon: It is responsible for depressed collagen content in bone with skull structure abnormalities, long bone abnormalities, decreased articular cartilage, water, hexosamine, and collagen as well as decreased levels of Ca, Mg, and P in tibias and skulls under Ca deficiency conditions.

Vanadium: It is responsible for death proceeded by convulsions, skeletal deformities and increased thyroid weight. It participates in oxidation of halide ions and/or the phosphorylation of receptor proteins.

Zinc: It is responsible for the loss of appetite, growth retardation, skin changes, immunological abnormalities, difficulty in parturition, teratogensis, hypogonadism, dwarfism, impaired wound healing, suboptimal growth, poor appetite, and impaired taste acuity in infants and children, diarrhoea, impaired immune function. It is a constituent of numerous enzymes and it aids in cellular membrane stability function.

Malnutrition and Disease Incidence

Micronutrients compose of the mineral and vitamin components of a healthy diet, required in small quantities, but essential for good health. In developing countries particularly in Africa, since the beginning of the early 1990’s, micronutrient deficiencies (also known as “hidden hunger”) have been put high up on the international public health agenda (Joy, 2011). Two causes of micronutrient deficiencies are inadequate intake of micronutrient-rich foods (including fruit, vegetables, meat, eggs and dairy) and general health problems associated with humans.

Micronutrient malnutrition not only affects the health, well-being and livelihood of all those individuals and families afflicted, but it also adversely impacts programs to control population growth, societal stability and national development efforts. If widespread within a population, deficiencies of any micronutrient can diminish economic growth, societal stability and national development. Unfortunately, in many nations, introduction of high yielding cereal crops and trends to less heterogeneous farming systems has resulted in reduced diversity of food available to low-income individuals and families and therefore, decreased access to and increased cost of more diverse food sources in the market place especially for the poor. As stated previously, this trend of less food diversity could be a contributing factor in the spread of micronutrient malnutrition among poor women, infants and children in developing nations (Welch, 2001).

Optimum nutrition can be provided by assuring dietary diversity and food abundance for all to ensure that adequate and balanced amounts of all micronutrients are available for consumption. To treat micronutrient deficiencies to large numbers of people, relatively quick interventions using micronutrient supplements and food fortificants are important programs currently being used globally. While this should continue to be used as short- to medium-term interventions for decreasing micronutrient malnutrition, agriculture should remain the primary intervention tool if we are to eliminate "hidden hunger" in sustainable ways (Welch *et al.*, 1997) by improving plant food nutritional quality and the nutrient output of agricultural systems.

Improving Plant Food Nutritional Quality and the Nutrient output of Agriculture systems

Several actions are commonly used to improve plant food nutritional quality and nutrient output of agricultural systems. These include cultural practices, variety selection, crop improvement programmes, and incorporation of indigenous and traditional food crops of high nutritive value in the farming systems, genetic engineering and plant breeding programmes as well as molecular alterations of plant genes to improve micronutrient supplies.

Bio-fortification is also practiced currently. This is the process by which the nutrient density of food crops is increased through conventional breeding of food crops and/or agronomic biotechnology without sacrificing any characteristics that is preferred by consumers or most importantly to farmers (Nestel *et al.*, 2006; Talsma and Pashon, 2017). Saltzman *et al.*, (2013) has stated that conventionally bred bio-fortified crops have been released and delivered to farmers in the developed economies to include Vitamin A orange, Vitamin A sweet potato, Vitamin A maize, Vitamin A cassava, iron-fortified beans, iron-fortified peal millet, zinc-rice and zinc-wheat. The availability of these crops may be low in most of Africa but it is expected to grow significantly in the years ahead.

Cultural Practices

Fertilizers and soil amendments: Macronutrient fertilizers containing N, P, K, and S, and certain micronutrient fertilizers containing, for example Zn, Ni, and Se, can have significant effects on the accumulation of micronutrients in edible plant products (Alloway, 1986; Grunes and Alloway, 1985). The use of farm-yard manures and other forms of organic matter can also change plant-available micronutrients by changing both the physical and biological characteristics of the soil. In many circumstances these changes improve soil physical structure and water holding capacity, resulting in more extensive root development and enhanced soil microflora and fauna activity. All of these can affect available micronutrient levels in soil for plants (Stevenson, 1991; Stevenson, 1994).

Variety selection: Using micronutrient-dense staple food crop varieties in cropping systems is one approach that could be used to increase the micronutrient output of farming systems albeit this approach has never been used to date (Bouis, 1996; Combs *et al.*, 1996; Graham and Welch, 1996).

Crop management: Crop management is another tool that can be used to improve the micronutrient output of farming systems. For example, using certain legume crops in rotation with cereal crops can result in substantial increases in the concentration of Zn in cereal grain in areas where soil-Zn is currently limiting wheat production (Holloway, 1997, cited in Welch and Graham, 2004).

Selecting micronutrient dense food crops and cultivating micronutrient-dense staple plant food varieties should be a major goal of agriculturalists in developing countries where micronutrient deficiencies among people are common.

Indigenous and traditional food crops of high nutritive value: Within many developing nations, certain indigenous food crops are being displaced and lost as important nutritional components of traditional diets. The production of many of these traditional crops has decreased even further because of importation of and subsidies paid for millions of tons of wheat, rice and maize that are sold at lower prices. Many traditional crops are much richer sources of micronutrients than the introduced cereal crops that are displacing them. Designing cropping systems for maximum nutrient output to improve nutrition and health should become an integral part of agriculture's goals and government policies. This calls for intensification in homestead food production programmes which integrate crop production with animal husbandry for increased dietary diversification (Trentmann, *et. al.*, 2012).

Genetic engineering and plant breeding: Plant breeding options have been documented (Welch and Graham, 2004). These show that the dominant staple crops can be enriched (i.e. 'bio-fortified') with micronutrients using plant breeding and/or transgenic strategies, because micronutrient enrichment traits exist within the plant genomes that can be used for substantially increasing micronutrient levels in these foods without negatively impacting crop productivity. 'Bio-fortification' is a word coined to refer to increasing the bioavailable micronutrient content of food crops through genetic selection via plant breeding. Agronomic bio-fortification involves the use of fertilizers in conjunction with appropriate soil amendments to increase micronutrients to optimum levels while genetic bio-fortification employs crop genotypes with increased abilities to acquire mineral elements and accumulate them in edible tissues (WHO, 2014).

Developing micronutrient-enriched staple plant foods, either through traditional plant breeding methods or via molecular biological techniques through genetically modified foods (GMF), is a powerful intervention tool that targets the most vulnerable people (resource-poor women, infants, and children; Combs Jr *et al.*, 1996). Welch and Graham, (2004) reported that breeding efforts to screen large numbers of promising micronutrient-dense lines of staple plant foods (rice, maize, wheat, beans, and cassava) at several CGIAR Centres (IRRI, CIMMYT, CIAT, and IITA) for bioavailable Fe were in progress.

There must therefore be a resolve of the agricultural community, the nutrition community, public health officials, private industry, and government policy makers to use agriculture as a primary means in alleviating micronutrient malnutrition.

These can be done through:

Molecular alterations of plant genes to improve micronutrient supplies: Modern molecular biological techniques could be used to genetically alter food plants with increased bioavailable concentrations of micronutrients in edible portions. However, this requires detailed knowledge of various physiological and biochemical processes in plants.

Increasing efficiency of micronutrient uptake: The mineral nutrition of plants is under genetic control and the mechanisms by which plants accumulate micronutrient elements are under genetic regulation. Selecting for the ability to accumulate more micronutrient elements from nutrient-poor soils is the first step in breeding for micronutrient-dense staple food crops.

Increasing translocation, re-mobilization and deposition of micronutrients: The second step in increasing the density of micronutrient in staple foods involves altering the genes that control the translocation of root-accumulated micronutrient elements to shoots. Once more micronutrients are accumulated in plant shoots, they must be re-translocated out of stems and leaves to reproductive organs before they can be deposited in developing seeds and grains.

Improving the bioavailability of micronutrients in plant foods: The knowledge of how micronutrients are stored and in what forms they occur in edible seeds and grains, is an important consideration for increasing the bioavailable content of micronutrients in edible parts of the plants.

Increasing the accumulation of vitamins in edible parts of food crops: Current molecular biological techniques are available that would allow for rapid genetic alterations of plant foods in ways that would increase vitamins in these foods once the biosynthetic pathways and their genetic regulation are understood (New York Academy of Sciences, 1996).

CONCLUSION

Soil micronutrients deficiencies pose global challenge with the sub-Saharan Africa largely unaware of the effects and correspondingly enormous impacts on soil, crops, animals and humans, thus creating a vicious cycle of poverty, health impairment, and low social status in the affected regions. It is therefore pertinent for the sub-Saharan African countries to make policies, embark on programmes and multiple intervention schemes on the micronutrients status of soils, food crops and dietary intake of animals and human beings.

Micronutrients deficiencies have to be addressed as part of a wider multi-sector strategy tailored to diverse conditions of major agro-ecological, socioeconomic and epidemiological situations and this entails inter-sectorial involvement in the design, implementation, management and evaluation of flexible programmes to increase production and consumption of micronutrient rich foods in the world and particularly in Africa. Considering the widespread incidences of micronutrients deficiency in Africa, the region is a huge market for research, development and sale of micronutrient fertilizers.

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