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REVIEW ON ROLE OF MICRO NUTRIENTS, CURRENT STATUS AND KNOWLEDGE GAPS IN ETHIOPIAN AGRICULTURE FOR ENSURING FOOD SECURITY

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Abstract

The main force behind Ethiopia's economic growth and long-term food security is agriculture. It generates around 45% of the GDP, 90% of the revenues from foreign exchange, and 85% of all employment. Soil fertility depletion is the fundamental biophysical root cause for declining per capital food production in Sub-Saharan African countries in general and in Ethiopia in particular. The deficiency of micronutrients, particularly in pastoral communities, might be severe due to poor diets mitigated by poor healthcare access, drought, and poverty. Therefore, soil fertility evaluation is one area that needs immediate attention since the reduction in the productivity of several crops is due to ever-decreasing soil fertility on one hand and an imbalanced application of plant nutrients on the other. However, there is very little information available in the country about soil nutrients availability, or the levels of nutrients that are needed to produce economically optimal yields of the crops. We need to pay more attention to fertilizer-use efficiency of the limited amounts that farmers can buy, instead of basing fertilizer recommendations on the face value of agronomic responses, which often suggests large requirements for inorganic fertilizers. Therefore, future research should focus on assessing the availability of these and other micronutrients by collecting large number of soil and plant samples and conducting field trials in the area.

Keywords: Micronutrients, Deficient, Food security, Knowledge gap

INTRODUCTION

The main force behind Ethiopia's economic growth and long-term food security is agriculture. It generates around 45% of the gross domestic product (GDP), 90% of the exports, and 85% of the country's workforce. The agricultural sector is dominated by small-scale farmers, accounting for 95% of the total area under crop cultivation and more than 93% of the total agricultural output (CSA, 2010). One of the major public health problem in Ethiopia is the deficiency of micronutrients, particularly in pastoral communities, might be severe due to poor diets mitigated by poor healthcare access, drought, and poverty (Gebremedhin T et al 2021).

Soil is a fundamental resource base for agricultural production systems. Besides being the main medium for crop growth, soil functions to sustain crop productivity, and thus provide food for plants and animals. The failure of past, present and future systems can be essentially attributed to poor agricultural research planning, to incorrect agricultural systems design and resource allocation and to an incomplete capacity to cope with short and long-term global climatic behavior. However, soil resources are finite and non-renewable over a human time frame and are prone to degradation by misuse and poor management (Lal, 2000).

The secret of ensuring food security for the ever-increasing world population is strongly linked to the productivity of soils. Soil, one of the most precious resources of land, plays a critical and irreplaceable role in determining man's standard of living. This implies that the overall productivity and sustainability of a given agricultural sector are heavily dependent on the fertility and productivity of soil resources (Wakene, 2001). Soil fertility depletion is the fundamental biophysical root cause for declining per capita food production in Sub-Saharan African countries in general (Sanchez et al., 1997) and in Ethiopia in particular.

The loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with unbalanced plant nutrition practices, has seriously threatened agricultural production (FAO, 2006a). Ellis and Foth (1997) pointed out that soil fertility and plant nutrition are two closely related subjects that emphasize the forms and availability of nutrients in soils, their movement to and their uptake by roots, and the utilization of nutrients within plants. Without maintaining soil fertility, one cannot expect the improvement of agricultural production to feed the increasing population.

In Ethiopia, declining soil fertility presents a major challenge to bring about increased and sustainable productivity in order to feed the ever-increasing population of the country. As a result, millions are suffering from poverty and malnutrition. Eyasu (2002) indicated that under increasing demographic pressure, cultivation becomes permanent. According to the same author, the conventional hypothesis is that the traditional farming systems in Sub-Saharan Africa lead to the mining of the natural soil fertility when cultivation becomes more permanent due to increasing population pressure. In many cases, the removal of vegetation cover, depletion of soil nutrients and organic matter (OM), and accelerated soil erosion have all led to a drastic decline in soil productivity.

Ensuring soil fertility is a basic requirement for any form of sustainable agriculture. However, various recent studies have shown that soil fertility is declining in many farmlands due mainly either to inadequate farming practices (Gobeille et al., 2006), insufficient fertilization, in which case the soil reserves are depleted, or over-fertilization. Therefore, soil fertility evaluation is one area that needs immediate attention since the reduction in the productivity of several crops is due to ever-decreasing soil fertility on one hand and an imbalanced application of plant nutrients on the other. Though the number of mineral nutrients required by plants is large and the availability of most of these nutrients varies depending on soil type, climatic condition and the type of crop grown, the nutrients usually included in fertilizer experiments up to now are macronutrients in particular nitrogen (N) and phosphorus (P). However, if the level of any one of the other essential nutrients, macronutrients as well as micronutrients falls below the critical level, the yield response to nitrogen and phosphorus will be seriously affected.

In Ethiopia commercial fertilizer mainly in the form of urea and DAP was introduced in the 60s by higher learning institutions through limited laboratory and research activities (Murphy, 1968). This was followed in the early 70s by nationwide on-farm demonstrations trials and as a result of these works a blanket rate of 100kg /ha (18-46kg/ha N-P2O5) or 50kg/ha Urea + 100kg DAP/ha(41-46 N-P2O5) were recommended irrespective of crop and soil types (EPID,1970).

Research continued from mid-70s onwards and recommendations specific to some soil types and crops were made. However, fertilizer trials carried out between 1975 and

1990 were conducted on few research stations, and little effort was made to extrapolate the results to a wider range of environments. The only exception was NFIU/ADD (National Fertilizer Input Unit and Agricultural Development Department of the Ministry of Agriculture) fertilizer trials which were conducted over wider geographical areas with the presumption that N and P in that order are the only plant nutrients that limit crop growth (ADD/NFIU Joint Working Paper No. 43, 1992).

NFIU made recommendations for different crops based on soil colors, and soil types by region and showed the profitability of fertilizer use in different crop and soil situations. It also suggested the application of more N than P i.e., 1:1 Urea and DAP application. Nevertheless, the NFIU trials were agronomic in nature and the soil test data gathered were of very limited value with regard to the development of soil test-crop yield response curves. As a result, the translation of the yield data from multi-location field trials into a site-specific rate of fertilizer recommendations was a problem. Since 1995, blanket fertilizer recommendation, 100 kg urea ha-1(46-0-0) and 100 kg DAP ha-1 (18-46-0) was reinstated as the sole fertilizer recommendation in the country despite criticisms. Even though micronutrients are as essential as macronutrients to increase crop production, they have not been applied regularly to the soil in conjunction with common fertilizers.

ROLE OF MICRONUTRIENTS IN PLANT NUTRITION

All plants must obtain a number of inorganic mineral elements from their environment to ensure the successful growth and development of both vegetative and reproductive tissues. These minerals serve numerous functions: as structural components in macromolecules, as cofactors in enzymatic reactions, as osmotic solutes needed to maintain proper water potential, or as ionized species to provide charge balance in cellular compartments (Michael, 2001).

There are seventeen chemical elements known to be essential for plant growth. Each essential plant nutrient is needed in different amounts by the plant, varies in mobility within the plant, and varies in concentration in harvested crop components. From the seventeen chemical elements carbon (C), hydrogen (H), and oxygen (O) are non-mineral nutrients because they are derived from air and water, rather than from soil. Although they represent approximately 95% of plant biomass, they are generally given little attention to plant nutrition because they are always in sufficient supply. However, other factors such as soil management and the environment can influence the availability and crop growth response (Agustin et al., 2014).

The remaining fourteen elements come from the soil and are classified as macronutrients and micronutrients based on their relative abundance in plants. The macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). Compared with macronutrients, the concentrations of the eight micronutrients iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), chloride (Cl), molybdenum (Mo), and nickel (Ni) are very small. Four additional elements, sodium (Na), cobalt (Co), vanadium (Va), and silicon (Si), have been established as essential micronutrients in some plants. Micronutrients are often referred to as minor elements, but this label does not mean that they are less important than macronutrients. Micronutrient deficiency or toxicity can reduce plant yield just as macronutrient deficiency or toxicity does (Havlin et al., 2010).

Most of the micronutrients are associated with the enzymatic system of plants. Whenever a micronutrient is deficient the abnormal growth of plant results which sometimes cause complete failure of the plants. Grains and flower formation do not take place in severe deficiency (Nazif et al., 2006).

Iron is required for the formation of chlorophyll in plant cells. It is essential in plant biochemical processes such as photosynthesis, respiration, symbiotic nitrogen fixation, hormone biosynthesis, and pathogen defense. Deficiency may occur if soils have high pH and high manganese content, especially under cold, wet conditions when uptake is reduced. Deficiency symptoms reflect iron's role in chlorophyll production and include interveinal chlorosis of young leaves, with a sharp distinction between the veins and other areas of the leaf. The entire leaf will become whitish-yellow as the deficiency develops, and then die (msucares.com/pubs/infosheets/is1038.pdf)

Manganese functions as an activator of an enzyme that is involved in the evolution of oxygen in photosynthesis. It is a component of several enzyme systems. It also functions as part of oxidation-reduction reactions and electron transport systems. It is a structural component of certain metalloproteinases. Most crops deficient in Mn become yellowish to olive green, but the pattern of symptoms varies among species. Because Mn is immobile in the plant, deficiency symptoms tend to be on the new young growth but may occur more generally over the plant. Excess available Mn occurs in acid soils with a pH of 5.5 or less, especially for soils low in organic matter and temporarily waterlogged. High Mn levels are most likely to occur in acid, sandy soils. Distorted leaves and dark specks on leaves are symptoms of Mn toxicity. As severe toxicity increases, leaf tissue begins to die at the leaf margins and progresses inward on the leaf (Regis, 1998).

Zinc is important in several plant enzyme systems for protein synthesis and energy production. It maintains the structural integrity of bio-membranes. It is involved in the synthesis of indoleacetic acid, an important plant growth regulator. It is estimated that more than 1,200 proteins contain, bind, or transport zinc. It is important in internodes elongation. Zinc deficiencies may occur on well-limed, sandy loam soils. Zinc-deficient leaves show interveinal chlorosis, particularly between the margin and midrib, which creates a striping effect. Because zinc plays a major role in internodes elongation, zinc deficiency will cause plants to be stunted (msucares.com/pubs/ infosheets/is1038.pdf)

Copper is involved in the activation of several enzyme systems and apparently cannot be replaced by other metal ions. It is involved in cell wall formation. It is necessary for protein synthesis and a deficiency causes a buildup of soluble nitrogen compounds. Copper deficiency in many plants shows up as wilting or lack of turgor and the development of a bluish green tint before leaf tips become chlorotic and die. Copper toxicity often results in plant stunting, a bluish tint to leaf color, and leaf cupping followed by leaf chlorosis or necrosis. Toxic levels in soil reduce seed germination, shoot vigor, and iron availability (Regis, 1998).

Boron is important in many plant processes, including protein synthesis, translocation of sugars and nutrients, respiration, and metabolism of plant hormones. More than 90 percent of plant boron is located in the cell walls. It is non-mobile in plants, and a continuous supply is needed throughout the growing season. Boron is more likely to be deficient under dry conditions on low exchange capacity, and well-limed soils. Deficiency symptoms include chlorosis of young leaves, death of the terminal buds, and initiation of secondary lateral buds (msucares.com/pubs/ infosheets/is1038.pdf)

Chlorine (chloride) takes part in the capture and storage of light energy through its involvement in photophosphorylation reactions in photosynthesis. It is not present in the plant as a true metabolite but as a mobile anion. It is involved with K in the regulation of osmotic pressure, acting as an anion to balance cations. Deficient plants wilt more readily. Bronzing of leaves can occur. Chloride suppresses some diseases on small grains and can reduce the impact of diseases such as take-all root rot, stripe rust, leaf rust, tan spot, and Septaria leaf spot. Toxicity from chloride results from excessive application of chloride salts or from high chloride levels in irrigation water. Usually, the effect is a "salt effect" from the high concentration of soluble materials, including cations, in the soil solution, which inhibits the uptake of water by plants causing them to wilt. The salt effect is more prevalent than plant uptake of excess chloride (Regis, 1998).

Molybdenum is a part of the nitrate reductase enzyme that is involved in the reduction of nitrate to ammonium after nitrate is taken up by the plant. It is also a structural component of the enzyme nitrogenase, which is involved in the fixation of atmospheric nitrogen into ammonium in a symbiotic relationship with legumes. The amount required by plants is very small. The first symptom of Mo deficiency is shown as an N deficiency (light yellow-green leaves) because Mo is required for N fixation by leguminous plants and for the conversion of nitrate to organic N in all plants. If the deficiency is severe, the leaf edges of some crops may turn brown and curl upward, termed cupping. Plants are tolerant of high soil Mo concentrations and toxicity to plant growth would be rare (Regis, 1998).

Nickel was reported as an essential nutrient in the early 1980s for some enzymes involved in seed germination. Deficiency symptoms include poor seed germination, chlorosis, and interveinal chlorosis in young leaves that move to tissue death. (msucares.com/pubs/infosheets /is1038.pdf)

SOURCES OF MICRONUTRIENTS AND FACTORS AFFECTING THEIR AVAILABILITY

Sources of micronutrients

The main sources of micronutrients are parent material and organic matter. These nutrients are present in small amounts ranging from a few mg kg-1 to several thousand mg kg-1 in soils. Inorganic micronutrients occur naturally in soil minerals. The parent material from which the soil developed and soil forming processes determine what the micronutrient content of the soil will be. As minerals break down during soil formation, micronutrients are gradually released in a form that is available to plants. Two sources of readily available micronutrients exist in soil: nutrients that are adsorbed onto soil colloids (very small soil particles) and nutrients that are in the form of salts dissolved in the soil solution (www1.agric.gov.ab.ca/$department/deptdocs .nsf/all/agdex713)

Organic matter is an important secondary source of some micronutrients. Most micronutrients are held tightly in complex organic compounds and may not be readily available to plants. However, they can be an important source of micronutrients when they are slowly released into a plant available form as organic matter decomposes (www1.agric.gov.ab.ca/$department/ deptdocs.nsf/all/agdex713).

Factors that affect the availability of micronutrients

There are many soil and environmental factors that affect the availability of micronutrients to plants. The primary factors include parent material, soil reaction or soil pH, soil texture, organic matter content and nutrient interactions (Brady and Weil, 2002).

1. Parent material

The micronutrients in the soil and their availability to plants are determined by the minerals contained in the original parent material and by the weathering processes that have taken place over the years. In general, the leached highly weathered soils of warm, moist regions contain smaller amounts of micronutrients than soils in cool, dry regions. There are exceptions, however, and the total amount of an element in soils is usually a poor indication of the amount available for plant uptake. The amount of each micronutrient in the soil varies considerably. Micronutrient deficiencies usually occur because sufficient amounts are not soluble and available to the crop and not because of insufficient amounts in the soil. Iron (Fe), for example, is one of the most abundant elements in soils. Some Oxisols are high in iron content, yet need iron fertilization for the profitable production of pineapple (Foth, 1990).

2. Soil pH

Micronutrient availability is greatly influenced by soil pH. As pH increases from 4 to 7, zinc, iron, manganese, copper, and boron decrease in solubility and availability, while molybdenum increases in solubility and availability. When soil is in the pH range of 6 to 6.5, most micronutrients are moderately available for plants. On severely acidic soils, pH below 5 manganese and aluminum are quite soluble and are often taken into plants in toxic amounts. Conversely, molybdenum is insoluble, and deficiencies often occur in these low-pH soils. At a pH of 5 to 5.5, certain plants may experience manganese toxicity and molybdenum deficiency. Soil pH values over 7 reduce the availability of boron, zinc, iron, and manganese, resulting in deficiencies (Hansch and Mendel, 2009).

3. Soil texture

Coarse textured soils. i.e. sandy soils, tend to be low in boron and copper is often low in leached calcareous soils. Poorly drained soils usually have poor aeration that contributes to iron, zinc and manganese deficiencies. Cool weather combined with poorly drained soils accentuates iron and zinc deficiency occurrences because of poor root growth. Under dry soil conditions, boron deficiencies are increased and molybdenum deficiencies tend to be more severe because less mineralization occurs and less soluble B is available (Regis, 1998).

4. Organic matter content

Low organic matter soils are low in boron and often low in zinc, especially sandy soils. Organic matter may form natural chelates aiding in maintaining iron in a soluble form. High organic matter content provides more available boron to plants but decreases copper availability due to the strong bonding of copper to organic matter and may tie up manganese into unavailable organic complexes (Regis, 1998).

5. Nutrient interactions

Other elements may affect the availability of most micronutrients. High amounts of phosphorus in soils borderline in copper, zinc, iron and manganese may reduce their availability and/or uptake by plants. Applications of: iron and zinc may reduce copper availability; copper, manganese and zinc may reduce iron availability; and copper, iron and zinc may reduce manganese availability. Applications of potassium may increase boron deficiency on soils low in boron, but high calcium availability increases the capacity of plants for boron. Soils high in iron and aluminum oxides tend to be low in molybdenum, but these soils also are highly weathered and frequently acidic. Plants and varieties are frequently different in their sensitivity to a particular micronutrient deficiency. Some crops are more sensitive than others and some varieties within a crop may exhibit a particular micronutrient deficiency while others do not even though the growing conditions are the same (www.agronext.iastate.edu/soilfertility/.../Micro nutrients_VossArticle.pdf).

CURRENT STATUS OF MICRONUTRIENTS AND KNOWLEDGE GAPS IN ETHIOPIAN AGRICULTURE FOR ENSURING FOOD SECURITY

Soil fertility decline is considered as an important cause of low productivity of many soils in sub-Saharan Africa (Lal, 1989; Sanchez, 2002). In particular, soil degradation such as soil nutrient depletion and physical degradation becomes a serious problem for agricultural productivity in Ethiopia (Fassil and Yamoah, 2009).

In Ethiopia, the role of micronutrients in crop production has not yet been studied systematically, except in the study on micro and macronutrient distribution in the Ethiopian Vertisols landscape (Fisseha, 1992) and investigation done by Desta (1983) in which considerable variation in micronutrient contents of soils and crops was reported. Manganese and iron levels were usually adequate, but zinc content varied from low to high and copper seemed to be deficient. However, what was satisfactory for traditional and subsistence agriculture will not remain satisfactory for modern agriculture based on the increased use of inputs required for high production levels. The micronutrient deficiency problems will grow in number and intensity of occurrence and become more serious, first on those soils inherently deficient in the specific micronutrients, and later even on those soils that are presently marginal in micronutrient supply.

In Ethiopia in the past, few investigations (Sillanpaa, 1982; Godfrey et al., 1987; Fekadu, 1987; Saleh et al., 1990) were either incidental or exploratory in nature, which made it difficult to obtain a real assessment of the magnitude of micronutrient problems. Due to these factors, there is very little information available in Ethiopia about micronutrient levels in soils. Tests for micronutrients based on soil extraction are not in routine use as an aid for predicting micronutrient deficiencies. Schutte and Amdurer (1960) stated that deficiencies of micronutrients could be severe in tropical soils that had been fully weathered and had been strongly leached in humid climates. Also, it would be expected that as farming becomes more intensive, high-yielding crop varieties were introduced and more nitrogen, phosphorus and potassium fertilizers were used, deficiencies of micronutrients might become a more serious fertility problem.

Even though micronutrients are as essential as macronutrients to increase crop production, they have not been applied regularly to the soil in conjunction with common fertilizers, especially in less developed countries like Ethiopia. On the other hand, FAO (1983) reported that increased yields through intensive cropping and use of high-yielding varieties, losses of micronutrients through leaching, liming, and a decreasing proportion of farmyard manure compared with chemical fertilizers and several other factors are contributing towards accelerated exhaustion of the available micronutrients. The same suggested that hidden micronutrient deficiencies are far more widespread than is generally estimated and the problems which today may be considered local, may well become more serious in the relatively near future, occurring extensively over new areas and creating widespread and complicated production restrictions if they are not properly studied and diagnosed in time.

It has been reported that, in spite of favorable development in the use of nitrogen and phosphorus fertilizers to increase crop production two to six times more of the micronutrients are being removed annually through crop harvest from the soil than are applied to it in soils of India (Katyal and Randhawa,1983). This could be significant, particularly in Ethiopia, where there is no micronutrient application toward soil in the form of chemical fertilizers or organic elements (Asgelil et al., 2007).

Berhanu (1997) carried out a study on the Nitosols of western Oromia and reported a deficiency of available Mo. Teklu et al. (2005) also indicated that the status of Fe, Zn, B and Mo were in the sufficient range whereas Cu status was in the deficient range in Andisols of Rift Valley. According to the same authors about 1.9% of the Nitisols of Western Ethiopia were deficient in Fe whereas 5.6% of the Nitisols were deficient in Cu. Zn status of all of the Nitisols under evaluation was in the deficient range whereas 31.9% of B and 4.4% of Mo are also deficient for maize production.

Recent studies also indicated that Zn and Cu are deficient in most soils, while Fe and Mn are generally above the critical limit and in some cases, Mn toxicity was noted (Asgelil et al., 2007). The Zn deficiency was the largest in Vertisols and Cambisols (78%), and the lowest in Nitisols, whereas Cu deficiency was the highest in Fluvisols and Nitisols with values of 75 and 69 %, respectively, (Asgelil et al., 2007). With respect to major crops, it was found that teff, wheat, maize and citrus showed no deficiency of Fe and Mn, whereas the deficiencies of Zn and Cu were severe ranging in values from 43 to 87% of the samples analyzed (Asgelil et al., 2007). This indicates the need for systematic investigation of the status of micronutrients and each soil type should be treated differently.

According to Wondwosen and Sheleme (2011), from micronutrients, Cu is the most limiting nutrient to support maize growth and development under Alfisols of southern Ethiopia. A similar study revealed micronutrient deficiencies with the alkaline Andosols in the central rift valley of Ethiopia (Abera and Wolde-meskel, 2013). Yifru and Mesfin (2013) also indicated that Fe and Zn appeared to be deficient in Akaki, Gimbichu, Ada'a, Lume and Minjar-Shenkora whereas copper is above the critical levels in all samples collected. On the other hand, Mn falls in sufficient range at Akaki, Ada'a and Minjar-Shenkora, but is deficient in 40% and 70% of soil samples from Lume and Gimbichu districts.

In addition, the recent characterization study conducted by Ethiopian Agricultural Transformation Agency (2013) indicated that soils from many locations in Ethiopia are deficient in micronutrients. With this regard, Fe, Mo and Zn contents vary widely among diverse Ethiopian soils across different agroecologies.

Currently, more attention is being given to fertilizing soil with micronutrients in many Sub Saharan Countries including Ethiopia due to many reasons such as crop's positive response towards micronutrients, long-time cropping has removed large amounts of these nutrients, widespread use of animal manures has been decreased, topsoil erosion has been removing certain micronutrients, spatial variability of micronutrients has been recognized and more concentration is being given to crop quality and nutritional value of crops (Fisseha, 1992).

CONCLUSION

A review of the past fertilizer trials on annual crops did not provide sufficient information to formulate reliable fertilizer recommendations. The main reasons encompass lack of basic data on crop nutrient requirements, climatic and soil conditions at trial sites.

Numerous crop response trials have been conducted in the country but little is known about nutrients available in the soil, the changes in nutrient status brought about by residual fertilizer, or the levels of nutrients that are needed to produce economically optimal yields of the crops. Moreover, many trials were carried out for only one or a few consecutive seasons and hence the stability of responses over seasons and the resulting implications for risks and long-term nutrient monitoring haven't received attention. We need to pay more attention to fertilizer-use efficiency of the limited amounts that farmers can buy, instead of basing fertilizer recommendations on the face value of agronomic responses, which often suggests large requirements for inorganic fertilizers. The risk of a nutrient-limiting crop yield must be balanced against cost and impact on the balance of nutrient levels in the soil. This call for site-specific assessment of both the agronomic and environmental risks is to determine a rate of nutrient application that maximizes its beneficial use.

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