

4.6 Micronutrients

Eight of the seventeen elements that are essential for plant growth are micronutrients. On soils with micronutrient deficiencies, the application of small amounts of these nutrients can greatly enhance crop production. The micronutrients are: Boron (B), chlorine (Cl), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). The term micronutrient does not imply that these elements occur in 'micro' amounts in rocks and soils. Two of the eight micronutrients, Fe and Mn, are among the most abundant elements in the earth's crust. The other six elements occur in concentrations of less than 0.1%, they are 'trace elements.' The term micronutrients only means that these elements are required in very small amounts by plants. In addition, there are other elements that are, in small amounts, helpful but not essential for the growth of certain plants, such as silicon (Si), vanadium (V), nickel (Ni) and sodium (Na). Small amounts of other elements, including chromium (Cr), tin (Sn), iodine (I), and fluorine (F) are essential for animal growth.

While the micronutrients are required in small amounts, they may be harmful when added to the soil in high amounts. There is a small 'window' of concentration of these elements where plant growth is optimal. Taking molybdenum as an example, it can be shown that the addition of 35-70 g Mo ha⁻¹ to specific soils will be beneficial to soils and plants. However, if applied at rates exceeding 3 kg Mo ha⁻¹ some plants may show toxicity signs. In addition, at these high rates the concentration in the forage may become toxic to animals consuming these plants. It is important to know the original concentration of micronutrients in the soils and add only as much of the micronutrient as is beneficial to plants and foraging animals.

The replenishment of micronutrients through fertilizers or other amendments is still in its infancy in many tropical countries. In most fertilizer applications, only the macronutrients are applied although cropping, erosion and leaching also remove micronutrients from the soils. Some of the nutrients 'lost' through harvesting, erosion or leaching are replenished by the return of organic residues, through farmyard manure and other organic matter.

The availability of micronutrients is influenced not only by the total amount of micronutrients but also by soil factors such as pH, soil texture, organic matter content, moisture, oxidation/reduction condition and others. The most obvious relationship is between total micronutrient concentration and parent material.

Micronutrients in soils of sub-Saharan Africa

Few accounts have been published of the micronutrient status of soils in sub-Saharan Africa (Schutte 1954; Sillanpaae 1982; Kang and Osiname 1985). Ironically, large numbers of soil samples from sub-Saharan Africa have been analyzed on their 'trace element' contents. These soils data outlining metallic trace element concentrations have been collected by geologists and geochemists from national geological surveys, international organizations and private exploration companies. Exploration geochemists commonly use trace element soil survey data as indicators to higher metal concentration and metal deposits. By and large, however, these trace element data compiled by geochemists have not been shared among the scientists of the two principle disciplines of agogeology, geology and agriculture.

In sub-Saharan Africa, micronutrient deficiencies or toxicities 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. Kang and Osiname (1985) provide examples of common micronutrient deficiencies in sub-Saharan Africa. The worldwide study by Sillanpaae (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.

Boron deficiencies have been reported mainly from research on cash crop oil palm and cotton-growing areas in West and East Africa (Kang and Osiname 1985), and response to boron fertilization has been reported in forestry research. A statistically significant reduction of 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).

Few systematic studies have been undertaken to determine the distribution of chlorine in soils of sub-Saharan Africa, although a preliminary survey of savanna soils of Nigeria indicates that about eighty percent of these soils may be chlorine deficient (Raji and Jimba 1999).

Cobalt is required by nitrogen-fixing microorganisms. It is an essential element for N-fixing legumes. In animal health, the lack of cobalt in forage plants can lead to muscular 'wasting' and death in ruminants. In New Zealand this deficiency-induced disease is called 'bush-sickness;' in Australia it is the 'coast disease' or 'wasting disease,' and in Kenya it is called 'Nakuritis' (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 proved a good source for iron on alkaline soils (Bangar *et al.* 1985). Barak *et al.* (1983) successfully used finely ground basalt and volcanic tuff from a local quarrying operation that contain several percent Fe as Fe (II) to remedy chlorosis of groundnuts (*Arachis hypogaea*) in calcareous soils.

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

Molybdenum, essential for nitrogen fixation through symbiotic microorganisms, 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) describe 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, 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 becomes 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).

Micronutrient resources

Natural abundances of micronutrients are closely linked to rock types. For example, igneous ultramafic and mafic rocks (pyroxenites, basalts) contain generally higher amounts of Cu, Co, Fe, and Mn than silica-rich granites. Several sediments are enriched in micronutrients; for example black shales contain elevated concentrations of boron and other trace elements. In general, basalts and shales are rock types with abundant micronutrient elements.

The highest concentrations of micronutrient elements found in rock-forming minerals.

- Boron occurs in tourmaline, in clay minerals and evaporate salts (borax, colemanite, kernite, ulexite) in desert playas,
- Chlorine is the primary component of common salt, halite (NaCl), and sylvite (KCl),
- Cobalt is common, in small amounts, in ferromagnesian silicates substituting for Fe, or associated with Mn oxides, or in sulfides, carbonates, and in marine Mn-nodules,
- Copper is a component in the sulfides chalcopyrite (CuFeS_2), bornite (Cu_5FeS_4), chalcocite (Cu_2S), or occurs as carbonates (malachite $\text{Cu}_2(\text{OH})_2\text{CO}_3$ or azurite $\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$),
- Iron occurs as constituent of certain silicates, and is the main metal compound in the Fe-oxides hematite, magnetite, goethite/limonite, as well as in the sulfides (mainly pyrite FeS_2),
- Manganese occurs mainly as oxides (pyrolusite MnO_2 , hausmannite Mn_3O_4 , manganite MnOOH), and less abundantly, as Mn-carbonates and in Mn-silicates,
- Molybdenum occurs as sulfide (MoS_2), and more rarely as molybdite (MoO_3) or as powellite (CaMoO_4) in hydrothermal veins,
- Zinc occurs as sulfide ZnS , carbonate (smithsonite ZnCO_3) or, in small amounts, in magnetite and silicate.

Most micronutrient element resources are of geological origin, derived either from primary ore or as a by-product. While some of the borates and chlorides can be concentrated and processed simply by dissolution in hot water (borax, halite, sylvite) or calcination (for colemanite), most micronutrient resources have to be processed by hydrometallurgical or pyrometallurgical processes to get them into a soluble form.

Commercial micronutrient fertilizers are generally manufactured as by-products or intermediate products of metal mining and processing industries. There are only a few large mineral deposits of micronutrients in sub-Saharan Africa, mainly iron oxide deposits and manganese oxide deposits, as well as copper/cobalt and zinc sulphide deposits. Only a few boron and molybdenum occurrences are known in sub-Saharan Africa. However, it should be kept in mind that only small amounts (traces) of these elements are needed to correct deficiencies. One kg of molybdenite (MoS_2), for example, contains about 600 g Mo. Obviously, molybdate would have to be subjected to an oxidizing environment to get it into a plant available form. But, on a total Mo basis, the 600 g of molybdenum would be enough to provide additional molybdenum to 10-20 hectares at a rate of 30-60 g total Mo per hectare. Currently, molybdenum fertilizers are sodium and ammonium molybdates that are either applied with commercial fertilizers or applied in the form of treated seeds.

Many of the existing mining and processing of metal deposits produce micronutrient-rich 'wastes,' which should be investigated on their suitability to remedy local micronutrient deficiencies. Examples for cobalt-rich 'wastes' include the 'waste-pyrites' at Kilembe mine in Uganda with 1% Co and many old mine tailings in the Democratic Republic of Congo. These materials need careful geochemical screening before testing on land to avoid introducing toxic elements to the soils.

Since only small amounts of nutrients are necessary to overcome micronutrient deficiencies it will be useful to test the application of organic wastes, which are commonly high in micronutrients, or to apply trace element rich rock wastes, for example quarry fines from basalt or 'black granite' (dolerite) operations. The mean micronutrient concentration (in mg kg^{-1}) of basaltic rocks are: B = 5; Cl = 60; Co = 50; Cu = 100; Fe = 86,000; Mn = 2,200; Mo = 1; and Zn = 100. Micronutrient concentrations in common shales are, in mg kg^{-1} : B = 100; Cl = 180; Co = 20; Cu = 50; Mn = 850; Mo = 3; and Zn = 100 (Levinson 1974). Organic-rich 'black shales' contain much higher concentrations of micronutrients. In fact the average Mo content of black shale is 70 mg Mo kg^{-1} (Ure and Berrow 1982). Disadvantages of using these rock materials are the large amounts needed to provide the micronutrients in the field, the availability of these resources close to the area where they are needed, and the value-to-cost ratio.