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Soil Micronutrients

Under traditional systems of agriculture in the humid tropics, micronutrient deficiencies are seldom a limiting factor in crop production.* The long fallow period in shifting agriculture in both forested and the savanna areas usually regenerates in the plant material returned to the surface soil sufficient micronutrients and macronutrients to supply the needs of subsistence crops. The use of refuse, composts, and animal manures where available also provides a good source of micronutrients to the surface soil. The low crop yields obtained under shifting agriculture require such small amounts of micronutrients that their importance in crop production in the humid tropics has been obscured.

Only with the advent of modern technology and intensification of crop production in the humid tropics has there been an awareness of the need for supplying one or more of the micronutrients along with other fertilizers. The increased productivity of commercial export crops in the tropics with the use of high-yielding varieties and the greater use of nitrogen, phosphorus, and potassium fertilizers has

*The term "micronutrients" is used in this chapter to refer to the plant nutrients zinc, copper, boron, molybdenum, iron, and manganese. Other terms commonly used in the literature to refer to these elements are "trace elements," "minor elements," and "oligoelements."

brought into sharper focus the need for greater attention to the micronutrient supply. Reports on deficiencies of zinc, molybdenum, boron, and other micronutrients in commercial plantings of coffee, cacao, rubber, oil palm, sugarcane, pineapple, citrus, and other crops grown extensively in the humid tropics are becoming more common (for example, Aldrich, 1960; Ananth *et al.*, 1965; Bould, 1968; Chapman, 1966; DuToit, 1963; Fox, 1969; Jordine, 1962; Lott *et al.*, 1961; Mestanza and Lainez, 1970; Muller, 1959; Newton and Said, 19[illegible]; *Plant Analysis and Fertilizer Problems*, 1954–1964; Tollenar, 19[illegible]6; Vicente-Chandler *et al.*, 1968). Reports on micronutrient deficiencies of annual food crops are less common, but undoubtedly the increased use of nitrogen, phosphorus, and potassium fertilizers on high-yielding varieties will stimulate a need for the application of micronutrients (Nye, 1966).

Sauchelli (1969) in his book *Trace Elements in Agriculture* reviews the background on the use of micronutrients for crop production and the soil-plant and animal interrelationships. He makes the point that, with the increasing use of higher and higher analysis fertilizers containing less micronutrient impurity, it would be expected that there would be a greater requirement for supplementary micronutrients. Also, the present limited use of organic fertilizers, which in the past usually furnished a sufficient supply of micronutrients, tends to accentuate the need for these elements.

GEOGRAPHIC OCCURRENCE OF MICRONUTRIENT DEFICIENCIES

Extensive soils in the humid tropics are formed on old land surfaces, and they have a very low natural fertility. Where these soils have a favorable topography and are deep, permeable, and well drained, they have a high potential productivity under good soil management, which requires the substantial use of fertilizers including one or more micronutrients. However, most of the soils now under continuous cultivation in the humid tropics have a relatively good level of natural fertility and they are less likely to be deficient in micronutrients. These soils are formed from recent alluvium or young terraces, volcanic ash, basic igneous rock of relatively recent origin, and loessial deposits relatively rich in primary minerals (Hodgson, 1963). Usually, nitrogen, phosphorus, and potassium fertilizers and occasionally lime are required for high production on these soils, but the

natural micronutrient supply has generally been adequate for the level of production attained.

Africa

Investigations with micronutrients by Cunningham (1964) on cacao in Ghana did not indicate any yield response to applied zinc, molybdenum, boron, copper, manganese, and iron except under special circumstances. Later, Cunningham (1966) stated that there was no evidence to suggest that any micronutrients need to be included in the fertilizer applied to cocoa. However, he did go on to say that most of the good cocoa in Ghana is confined to the slightly acid to neutral forest Ochrosols, and it was on such soils that much of the fertilizer work was done.

The fact that much of the experimental work in Africa has been on soils fairly well supplied with micronutrients prompted Russell (1968) to state that there is very little evidence that crop yields are limited in any extensive areas of tropical Africa by either deficiencies or excesses of micronutrients. However, Russell did indicate that in isolated areas boron deficiency may become important: In an area in Kenya, the soil derived from a particular volcanic ash shower is low in copper; in some areas, zinc deficiencies have been found; and in some high-altitude pastures in Kenya, molybdenum deficiency has been recognized.

In his review of soil research in Tanzania, Le Mare (1970) states that boron deficiency probably occurs widely in Tanganyika, especially on light-textured soils in wetter areas. It has been observed on sisal in the northeastern part of the country, and slight symptoms of the deficiency occur widely on cotton in the western area. On Ukerewe Island, a severe deficiency occurs, and cotton has given yield responses to applications of boron. Dieback in wattle, pines, and coffee in southern Tanganyika has been cured by boron or boron plus zinc. With the occurrence of dieback on other perennial crops and ornamental trees, Le Mare postulates that a micronutrient deficiency may be the cause of the trouble.

In a survey of minor element deficiencies in Africa, Schütte (1954) reports that they are widely distributed throughout Africa. About 80 percent of the agricultural land in South Africa shows some minor element deficiency. Citrus orchards especially show deficiencies of zinc, boron, copper, and manganese.

Chaminade (1970) has reviewed the agricultural research work car-

ried out by the Institut de Recherches Agronomiques Tropicales et de Cultures Vivrières in Africa, and there is not much indication of response to micronutrients on the soils investigated. However, in field tests to determine response curves for nitrogen, phosphorus, and potassium, there seem to be differences in the magnitude of responses to the macronutrients on the different soils, which indicates that other limiting factors, such as an insufficient supply of micronutrients, may be operating.

In the cultivation of groundnuts in northern Senegal, Nutramin containing iron, manganese, copper, zinc, boron, and molybdenum applied at the rate of 3 kg/ha markedly increased yields. Factorial experiments showed the active element to be molybdenum, and ammonium molybdate at 28 g/ha gave responses as good as those obtained with Nutramin at 3 kg/ha (Martin and Fourrier, 1965). Stephens (1959) investigated the responses of annual food crops to manganese, boron, copper, magnesium, iron, zinc, and molybdenum at 10 agricultural stations in Ghana in small-scale and factorial field trials. The only favorable response was a small one to molybdenum by groundnuts.

In field trials in northern Nigeria with cotton and maize on a well-drained, acid ferruginous soil formed over acid crystalline rock, Heathcote (1970) got increased yields from applications of lime. Foliar analysis and other evidence indicated that the increased availability of molybdenum may account for much of the response due to liming. Trace-element analysis of leaf samples from the 1967 cotton crop showed that molybdenum increased from 0.05 to 0.24 ppm while boron, copper, and zinc did not increase much, if at all, though these elements were applied.

To sum up, this sampling of references and some others (Bouyer, 1963; Calton and Vail, 1956; Chenery, 1958; Duthie, 1953; Jackson *et al.*, 1967; Peive, 1963; Stephens, 1969) on micronutrient deficiencies in Africa indicate that more and more micronutrient deficiencies are being recognized in a wide variety of crops on a wide range of soils. This is especially true of acid soils that have a relatively low reserve of micronutrients and that are under continuous cultivation and improved cultural practices and are receiving relatively high applications of nitrogen and phosphorus fertilizers. As diagnostic techniques are perfected, greater attention will undoubtedly be given to micronutrient deficiencies and their control. Apparently, molybdenum, zinc, and boron deficiencies are the most prevalent, but copper, manganese, and iron deficiencies have oc-

casionally been identified under particular conditions. On acid soils high in manganese, instances of manganese toxicity have been reported.

Asia

Considerable work has been done in India on micronutrient deficiencies of various crops and on the micronutrient status of different soils (Ananth *et al.*, 1965; Eswarappa *et al.*, 1969; Govinda *et al.*, 1964; Jain and Mehta, 1963; Kanwar, 1964; Nair and Mehta, 1959; Newton and Said, 1957; Randhawa and Kanwar, 1964). This work has been reviewed in a publication on micronutrient research in soils and plants in India (Kanwar and Randhawa, 1967). Much of the micronutrient research in India has been on soils relatively well supplied with micronutrients and on neutral to alkaline soils. On alkaline soils, zinc deficiency is widespread in several states on a variety of crops, including the cereals (Rahaja *et al.*, 1959). Manganese deficiency is also common on alkaline soils. In a study on 44 surface soils and subsoils in Uttar Pradesh, many had relatively low levels of "available" (hot water extractable) molybdenum, which could be in the deficiency range (Pathak *et al.*, 1968).

In his review of investigations on the fertility and management of the soils of Malaysia, Coulter (1970) cites several articles on micronutrient deficiencies in rubber, oil palm, pineapple, and cocoa. They were mainly zinc and boron deficiencies, but copper deficiency in the field was reported on peat soils. There were no reports on molybdenum deficiency in the field. In pot experiments with three soil types, Watson (1960) found that the uptake of molybdenum at pH less than 5 was low enough to limit growth. Liming the soil to pH 6 increased the molybdenum content of the plant and increased dry weight production. Molybdenum deficiency of groundnuts has been reported on the Latosols of Java (Newton and Said, 1957). Applications of various combinations of phosphorus, potassium, lime, and trace elements indicated a response to molybdenum. Sodium molybdate applied at the rate of 1 kg/ha increased yields and improved nodulation of the roots.

Latin America

Dramatic responses have been obtained to the application of micronutrients to crops on the Campo Cerrado soils in the central plateau

area of Brazil. These soils have been developed mostly from parent materials of ancient sediments and are highly weathered and leached, but they generally have good surface and internal drainage and favorable topography. The dominant vegetation is grass with scattered shrubs and small trees, and the climate is characterized by a strong wet-dry cycle with a mean annual rainfall of about 1,500 mm. It is estimated that there are about 160 million hectares of land in the central plateau of Brazil with this kind of vegetation and climate.

Zinc deficiency of corn was first noted in the Campo Cerrado near Matão, in the state of São Paulo, in a commercial planting that had been fertilized with nitrogen and phosphorus (Igue and Gallo, 1960). The symptoms were corrected by either foliar sprays or soil applications. In subsequent field tests on similar adjacent soils previously uncultivated, zinc applications increased yields, but in two cases there was no yield increase though the zinc deficiency symptoms were corrected. A nearby area fertilized with only nitrogen, phosphorus, and sulfur produced moderately well and had no zinc-deficiency symptoms.

In subsequent experiments on Campo Cerrado soils in Brazil, zinc, boron, and molybdenum applied in combination to supplement nitrogen, phosphorus, potassium, and lime treatments increased seed cotton yields 72 percent on a deep sandy soil, 12 percent on a Yellow Latosol, and 41 percent on a Dark Red Latosol (Mikkelsen *et al.*, 1963). Maize yields were increased 41 percent, 17 percent, and 5 percent on these same soils by the added micronutrients. No attempt was made to separate the effects of the three micronutrients. In two other field experiments on previously uncultivated Humic Latosols, one near Anápolis, Goiás, and one near São Joaquim, São Paulo, a definite response to zinc applications by soybeans was obtained in the first location and not in the second (Freitas *et al.*, 1960). No response was obtained from application of molybdenum in either location. With maize, there was a significant depression in yield in the minus zinc plots. In general, the results of these experiments were inconclusive and indicate considerable differences in responses to micronutrients by the different crops in the different locations.

Similar conclusions were drawn from results of cotton fertilization experiments on Campo Cerrado (McClung *et al.*, 1961). There were significant yield differences in a few experiments with boron and molybdenum, and though zinc deficiency was noted in some plots, there was no yield response to zinc. No clear-cut pattern of response to applications of micronutrients was apparent, but it was suggested

that this area of soil fertility research on the Campo Cerrado soils deserves closer attention.

Boron deficiency has been reported for several crops on some volcanic soils in Ecuador (Tollenar, 1966). In a field trial on a sandy loam to loam soil of pH 6.2, a boron spray corrected leaf symptoms of cacao and increased yields (Mestanza and Lainez, 1970).

Using the missing-element technique in greenhouse studies, Martini (1969, 1970) studied a number of Andosols and Latosols of Costa Rica. He concluded that both groups of soils were low in micronutrients, showing significant deficiencies, especially under successive cropping and fertilization with nitrogen, phosphorus, and potassium. Among other recommendations, he suggested that work be intensified on the micronutrients, especially on the Andosols and Latosols.

The results of micronutrient research in Puerto Rico during the period 1949–1954 have been summarized by Landrau and Samuels (1956). In general, they found no consistent yield increases with the use of micronutrients. Deficiency symptoms of several of the micronutrients occurred on a number of crops without affecting yields. One marked increase in yield of pineapples resulted from the use of iron sprays and fritted trace elements. Some crops such as maize and plantains showed no yield response in any of the work on which Landrau and Samuels (1956) reported. More recent field experiments with plantains showed that soil applications of micronutrients on Lares clay (Aquic Tropohumult) significantly increased yields (Hernández and Lopez, 1969). Omission of both zinc and iron from foliar sprays significantly reduced yield. Recent field observations of severe zinc deficiency in fertilizer experiments with corn on two different soils in Puerto Rico illustrate the range of pH conditions under which zinc deficiency may occur. One soil is a sandy Oxisol with a pH less than 5 and the other is a clayey Oxisol with a pH over 6 and with free calcium carbonate in the lower subsoil.

GENERAL EVALUATION

From this brief review of the literature, it appears that no systematic or definitive study has been undertaken of the role of micronutrients in crop production in the humid tropics. There are many reports of the occurrence of deficiency symptoms of zinc, boron, molybdenum, manganese, copper, and iron, and of successful measures of control. In some cases, increased yields have been associated with control of the

symptoms, and in other cases they have not. This inconsistency of response to treatments characterizes many of the studies.

There are many difficulties in assessing the micronutrient investigations in the humid tropics with respect to the soil-plant relationship. One is the general lack of specific information on the characteristics of the soils under study. In many instances, no information at all is given on the kind of soil, merely the location. In other cases, a series or local name is given without any additional information. Sometimes a few chemical or physical properties of the soil, such as pH, texture, or drainage, are reported, but generally the information is limited and difficult to interpret. Commonly, the soil under study is described in terms of a broad group such as Latosols, which covers a rather wide range of characteristics.

Bleeker and Austin (1970) attempted to show the relationship between the total micronutrient content and a number of other soil variables in horizons of six texture-contrast soils from Papua-New Guinea. The soils were classified according to the new United States soil taxonomy. One conclusion of the study was that the variation in the behavior of the trace elements appears to be closely associated with the processes determining the differentiation of soil types. However, no attempt was made to evaluate the significance of the total amounts of the elements to their availability to plants. Other studies have also reported total micronutrient contents in soils without any follow-up on the soil-plant interrelationship.

One of the more definitive micronutrient studies was made in Hawaii on the relation of total and extractable zinc to the occurrence of zinc deficiency on soils classified at the great group level in the new United States soil taxonomy (Kanehiro and Sherman, 1967). Though a correlation at the 1 percent level of significance was found between the extractable and total zinc levels for all the soils studied, the correlation coefficient of 0.30 is not very conclusive. There appeared to be no consistent pattern in total zinc content among the highly weathered Oxisols and Ultisols, although, in general, they had relatively low total zinc contents and low extractable zinc. The authors suggest that most of the zinc deficiency problems are associated with the highly weathered Oxisols, Ultisols, and Inceptisols in the tropics, although their data are not conclusive.

With reference to the occurrence of zinc deficiency, Stanton and Burger (1967) present evidence that sesquioxides play a prominent role in limiting zinc availability to plants. Using millet seedlings and root sorption techniques, they found that phosphated hydrous iron

oxides fixed zinc against absorption by plant roots. In the absence of phosphate ions, the availability of sorbed zinc decreases as the crystallinity of the sesquioxides increases. Although the amorphous hydrous sesquioxides readily sorb zinc, they do not fix it in an unavailable form, whereas goethite does. On the other hand, the zinc is fixed just as strongly against plant uptake by the amorphous and crystalline sesquioxide varieties if linked through the medium of polyvalent phosphate ions.

A number of studies have indicated that molybdenum may be deficient for many crops on the leached, highly weathered, acid soils in the humid tropics, especially those developed from old parent materials. Since Anderson (1942) demonstrated molybdenum deficiency on soils formed from old materials in South Australia, the necessity for supplying this element on these kinds of soils has been given much attention. In South Australia, hundreds of thousands of acres of pastureland are now treated with molybdate along with superphosphate. One of the principal effects of supplying molybdenum was the stimulation of nitrogen fixation of legumes, and this has received considerable study (Andrew, 1962; Younge and Takahashi, 1953). In many cases, liming was found to increase molybdenum availability to plants. However, in some instances, while the addition of lime corrected molybdenum deficiency, it caused manganese, zinc, iron, and boron deficiencies in some plants if these elements were at marginal levels in the soil or if too much lime was used.

Boron deficiency commonly occurs on some crops in the humid tropics on highly acid, deeply weathered soils, on deep sands, and on neutral to alkaline soils. There is some indication that soils high in sesquioxides have a marked affinity for boron. Okazaki and Chao (1968) found that hot-water extractions of boron adsorbed on iron and aluminum oxides required longer periods of heating, wider soil-to-water ratios, and a greater number of extractions.

Reports on deficiencies of copper, iron, and manganese on crops in the humid tropics are less common than those on deficiencies of zinc, molybdenum, and boron. Copper deficiency is most commonly associated with peat soils in the tropics as it is in temperate regions, and occasionally it occurs on very sandy soils. Iron and manganese deficiencies are usually associated with neutral to alkaline soils, especially those containing free calcium carbonate in the profile. In acid soils high in soluble manganese, iron deficiency or manganese toxicity may occur. This can be accentuated by heavy applications of residually acid nitrogen fertilizers. Abruña-Rodriguez *et al.* (1970)

found in experiments with tobacco on an Oxisol (Tropeptic Haplorthox) high in exchangeable and easily reducible manganese, that yields were substantially increased by liming. They attributed the increase to a reduction of manganese toxicity. Vicente-Chandler *et al.* (1964) also found that heavy applications to pastures of residual acid nitrogen fertilizers can result in manganese toxicity unless corrected by applications of lime.

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J. D'HOORE AND J. K. COULTER

Soil Silicon and Plant Nutrition

Although from 10 percent to 50 percent of the ash from plant and animal tissues and from the dry matter of soil solutions may be silica (SiO_2), silicon is not normally regarded by physiologists as an essential element. Furthermore, the soils used for intensive agriculture in temperate regions are usually very well supplied with soluble silica, and the substitution of phosphorus for silicon probably masks any deficiency.

In the humid tropics, silica deficiency has not been recorded either in the natural vegetation or in the crops from traditional agricultural systems. However, the widespread phosphorus deficiency and the comparative ease with which silica is removed from the weathering zone, as illustrated by the relative accumulation of sesquioxides in freely drained humid areas and the accumulation of silica in poorly drained areas, would indicate probable low levels of soluble silica in many areas in the tropics. Where there is intensive agriculture on highly weathered and highly leached soils, there is increasing evidence of the beneficial effects of added silicate on the growth and yield of certain species of Gramineae.