3. Micronutrient problems in tropical Asia

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Introduction

The total land area of tropical Asia is approximately 800 million ha. Of this area, around 28%–29% is arable land [39], and this percentage has remained more or less stable over the last decade. Agricultural production, on the other hand, has increased dramatically over the same period. For instance, cereal production in the 11 largest south and southeast Asian countries increased by 30%, reflecting the intensification of agricultural production in tropical Asia. Most of this progress is due to the introduction of high-yielding varieties, increased fertilizer use and irrigation, and other technological improvements. Mudahar [95] estimated the contribution of fertilizers to the growth in rice production alone to be 7% in Nepal and as much as 45% in India, with a regionwide average of 24% for south and southeast Asia.

Increased productivity has greatly increased the demands on the soil for nutrients (see Chapter 2). Whereas traditional fertilizer practices were designed to meet these needs for the major elements (NPK), micronutrients taken up by the crop were generally not replenished. Micronutrient problems in food crops in tropical Asia were observed in rice as early as 1908. Until the mid-1960s, Mn and Fe deficiencies were considered the major problems in rice [3]. During the 1960s Zn deficiency in rice was first identified in tropical Asia [101], and since that time Zn deficiency has been recognized in virtually all food crops [141, 142]. In India alone it is estimated that 47% of the soils are now unable to supply adequate amounts of Zn to the crop [62]. High-yielding varieties combined with intensified land use in tropical Asia have led to an upsurge in the incidence of micronutrient deficiencies, as well as the number of reports on the subject [65].

Climate, geology and soils

The land mass of tropical Asia is small in comparison with that of Africa and Latin America. However, the delimitation of tropical Asia depends on

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the thermal criteria used. By most classification systems tropical Asia extends north of the tropic of Cancer into the foothills of the Himalayas. Other classification systems [103, 161] exclude most of northeast India from the tropics – senso stricto – because the mean annual temperature range exceeds the mean daily temperature range. Desert environments at the fringe of the intertropical zone are often excluded [162].

Malayasia, Indonesia, and the southern Philippines (Mindanao) are located in the equatorial zone and are surrounded by warm tropical seas. The climate is generally hot and humid throughout the year. Modifications in this general pattern are likely due to topography and geography of the islands. Distinct dry seasons develop only in the southern part of Indonesia as a result of a relatively dry east monsoon. North of the equatorial zone the humid region extends into western Thailand, Burma, eastern Bangladesh, and Assam. In the west it extends into the eastern Philippines. Most of these regions experience a dry season of short duration.

The typical subhumid tropics with 2½–5 dry months are found in the western Philippines extending westward through south China, Vietnam, Kampuchea, Laos, and parts of India. The rainy season starts in early summer in Sri Lanka and southern India and progressively later further north. In the southern hemisphere, the subhumid tropics are limited to eastern Java and the islands directly east of Java extending to the south-central section of New Guinea.

The most important semiarid regions are found in the Arabian Peninsula, the Indian subcontinent, and in eastern Burma and northeast Thailand. The rainy season is generally less than 7 months. On the Arabian Peninsula the rain diminishes in the northeast direction, while on the Indian subcontinent this gradient is in the northwest direction. The semiarid regions border on desert-type environments in all these cases. An overview of the climatic zones according to Troll and Paffen is given in Figure 1.

In contrast to tropical Latin America and Africa, tropical Asia has a physiography and geology characterized by the absence of vast land masses. The Precambrian Indian and Arabian shields were part of Gondwana land, and the Indian shield remained in place following the breakup during early Eocene.

The four major morphostructural regions of tropical Asia are (1) the Indian shield and Indo-Gangetic plain, (2) the Arabian shield, (3) the Sunda shelf, (4) the Tethys geosyncline and circum-Sunda orogenic system. Small parts of Asia fall within the Sahul shelf area and the circum-Australian orogenic system. A detailed description of these regions can be found in the FAO/UNESCO publications 'Soil Map of the World' [37, 38].

The tropical part of the Arabian shield stretches from the coastal plain bordering the Red Sea to the Oman mountains in the west. The interior plateau consists of calcareous Tertiary rocks, with massive gypsum and marl deposits in the east. Near the coast, soils are formed from sand and siltstone shale, marl, or recent alluvium.

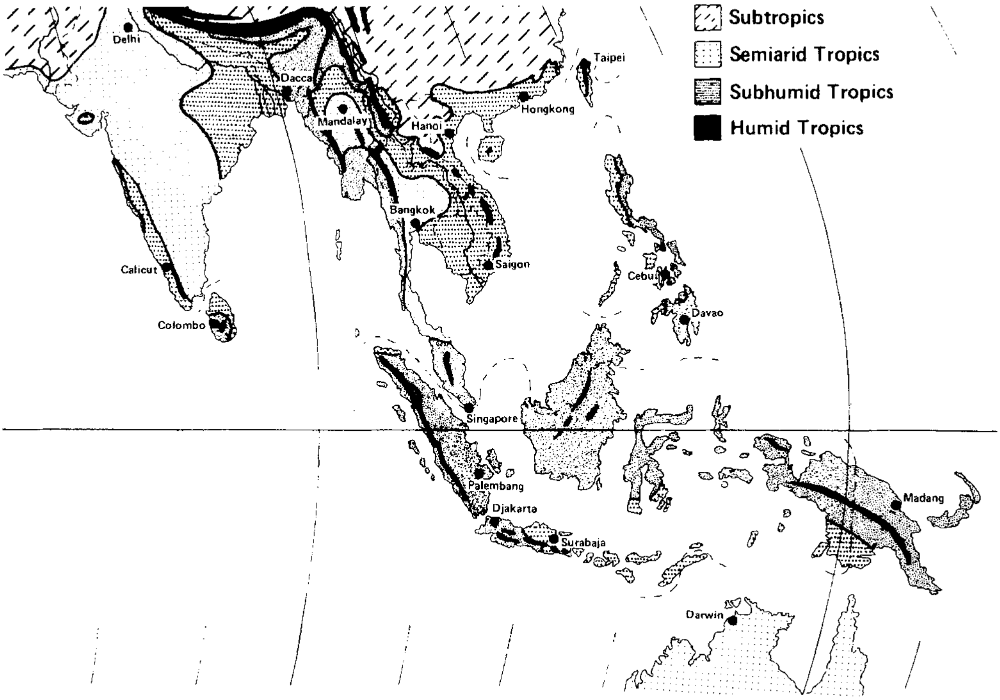

Figure 1. Climates of tropical Asia (after Troll and Paffen, 1966)

The Indian shield is an undulating plateau (200–1000 m) and includes Sri Lanka and the Assam plateau. The basement complex consists of a complex of gneisses and schists, which are exposed over more than 50% of the area. Other parent rocks are the thick basaltic lava beds of the Deccan plateau and northern part of western Ghats mountains and the fluviatile and lacustrine deposits along the Godavari and Mahanadi rivers and scattered throughout Bengal. The remaining part of the Indian shield comprises compacted shale, slate, quartzite, silaceous hornstone, sandstone, and limestone. The shield is bordered by alluvium of the Indo-Gangetic plain. Pleistocene and recent alluvia cover the surface of the Indo-Gangetic plain and coastal lowlands.

Aside from the Brahmaputra Valley, the most important geomorphological regions of the Tethys geosyncline in tropical Asia are the Arakan Yoma range and the Irrawaddy plain. The Arakan Yoma surface is formed from more or less metamorphosed Tertiary shale, sandstone, and limestone. The Irrawaddy geosynclinal is largely filled with sediments that are fluviatile to marine in origin. The Arakan Yoma range continues in the western mountain ranges of Sumatra, across Java, the lesser Sunda Islands, and westward to the Banda arc. Throughout its entire 7000 km, this Sunda mountain system comprises two concentric belts, the inner volcanic and the outer nonvolcanic. The circum-Sunda orogenic system extends further in the northeast direction to include all of the Philippines. The lithology of the circum-Sunda orogenic system is extremely complex.

The western limit of the Sunda shelf is the Shan Plateau, which is covered with Tertiary and Pleistocene shales, clays, and lacustrine sediments and flanked by gneiss in the west and granite in the east. To the east, the Shan Plateau, which extends into the geosyncline of western Thailand and the Malay Peninsula is composed of partly metamorphosed sandstone and shale. The remainder of Indochina belonging to the Sunda shelf comprises two structures: a region of narrow troughs, known as the Indochinese complex, filled with sediments, and the Indochinese massif comprising the massifs of northeast Thailand, of eastern Laos, Kampuchea, most of Vietnam, and south China. These massifs are largely formed from sedimentary deposits (sandstone, siltstone, shale, and limestone) of various age with some metamorphosis in the most western part. Two Quarternary basis (Mekong and Chao Phraya) contain recent and older alluvium. Away from the continent the Sunda shelf continues in Borneo, the east coast of Sumatra, Banka, and Belitung.

The Sahul shelf is the northern extension of the Australian continent. The coraline Aru islands and the alluvial plain in south New Guinea belong to this shelf. The circum-Australian orogenic system comprises the mountainous area of New Guinea, which consists of sedimentary deposits that have been locally metamorphosed.

The most important soils of tropical Asia are presented in Figure 2. They include the Vertisols and Alfisols in arid and semiarid India, Thailand, Kampuchea, and subhumid east Java. Most of the remaining humid and subhumid regions are dominated by Ultisols and Inceptisols while mountainous regions are complex and undifferentiated. More detailed soil maps exist for some countries, but the only unified map for tropical Asia is the FAO soil map [37, 38].

Distribution of micronutrients in soils

Total micronutrients

Rao [125] reported that total Zn in some soils of India varied between 300 and 600 ppm. As was evident from subsequent investigations, the values of total Zn in fact were much lower. Recent analysis of some benchmark soils of India by Katyal et al. [69] provides typical total Zn values, ranging from 80–89 ppm (Table 1). A range of 20–95 ppm Zn in surface soils of 58 Gujarat soils was reported by Nair and Mehta [97]. Among the different soils analyzed by Lal et al. [79], alkaline Vertisols had the highest total Zn levels (69–76 ppm), whereas the lowest values (24–30 ppm) were found in relatively coarse-textured Oxisols. Sharma and Motiramani [163]

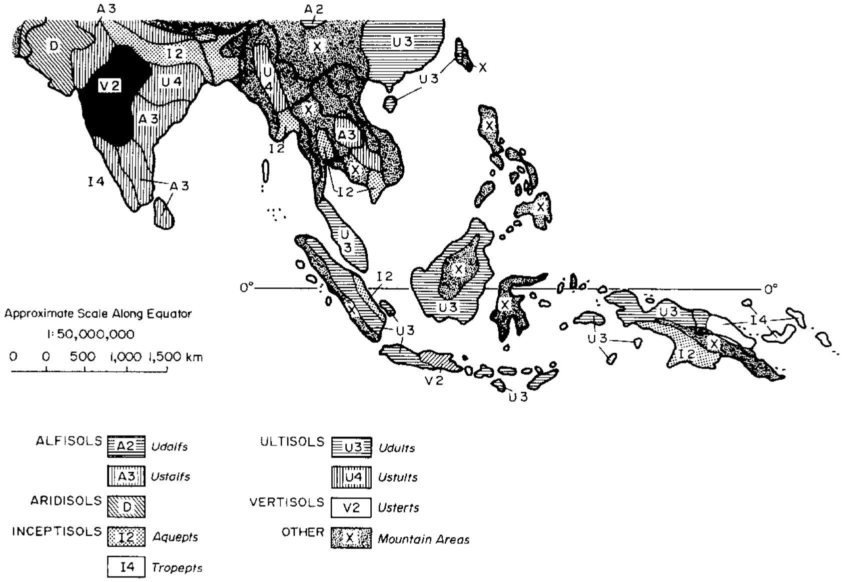

Figure 2. Soils of tropical Asia

Table 1. Distribution of total Zn, Mn, Fe, and Cu in tropical benchmark soils of India [68, 69] (range and mean in ppm)

Soil group	No. of soils	Zn Range	Zn Mean	Mn Range	Mn Mean	Fe Range	Fe Mean	Cu Range	Cu Mean
				Arid-Semiarid					
Inceptisols	5	50–71	62	440–1326	847	2.7–5.4	3.8	19–97	51
Vertisols	9	48–87	64	621–1060	774	3.0–6.1	4.2	41–148	68
Alfisols	5	20–89	49	233–950	488	1.6–6.3	3.3	23–122	50
All soils	19	20–89	59	233–1326	718	1.6–6.3	3.8	19–148	59
				Humid-Subhumid					
Inceptisol	4	46–71	59	38–393	266	2.5–3.1	2.7	23–34	29
Alfisols	3	22–42	33	210–469	347	1.6–2.1	2.0	19–25	22
Oxisols	2	70–74	72	405–800	602	4.6–6.3	5.5	54–58	56
Ultisols	1	–	43	–	400	–	2.0	–	22
All soils	10	22–74	52	38–800	371	1.6–6.3	2.9	19–58	32

reported that total Zn was the highest in fine-textured Vertisols and the lowest in coarse-textured alluvial soils (Fluvents). Only 7 ppm total Zn was present in certain alluvial soils [40], whereas some deep Vertisols from Maharashtra contained as much as 254 ppm Zn [83].

Raychaudhuri and Datta Biswas [128] showed that soils of Gujarat developed over limestone were richer in Zn than those formed either on sandstone or schists. A highly significant coefficient of correlation existed between lime contents and Zn levels of soils [68]. Similarly, negative correlation coefficients between total Zn and sand strengthens the belief that soils developed over sandstone are inherently low in Zn.

Katyal [63] determined total Zn in 13 diverse surface soil samples representing major rice-growing areas of the Philippines. The range and mean of total Zn in these soils were 63–135 ppm and 88 ppm, respectively. In his analysis total Zn did not seem to have a significant effect on the incidence of Zn deficiency in rice. Similarly, in Sri Lanka, the range and mean in total Zn contents of wet-patana soils (characterized by high organic matter [OM]) were 35–101 and 75 ppm, respectively [107]. The variations in Zn content of these soils were related to the finer soil fractions. Organic matter level had no effect. Glinski and Thai [42] determined the total Zn content of 20 ferralitic soils of Vietnam ranging from 40 to 485 ppm (mean 102 ppm). Soepartini et al. [152] reported that the total Zn levels in 140 topsoils from Indonesia (Sulawesi and Sumatra) ranged from 33.3 to 173.5, with 25% of the soils containing less than 60 ppm Zn. Although a wide range of soils was sampled, no effort was made to relate total Zn levels to soil type in any of these studies.

Snitwongse [149] reported total Zn levels for 152 soils from Thailand to range from 5 to 158 ppm (average 45 ppm), with the lowest levels found in the northeast (average 20 ppm).

Manganese levels in Asian soils are generally an order of magnitude higher than those of Zn. Among the Indian soils investigated by Iyer and Rajagopalan [51], Vertisols from the Deccan contained more manganese than did the others. Several years later, Biswas [11] confirmed that similar soils were conspicuously rich in total Mn. In comparison, acid Oxisols were characteristically poor. Raychaudhuri and Datta Biswas [128] recorded an average of 1,270, 500, 805, and 368 ppm Mn in black, red, lateritic, and alluvial soils, respectively. These findings are in general agreement with those summarized in Table 1.

Total Mn levels for 20 ferralitic (top) soils from Vietnam ranged from 40 to 4,400 ppm (mean 940 ppm) [42]. Koch [73] analyzed 18 surface soils from rice-growing areas in Sri Lanka which contained Mn values between 24 and 1,204 ppm Mn with a mean of 500 ppm, whereas certain tea soils had less than 15 ppm total Mn [59]. Kalpage and Silva [60] showed that wide variations in Mn in Sri Lanka soils were related to rainfall and parent material. Bleeker and Austin [15] studied the distribution of Mn in six soils of Papua-New Guinea and concluded that Mn levels were greatly influenced by the presence or absence of a fluctuating water table. The transformations of Fe and Mn under anoxic conditions were studied extensively by Ponnamperuma [111, 112, 114].

Finer soil fractions appear to contribute significantly to variability in total Mn in diverse soils [104, 20]. Biswas [12] demonstrated that the concentration of Mn in genetic horizons was principally linked with montmorillonite in the clay fraction. Leaching and lime further modified the distribution of Mn in soil profiles [14]. Recently, Katyal et al. [69] found that surface soils from the semiarid tropics, where leaching is generally limited, averaged 718 ppm Mn (Table 1). On the other hand, soils from the humid tropics, where free leaching due to heavy precipitation might occur, contained only 371 ppm Mn.

The total Fe content of Indian soils varies from less than 1% to more than 10% with an average of about 3% [65]. Katyal et al. [69] showed that, among the major groups of soils in tropical India, acid Oxisols were the richest in total Fe (Table 1). Next in order were Vertisols followed by Alfisols. One Ultisol showed the lowest amount of Fe. Total Fe in the surface soil increased with the aridity of the climate. Arunachalam and Mosi [6] found that the variations in total Fe in soils depended on OM and the finer soil fractions. In heavily leached lowland soils of the humid tropics, Fe had a tendency to move down and concentrate in the lower horizons [34], whereas it tended to be more uniformly distributed in the soils of arid and semiarid climates [77].

The total Cu content of 28 soils from western India varied between 21 and 101 ppm in the A horizon and between 4 and 32 ppm in the B horizon [52]. Satyanarayan [132] reported a range in total Cu for Vertisols between 63 and 167 ppm. Soepartini et al. [152] reported that the total Cu levels for 14 soils, representing 8 soil orders, from the islands of Sumatra and Sulawesi (Indonesia) ranged from 2.0 to 135.6 ppm. Fifty percent of these soils contained less than 30 ppm Cu. The Cu content of hydromorphic organic soils from Sri Lanka ranged from 15 to 68 ppm with a mean of 38 ppm [107]. Glinski and Thai [42] found the Cu content of 20 ferralitic soils from Vietnam to range from 10 to 143 ppm (mean 57 ppm).

According to Lal et al. [78] and Katyal et al. [69] heavy-textured Vertisols are better endowed with Cu than are lighter textured Alfisols and Entisols (Table 1). Others also had found that copper in soils increases with fineness of soil texture [92, 124, 42]. The level of Cu in the surface horizons appear to be influenced by climate. Soils in a semiarid tropical climate contained more Cu in their surface horizons than did those in humid and subhumid regions (Table 1).

Total B in soils of tropical India varies between 5 and 80 ppm. Iyer and Satyanarayan [52] reported that the average B content of soils changed on the basis of the surface geology as follows: acid lavas 22 ppm, basalt 36 ppm, limestone 13 ppm, alluvium 62 ppm, slate 44 ppm, gneiss 7 ppm, and laterite 37 ppm. Glinski and Thai [42] reported low total B levels in Vietnam soils derived from gneiss (< 20 ppm), crystalline shale (< 5 ppm), and basalt or andesite (< 25 ppm). For all 20 soils studied, the average B content was 45 ppm. Raychaudhuri and Datta Biswas [128] found that loamy Xerochrepts developed on granite and crystalline gneiss contained 8.5 ppm B. A laterite (Aquox) from a more or less similar geologic region contained 25 ppm B. On the other hand, Vertisols and mixed Alfisols and Vertisols formed over Deccan trap aggite, basalt igneous rock and shales, slates, quartzite, and limestone had between 28 and 57 ppm total B. Certain young alluvials (Inceptisols) from, Bihar contained up to 83 ppm total B [53]. Soil B had a tendency to decrease with the geological age of the rocks from which the soils originate [76] and to increase with tourmaline content [25, 148].

Tyer and Satyanarayan [52] found that heavily leached soils were low in total B. Indeed, Jha [53] reported that coarse-textured soils, apparently vulnerable to leaching, contained less than 20 ppm B. Soils irrigated with high B irrigation waters may accumulate B [88, 80]. Cultivated soils had more B than did virgin soils [52]. High B contents were noted in saline-alkali soils [144]. Accumulation of B in the horizons of a soil profile was affected by lime content [76] and irrigation practices, but B tended to accumulate mostly in the subsoil horizons [144].

In tropical Indian soils total molybdenum contents range between 0.4 to 14.5 ppm. In a majority of the soils, concentrations vary from 1 to 2 ppm. Recent alluvial soils (Fluvents) derived from granite and metamorphic crystalline basalts contained 1.5–5.1 ppm Mo [128]. The corresponding values for Vertisols formed over trap and limestone were 1.5–1.8 ppm. Earlier, Chatterjee and Dakshinamurti [19] reported a range in total Mo between 2.0 and 5.6 ppm, 0.6 and 11.6 ppm, and 1.3 and 2.0 ppm for alluvial soils, Vertisols, and Oxisols, respectively. Verma and Jha [167] and Balaguru and Mosi [8] confirmed that alkaline alluvial soils and Vertisols contained more Mo than did Oxisols and Alfisols. From the study of 46 representative soils from Gujarat, Reddy [129] reported a range and mean of 0.5 to 4.1 and 1.8 ppm Mo, respectively. Recently, Chavan et al. [20] showed that representative soils from Maharashtra contained around 1.9 ppm Mo. Total Mo tends to be higher in neutral-to-alkaline soils. Balaguru and Mosi [8] related the higher total Mo in Vertisols to their high clay contents. Mali and More [84] also reported the highest Mo levels in clay loam and clay soils.

Total Mo in OM-rich mountain soils of Sri Lanka varied between 0.25 and 3.3 with an average content of 2.1 ppm [108]. Ill-drained Deniya soils (low humic gley) contained less Mo in comparison to the well-drained soils in forested areas (Typical wet-patanas).

Available micronutrients

Plant-available Zn generally makes up only a small fraction of the total soil Zn, the size of which may vary with extraction method and soil type. Katyal et al. [69] using DTPA found available Zn to account for no more than 1% of total Zn in various Indian benchmark soils. Using 0.1 N HCl on 20 ferralitic soils from Vietnam, Glinski and Thai [42] extracted between 0.2% and 10.6% of the total Zn. They found available Zn well correlated with total Zn ($r = 0.76$). On the other hand, Soepartini et al. [152] found this correlation to be less (r = 0.55) for Indonesian soils, and they reported even lower correlation coefficients using EDTA and dithizone as extractants. Nair and Mehta [97], Sharma and Motiramani [136], and Ganjir et al. [40] found good correlations between available and total Zn in Indian soils; Lal et al. [79] and Rastogi and Rai [126], however, did not.

Judged by the increase in retention of added Zn with the fineness of soil texture [96] and the increase in available Zn with the clay content [44], light-textured sandy soils appear more vulnerable than others to Zn deficiency. Chavan et al. [20] reported that low pH Oxisols contained more available Zn than did neutral-to-alkaline Alfisols and Vertisols. Various correlation studies [119, 45] have confirmed the decline in available Zn with a rise in pH. Zinc deficiency, generally observed in crops growing on calcareous soils, thus seems mostly due to the reaction of the crops to the alkaline soil [65].

The climatic influence on micronutrient availability in soils has been given scant attention. In addition to its effect on soil pH, climate effects the OM level in the soil. Katyal et al. [69] considered low organic matter a cause for generally low DTPA-extractable Zn in arid and semiarid soils (Table 2). Misra and Pandey [93] and Haldar and Mandal [44] demonstrated the favorable effect of OM on Zn availability. Similarly, Pavanasasivam and Kalpage [106, 107] considered the high organic soils (wet patana) of Sri Lanka well supplied with Zn. However, Rajagopal et al. [120] working with high OM soils from Nilgiri Hills, Tamil Nadu, India, reported a reduction in Zn availability when soils contained more than 5.0% OM.

A substantial effort was made by the International Atomic Energy Agency (IAEA) [48] to survey the major rice-growing soils of Bangladesh, Java (Indonesia), the Philippines, and Thailand. Soils were classified on the basis of Zn levels in soil extracts (< 1 ppm) and plant leaves (< 20 ppm). Soils identified as deficient were subsequently selected for greenhouse and field experiments. The survey results proved that Zn content of soils correlated poorly with greenhouse and field results; frequently no yield response and little increase in Zn uptake were obtained from fertilizer Zn. Possibly, the dynamics of Zn in flooded soil prevent adequate prediction of Zn response.

Ponnamperuma [113], Katyal [64], and Haldar and Mandal [45] observed a decline in Zn availability after submergence. Earlier, Katyal [63] demonstrated a reduction in the Zn concentration of the soil solution upon submergence, irrespective of the air-dry soil pH (Table 3). The increase in severity of Zn deficiency with a decrease in altitude along a toposequence reflects the effect of poor soil aeration on Zn availability [164, 166]. On the other hand, mid-season soil drying improves soil aeration and was shown to enhance Zn availability [18].

A highly significant coefficient of correlation has been reported between reducible Mn and total Mn [91, 27]. Glinski and Thai [42] reported that easily reducible Mn levels for various Vietnamese soils range from 5 to 400

Table 2. Distribution of available Zn, Mn, Fe, and Cu in tropical benchmark soils of India [69] (range and mean in ppm)

		DTPA extractable							
		Zn		Mn		Fe		Cu	
Soil group	No. of soils	Range	Mean	Range	Mean	Range	Mean	Range	Mean
			Arid-Semiarid						
Inceptisol	5	0.2–0.6	0.4	7.5–48.8	19.0	3.4–22.8	11.6	0.9–3.6	1.9
Vertisol	9	0.2–1.3	0.4	4.8–16.4	9.8	4.7–9.5	8.0	0.8–2.0	1.4
Alfisols	5	0.3–0.5	0.4	10.3–48.4	24.2	6.7–25.4	17.4	0.9–2.2	1.3
All soils	19	0.2–1.3	0.4	4.8–48.8	16.0	3.4–25.4	11.4	0.8–3.6	1.5
			Humid-Subhumid						
Inceptisol	4	0.3–1.0	0.8	5.1–102.4	40.0	7.9–51.3	30.4	0.2–4.5	2.5
Alfisols	3	0.2–0.7	0.4	17.5–76.0	45.5	14.3–51.2	34.5	0.2–4.9	2.1
Oxisols	2	0.3–1.4	0.9	18.1–155.4	86.8	19.3–26.3	22.8	0.5–2.9	1.7
Ultisols	1	–	0.3	–	40.1	–	17.5	–	0.5
All soils	10	0.2–1.4	0.6	5.1–155.4	51.0	7.9–51.3	28.8	0.2–4.9	2.0

Table 3. Influence of soil pH on the changes of zinc in the solution of flooded soils [63]

		Zn (10^{-2} ppm)				
		Weeks submerged				
Soil	pH	0	2	4	6	10
Acid sulfate clay (Philippines)	3.7	51	17	21	11	12
Luisiana clay	3.9	30	17	22	8	15
Kalayaan clay loam	5.6	48	15	17	14	9
Antipolo clay	6.0	35	14	13	10	7
Butuan clay	6.8	26	21	21	5	5
Luna clay	7.1	29	18	16	7	5
Maahas clay	7.1	16	13	–	12	7
San Pablo clay	7.4	22	10	14	6	4

ppm (average 113 ppm) constituting 2.7%–26% of total Mn. The lowest levels were found in soils from crystalline shale, acid igneous rocks and elastic materials, and high levels in basalt, clay shale, and limestone-derived soils. Easily reducible Mn in different Indian soils varied from 6 to 820 ppm, i.e., 5%–46% of the total [13]. Reducible Mn, like total, was highest in Vertisols and lowest in Oxisols. Sharma and Motiramani [135] also noted a high content of reducible Mn in Vertisols. The concentration of water-soluble Mn in soils is extremely low [14]. Anaerobic soils, however, are exceptions, and the level of water-soluble Mn may rise to unusually high levels after submergence [111, 64, 58, 98], reflecting the presence of easily reducible Mn in soils. Calcareous soils in the Indian arid and semiarid tropics were generally low in exchangeable Mn [158, 116]. Biswas [13] showed that Oxisols and Alfisols were richer in exchangeable Mn than were Vertisols and (calcareous) alluvial soils. Sharma and Motiramani [135] reported a range of 1–93 ppm for Vertisols and 2–170 ppm for Alfisols.

Anjaneyulu [4] and Mehta and Patel [91] reported that coarse-textured soils contained more available Mn than did soils with heavy texture. A positive effect of OM content of soils on Mn availability was reported by several workers [171, 7, 2, 127]. On the other hand, Pavanasasivam [105] reported an adverse effect of high OM on Mn availability. Glinski and Thai [42] failed to find a correlation between available Mn and OM at all.

In the few studies that have been conducted [117, 68], the relation between soil-extractable Fe and total uptake or response to added Fe has generally been poor. Iron present in organic combination appears to be the main resource of plant-available Fe [118, 120, 119]. The higher availability of Fe in soils of the humid tropics than in those in semiarid tropics might, in part, be due to higher OM content (Table 2) [69].

Water-soluble Fe, like Mn, is negligible in upland soils but increases after submergence. Mandal [86], Ponnamperuma [111], Katyal [64], and Kabeerathumma and Patnaik [58] reported that the magnitude of increase in Fe availability depended mainly on soil pH, intensity of soil reduction, and active iron content. Quickly decomposing green manure treatment enhanced soil reduction, caused more CO_2 production, and brought about early and far greater accumulation of available Fe [110, 43, 87, 64].

The Cu extractable by different reagents has been shown to increase with total Cu in soils [42, 152, 100, 1, 44] and to decrease with a rise in soil pH. A high proportion of clay in soils was found to favor Cu availability [160, 44]. Glinski and Thai [42] found Cu availability correlated with soil OM ($r = 0.50$) in various Vietnamese soils. Soepartini et al. [152] found no correlation between soil OM and extractable Cu, irrespective of the extraction method employed. Katyal et al. [69] were able to explain 58% of the variability in DTPA-Cu by OM alone in soils of arid and semiarid India. Similarly, any increase in OM seemed to enhance Cu availability in low OM tropical soils [7, 115, 160]. In marked contradiction, Rajagopal et al. [120] showed that in high OM soils from Nilgiri Hills in India OM impaired Cu availability. Peat soils from Malaysia are notoriously low in available Cu [61].

The variations in available B may be traced to various soil factors and certain management practices. Some workers [94, 20] noticed a close association between total and hot water-soluble B, but others [148, 42] could not verify this. Bokde [16] considered 5% of the total B to be plant available. Talati and Agarwal [157] and Chavan et al. [20] noticed an increase in water-soluble B with the fineness of texture. Soil OM seemed to have a favorable effect on B availability [82, 116]. In soils of arid and semiarid Rajasthan, available B increased with increasing pH [88, 94, 82, 157], but alkaline calcareous soils seemed to be exceptions [147]. No correlation with pH was found ($r = 0.1$) in acid soils from humid and subhumid Vietnam [42].

High clay content, low pH, and large amounts of sesquioxides all tend to reduce Mo availability to plants. To some extent this is reflected in the extractable Mo levels in soils. Plant-available Mo has mostly been assessed by extracting soils with acidic ammonium oxalate. The contents range from traces to less than 1.0 ppm. Based upon the analysis of 1,000 soil samples representing Psamments, Orthents, Vertisols, and Vertic Eutropepts, Duarte et al. [36] reported a range in available Mo from 0.02 to 0.5 ppm. Among the soils studied by Chatterjee and Dakshinamurti [19], Fluvents had the highest available Mo, which varied from 0.10 to 0.34 ppm. Vertisols and Oxisols seldom exceeded 0.05 ppm. On the whole, available Mo was less than 10% of the total. Likewise, in the study of Verma and Jha [167], alkaline alluvial soils exhibited higher available Mo levels than did soils acidic in reaction and sedentary in origin. Balaguru and Mosi [8] also reported certain alluvial soils of Tamil Nadu, India, which analyzed 0.30–0.34 ppm available Mo, to be the richest. High pH Vertisols were relatively poor in Mo availability (0.13–0.16 ppm Mo), and acidic-to-neutral Alfisols were the lowest (0.10–0.15 ppm Mo).

Geographical distribution of micronutrient problems

Semiarid tropics

Zinc – Soils of the arid and semiarid regions of India were found more frequently Zn deficient than those in humid and subhumid zones [69]. Mehta et al. [92] considered a large number of soils from Gujarat Zn deficient. Neutral-to-alkaline red loamy soils (Alfisols) and low-lying alluvial rice soils were more susceptible to Zn deficiency than soils acidic in reaction [74]. As much as 74% of the rice-growing soils (mainly Vertisols and Alfisols) of Andhra Pradesh were found to be deficient in available Zn [195]. Rai et al. [116] showed that on 15%–43% of the black soils from Madhya Pradesh (MP) crops could benefit from Zn treatment. On the basis of available Zn, Rathore et al. [127] classified 69% of the 120 alluvial soils (alkaline Fluvents) studied as Zn deficient. On an overall basis, Katyal and Sharma [67] indicated that on 50% of the Indian soils crops may suffer from Zn deficiency.

Dastur and Singh [32] recorded improvement in yields of cotton on Vertisols resulting from zinc sulfate application. Ramanathan and Nagarajan [123] found that application of 75 kg $ZnSO_4$/ha brought about an increase in yield of cotton on a red loam soil of Tamil Nadu (DTPA-Zn 0.2 ppm). Savithri and Sree Ramulu US [133] were able to raise the kernel yield of groundnut by about 25% through Zn application to a Zn-deficient Alfisol. Solanky et al. [153] also obtained a significant increase in groundnut yield upon Zn treatment of a Vertisol.

On the basis of a micronutrient survey of paddy soils of Thailand [149], the semiarid region (northeast) was considered most susceptible to Zn

Table 4. Summary of field surveys for zinc status in paddy soil in Thailand [149]

Region		DTPA (ppm)	0.05 N HCl (ppm)	Zinc in leaves (ppm)	Total zinc (ppm)	Number of sample	Number of location
Central	Range	0.9–3.4	0.4–1.5	22–52	28–258	36	15
	Average	1.35	0.9	31.7	77.0		
South	Range	0.8–3.0	0.6–1.5	33–45	20–53	7	4
	Average	1.7	0.9	40.1	31.9		
Northeast	Range	0.3–1.6	0.5–2.3	14–30	5.0–120	62	17
	Average	0.8	0.9	20.6	20.1		
Northern	Range	1.0–3.3	0.8–3.5	16–26	10.2–105	47	18
	Average	2.0	1.8	21.3	55.2		

deficiency (Table 4). Four of the ten soils thus identified as Zn deficient showed a response to Zn when cropped to rice in the greenhouse [48].

In the studies of Ramakrishnan and Kaliappa [122], Zn application markedly increased the yield of maize on Vertisol. Deshmukh et al. [35] obtained a 24% increase in sorghum grain yield attributable to 20 kg $ZnSO_4$/ha applied to a Vertisol, (dithizone Zn, 0.82 ppm). On a similar soil Kene and Deshpande [71] reported that the addition of Zn to the NPK (12.5 kg $ZnSO_4$/ha) produced 0.8 ton grain/ha extra sorghum grain. Shinde et al. [138] observed a significant increase in wheat yield on Vertisols from 20 kg Zn/ha supplied as $ZnSO_4$ or ZnO. Field trials conducted in nine villages of North Gujarat (alluvial sandy soils, dithizone-Zn 0.15–0.55 ppm) revealed a wheat yield increase of 5%–25% upon addition of 50 kg $ZnSO_4$/ha [90].

Work done under the ICAR's Coordinated Micronutrient Scheme revealed a response of rice to added Zn in several districts of Andhra Pradesh [155]. Krishnamoorthy et al. [75] obtained an increase of 1.8 tons/ha rice grain yield on a calcareous red soil (pH 7.6, Alfisol) in that state with 10 kg Zn/ha. Studies in Gujarat [156] showed that rice grown on a Zn-deficient soil (dithizone Zn 0.6 ppm) yielded 50% more when treated with 10 kg Zn/ha. In Karnataka, Bhadrapur et al. [10] recommended 50 kg $ZnSO_4$/ha to improve rice yields in salt-affected black soils of the Tung Bhadra Project area. On extremely Zn-deficient Vertisols of Madhya Pradesh (DTPA Zn < 0.30 ppm), yield of rainfed rice was almost doubled upon $ZnSO_4$ treatment [72].

Manganese and iron. Sharma and Motiramani [135] suspected Mn deficiency (less than 3 ppm available Mn) in about 11% of the Vertisols of Madhya Pradesh. Sharma and Shinde [137] also noted low content of available Mn in black soils. However, deep Vertisols from the same state were found adequate in Mn availability [118]. Zende and Pharande [171] did not come across any sample out of 87 soils from the Bombay Deccan that could be considered low in available Mn. It thus appears that, with the possible exception of alkaline, calcareous Vertisols, Mn deficiency is not a serious constraint to crop production in semiarid tropical India. However, responses to Mn do occur. Dargan and Sahni [26] recorded a 7% increase in cotton yield brought about by Mn treatment of Vertisols. Similarly, Vamadevan and Mariakulandai [163] observed an increase in yield of rice when $MnSO_4$ or MnO was applied to a Vertisol from Tamil Nadu. Bhadrapur et al. [10] recommended $MnSO_4$ application (5 kg Mn/ha) along with Zn and Fe to increase rice yields in salt-affected Vertisols of Siruguppa (Karnataka).

Rai et al [118] concluded that 38%–58% of the soils from the deep Vertisol zone of Madhya Pradesh were deficient ($<$ 2.0 ppm Fe) in Fe. Subsequently, Rai et al. [117] employing the same criteria, classified 47% of the medium Vertisols of Sehore district as Fe deficient. Remarkably all of the 120 alluvial soils (Fluvents) sampled in the same state were considered sufficient in Fe [127]. Widespread deficiencies of Fe, affecting sugarcane in Tamil Nadu (TNAU Scientists – personal communication), are being corrected with several sprays of 2%–3% $FeSO_4$ solution. The success of foliar application of $FeSO_4$ in alleviating chlorosis and increasing yield was confirmed by Saxena and Sheldrake [134]. They reported a yield improvement of chickpea grown on a Vertisol near Hyderabad of up to 50%. However, in the case of iron-efficient varieties, no benefit was derived from $FeSO_4$.

Copper. Katyal and Sharma [67], employing a critical limit of 0.2 ppm NH_4OAc-Cu, reported that merely 1% of the 40 000 soil samples from 10 Indian states were likely to be deficient in Cu. However, a majority of the soils (acid-to-slightly alkaline in reaction and well supplied with OM) from Kerala and hilly tracts of Tamil Nadu [120, 119] tested less than 0.5 ppm in *N* NH_4OAc and were categorized Cu deficient. Singh et al. [145] considered 92% of 120 Vertic Eutropepts in the deficient range. They classified a soil deficient if it tested less than 1.0 ppm in *N* NH_4OAc-extractable Cu – an unusually high critical limit. This may explain the virtual lack of Cu deficiency in similar soils (Vertic Eutropepts and Vertisols) in the studies of Kavimandan et al. [70] and Rai et al. [118, 115] who proposed a critical limit of 0.2 ppm NH_4OAc-Cu. On the same basis none of 120 alluvial soils (Fluvents) from Madhya Pradesh were found to be deficient in Cu [127].

Joshi and Joshi [55] reported an increase in rice yield by about 38% upon application of 1 kg $CuSO_4$/ha to certain soils of Ratnagiri district of Maharashtra. Subsequently, on the basis of response to applied Cu in pots, Joshi and Joshi [56] suspected Cu deficiency in the majority of the agricultural soils from the same state.

Boron. Excess B may be more often a problem of soils in the arid and semiarid tropics than is B deficiency, particularly in salt-affected soils. Singh and Singh [146] showed that in saline-alkali soils from south and southwest Bihar water-soluble B was present in toxic amounts ($>$ 1.5 ppm). Moghe and

Maghur [94] also suspected B toxicity in saline soils from arid regions of Rajasthan. In comparison to saline or saline-alkali soils, other soils seldom contain more than 1.0 ppm water-soluble B [53]. On the average, alluvial, black, lateritic, and red soils of Tamil Nadu contained 0.64, 1.03, 0.50, and 0.61 ppm extractable B, respectively [9].

Molybdenum. Indian workers adopted 0.05–0.10 ppm Mo (Grigg's Method) as the critical limit for delineating deficient soils. Of 46 soils from Gujarat studied by Reddy [129], 11 contained less than 0.05 ppm Mo, and crops growing on these soils indeed showed Mo deficiency symptoms. In another survey of the same state, 35% of the 109 soil samples tested below the critical limit of 0.05 ppm Mo [92]. Shinde et al. [140] suspected a need for Mo treatment in 11% of the sugarcane-growing soils from Maharashtra. In general, acid laterites and alkaline black clay soils generally contain a low level of available Mo, and crops, particularly legumes, may benefit from Mo addition to these soils.

On the basis of a 3-year study on an experimental farm (available Mo = 0.066 ppm) and on a large number of trials on cultivators' fields (average available Mo = 0.088 ppm) in Aurangabad district of Maharashtra (largely Vertisols), Chavan et al. [21] reported a significant increase in wheat yield from a single foliar spray of 210 g sodium molybdate/1 100 liters of water/ha. Overall wheat grain yields increased by 304 and 120 kg/ha at the experimental farm and in cultivators' fields, respectively. Recently, Shinde et al. [139] working on more or less similar soils observed a yield increase for wheat of up to 20% when treated with Mo.

Humid and subhumid tropics

Zinc. Few efforts have been made in Asia to use available Zn as a tool to map Zn-deficient areas. Soepardi et al. [151] delineated micronutrient-deficient soils from northern central plains of West Java representing an area of about 2 500 000 ha. Judged by the available Zn level of 162 soil samples and actual yield response, 29% of the soils were categorized as Zn deficient. A soil map of zinc deficiency in Java has since been published by Soepardi [150]. He proposed that if soils tested less than 1 ppm 0.05*N* HCl-Zn or DTPA-Zn or rice plants analyzed below 15 ppm Zn, a Zn deficiency was likely. However, Ismunadji et al. [49] considered 0.15 ppm Zn extractable in 0.1*N* HCl the critical limit and concluded that many upland soils of Indonesia (alluvial, Regosols, Lithosols, and Aridisols) were likely to be deficient on that basis. The extent of Zn problems in Java has been confirmed through response studies with corn and rice [46, 47].

De and Chatterjee [33] observed an increase of 42% in pod yield of groundnut when 20 kg $ZnSO_4$/ha was supplied to an acid-leached sandy loam soil of West Bengal (total Zn 12–14 ppm). De and Chatterjee [34] obtained more than 20% improvement in rice yield through Zn application on these soils of West Bengal. Regardless of soil, benefits from Zn application were greater in cold, dry seasons than in hot, wet seasons [131, 121]. Application of 6.25 kg $ZnSO_4$/ha yielded 245 kg extra wheat grain on an alluvial soil of West Bengal [89]. On the basis of the 0.1 *N* HCl test, Chowdhury et al. [23] judged most soils from south and southeastern Bangladesh to be adequately supplied with Zn, whereas Zn deficiency was common in the northern parts of the country. Response to Zn fertilization is observed in the north.

Juang et al. [57] reported a significant increase in cane and sugar yield on four tropical soils of Taiwan (pH 6.4–8.4, 0.1 *N* HCl-Zn 1.0–7.9 ppm). The lower the soil Zn content, the higher was the efficiency of applied Zn. On an overall basis cane and sugar yield increased by about 10% through Zn treatment. In China calcareous paddy soils, especially with impeded drainage, gave a significant response of rice to Zn application [85].

In the Philippines responses to added Zn have been spectacular. Katyal [63] reported Zn deficiency in rice on certain Hydrosols to be so severe that Zn treatment meant the difference between yield and no yield. Even fertilization of such soils with NPK + Zn was of no avail (Table 5) [66]. However, an increase of 4.4 tons/ha rice grain was obtained on these soils through dipping seedling roots in a 2%–4% ZnO suspension, equivalent to about 1 kg ZnO/ha. Yoshida et al. [170] recorded a yield increase of 4.8 tons/ha through an application of 50 kg Zn/ha to calcareous soil. Several other examples of response of rice to added Zn, and information on methods, sources, levels, and time of application can be obtained from some recent reviews [18, 54]. It is estimated that about half a million hectares of current and potential rice land in the Philippines alone are zinc deficient [102, 48].

Preliminary research from the subhumid zone of Sri Lanka by Nagarajah (personal communcation) indicates a region of severe Zn deficiency (0.224 ppm Zn in 0.05 *N* HCl) in the area near Matale on slightly acid soil which is representative of approximately 10 000 ha. A crop response to Zn was observed after the first rice season.

Manganese and iron. Deficiencies of iron and manganese have rarely been reported for humid and subhumid tropical regions. Deficiency of these elements in lowland rice is unlikely [159], but iron deficiency in upland rice may present a major problem in some soils [113]. Pillai [109] reported a response to Mn for rice grown on an Oxisol in India when seeds were presoaked in an 8% $MnSO_4$ solution. Iron toxicity was identified as a major problem to wetland rice [165, 5].

In West Bengal pod yields of groundnut were improved by about 40% with 40 kg $FeSO_4$/ha applied to an acid-leached soil (total iron 1.0% in 0 to 30 cm depth) [33]. Recently, Ismunadji et al. [49] reported Fe chlorosis in several crops growing on high pH calcareous upland soils of Indonesia.

Table 5. Yield of rice with or without NPK and/or zinc treatment in eight farmers' fields [66]

Treatment		Grain yield (tons/ha)							
		Farm number							
Zinc	NPK	1	2	3	4	5	6	7	8
No	No	1.6	3.0	1.0	4.1	3.1	2.5	2.6	0.0
No	Yes	0.0	2.2	1.8	3.9	4.8	3.7	1.4	0.0
Yes	No	3.9	5.1	5.4	4.7	4.0	3.7	4.7	4.2
Yes	Yes	3.1	6.1	6.7	5.1	5.0	4.6	4.2	4.9

Copper. Ponnamperuma [114] showed that the concentration of Cu in the soil solution decreased after submergence. Despite this, Cu deficiency, unlike Zn deficiency, has seldom been encountered in the Philippines. Response of rice to application of Cu (0.13% $CuSO_4$ foliar spray) on a clay soil has been recorded in Bangladesh [17]. Sreedharan and George [154] noted an increase in both grain and straw yields of rice on a high OM, acid red loam soil of Kerala as a result of Cu application. Samui and Bhattacharya [130] obtained an additional 324 kg grain/ha from $CuSO_4$ treatment of Boro rice (spring rice) on an acid-leached soil of West Bengal, whereas the Kharif rice (summer, wet season rice) did not respond to Cu. On more or less similar soils, De and Chatterjee [34] reported an 18% increase in yield of upland, direct-seeded rice, attributable to 5 kg $CuSO_4$/ha. The performance of flooded transplanted rice, however, remained unaffected. Rice-growing alluvial soils from West Bengal are considered adequately supplied with Cu [44].

Micronutrient studies in Malaysia have concentrated on peat soils, which occupy extensive areas of southeast Asia. Deficiency of Cu is the most widespread on these soils. Coulter [24] found that palms growing on peat and showing yellowing or browning symptoms were characteristically low in Cu ($<$ 3 ppm). Such symptoms in palms are known as 'peat yellow' and are easily controlled by $CuSO_4$ application before planting or even by top-dressing. Kanapathy [61] reported a significant increase in yield of maize on a peat testing 7 ppm total Cu. So pronounced was the Cu deficiency that he considered Cu to be an indispensable component of peat reclamation. One application of 30 kg $CuSO_4$/ha was able to check Cu deficiency in nine successive crops. In the studies of Chew et al. [22] conducted on two peats (total Cu 6.5 and 5.6 ppm, Mn 43 and 32 ppm, and Zn 25 and 20 ppm), significant responses to Cu application were confirmed. In Indonesia, the wide coastal plains of eastern Sumatra, western and southern Kalimantan, and the southern coast of West Irian are covered with swamp forests with thick peat layers. On these peat soils, the yield of corn was almost doubled through Cu treatment [49].

Boron. If soils test less than 0.5 ppm hot water-soluble B, they are considered incapable of supplying sufficient B to support normal plant growth. On this basis the majority of the Indian soils are well supplied with B except in certain humid and subhumid areas, such as various parts of Bihar [148]. Ghani and Haque [41] reported that available B in 26 soils from Bengal ranged from 0.4 to 2.0 ppm. Soils frequently flooded with sea water contained higher B than those free from marine influence.

In the southern parts of tropical China, B-deficient soils have been found in large areas [81]. These soils are derived from low B granite and other acid igneous rocks, gneiss, etc. Symptoms of serious B deficiency were observed on these soils in many areas of 11 provinces in southern China. An application of B increased the yield of rape and other B-sensitive crops.

Molybdenum. Relatively little research has been conducted on Mo in humid and subhumid tropical Asia. To some extent this may reflect the inadequacy of available soil tests for Mo. For instance, in spite of the acid nature of a number of Sri Lanka soils tested, a majority of these soils contained more than 0.5 ppm (Grigg) extractable Mo and were suspected to be adequately supplied [108]. However, a beneficial effect from Mo treatment was obtained on soybeans grown on an acid (pH, 5.3) Oxisol. These benefits, due to enhanced N_2 fixation, were measurable in terms of N content as well as yield [168, 169].

Similarly in India, Das Gupta and his associates [31, 28, 29, 30] reported advantages of Mo application to rice not only in terms of yield but in N utilization as well. In variance, Nayar et al. [99] were not able to confirm the usefulness of this treatment for rice grown on an acidic alluvial soil. Except in the findings of Ponnamperuma [114], who reported a positive response of rice to Mo application on an organic soil, no report of Mo deficiency in the Philippines has come to our attention.

A very low dose of Mo (0.5 kg sodium molybdate/ha) applied to foliage at late tillering stage of wheat grown on some alluvial soils of West Bengal brought about a 30% increase in grain yield [131].

Conclusions and future research needs

The interest in micronutrient research in tropical Asia increased following the development of modern crop varieties and Nene's discovery in 1964 of Zn deficiency in rice. Except in India and the Philippines, research on micronutrients is of recent origin and is mostly directed to Zn nutrition of rice. Obviously, there is need to extend this research to other nutrients and crops. In the tropical climate several crops of commercial value such as coconut, coffee, tea, rubber, and cocoa are widely grown. In view of their economic value, studies on micronutrient requirement of these crops should be an important aspect of future research strategies of this region. The role of Cu in peat reclamation needs to be investigated further.

The work on distribution of micronutrients is very sketchy. Rarely an attempt is made to associate micronutrient problems with the parent material, climate, or other soil-forming factors. From all the studies reviewed here, we can merely conclude that total B levels appear low in gneiss, granite, shale, and basalt of the Indian shield, as do Zn levels in the sandstones and schists of the Indo-Chinese massif. Copper deficiency is a problem in peats of the Indonesian archipelago. Information on the basis of well-defined soil classification units is largely lacking. A better knowledge of the micronutrient distribution on this basis would make it possible to delineate geographical areas where micronutrient deficiencies are likely to be constraints to crop production. Large-scale sampling of typical soils and plants of diverse physiographical, climate, and landscape characteristics and evaluation of their micronutrient status in the laboratory and greenhouse would probably be desirable. The existence of micronutrient deficiencies, however, can be proven only through simple field experiments.

Research on micronutrients in tropical Asia is primarily conducted in India and the Philippines. Coordination of research among countries is nonexistent. Aside from the recent effort by IAEA [48] and FAO [143], micronutrient surveys are regional in scope. The organization of a micronutrient workgroup involving all tropical Asian countries to establish unified testing procedures and organize data collection and storage would greatly facilitate the transfer of information among countries and allow for a continuous assessment of the role of micronutrients in this most populous part of the world.

The information gathered thus far points out that for alleviation of micronutrient disorders, treatment of soil with the deficient nutrient is the standard remedy. Few attempts have been made to develop management practices capable of minimizing the use of micronutrients, although this is an important strategy in light of the poor economic conditions of the Asian farmer and the escalating costs of amelioration. The role of organic manures in preventing nutrient deficiencies needs critical evaluation. Selection of varieties tolerant to micronutrient stresses and their adoption on deficient soils can save on nutrients. Finally, because specific genes control a plant's capacity for nutrient absorption, varietal tolerance to available nutrients can be incorporated in the breeding objectives.

References

1. Agarwal HP and Motiramani DP (1966) Copper status in soils of Madhya Pradesh. J Indian Soc Soil Sci 14, 162–171
2. Agarwal HP and Reddy CJ (1972) Distribution of manganese in Vindhyan soils. J Indian Soc Soil Sci 20, 241–247

3. Aiyar SP (1946) The place of minor elements in rice growing. Indian Farm 7, 11–14
4. Anjaneyulu BSR (1964) Availability of manganese in some Indian soils growing sugarcane. J Indian Soc Soil Sci 12, 269–273
5. Aranda VP and Ponnamperuma FN (1977) Iron toxicity: a widespread nutritional disorder of rice in the tropics. 8th annual scientific meeting, Crop Science Soc of Philippines, La Trinidad, Benguet
6. Arunachalam G and Mosi AD (1973) Distribution of forms of iron and manganese in some soils of Tamil Nadu. Madras Agric J 60, 913–917
7. Badhe NN, Naphade KT and Ballal DK (1971) Status of available copper and manganese in soils from Bhandara district in Maharashtra. J Indian Soc Soil Sci 19, 175–178
8. Balaguru T and Mosi AD (1973) Studies on soil molybdenum in Tamil Nadu soils. Madras Agric J 70, 147–151
9. Balasundaram CS, Lakshinarasimha CR, Rajakannu K and Kanakadass A (1972) Water soluble boron status of Tamil Nadu soils. Madras Agric J 59, 426–430
10. Bhadrapur TG, Badiger MK and Panchal YC (1977) Application of zinc, manganese and iron to salt affected soils of TBP area can increase paddy yields. Curr Res 132–134
11. Biswas TD (1951) Manganese status of some Indian soils. Indian J Agric Sci 21, 97–107
12. Biswas TD (1955a) Study of manganese in soil profiles. Proc Nat Acad Sci India, A-24 (Part V), 588–595
13. Biswas TD (1955b) Available manganese in soil. Proc Symp Nat Inst Sci India 8, 25–30
14. Biswas TD and Gawande SP (1946) Relation of manganese in genesis of catenary soils. J Indian Soc Soil Sci 12, 261–267
15. Bleeker P and Austin MP (1970) Relationship between trace element contents and other soil variables in some Papua-New Guinea soils as shown by regression analysis. Aust J Soil Res 8, 133–143
16. Bokde S (1963) Mineral elements in plant nutrition and use of micronutrients. Fertilizer News 9(2), 24–26
17. Bangladesh Rice Research Institute BRRI (1980) International Rice Research Institute Library, SB210B3A516
18. Castro RU (1977) IRRI research paper series No. 9. International Rice Research Institute, Los Banos, Laguna, Philippines, 18 p.
19. Chatterjee RK and Dakshinamurti C (1962) Available molybdenum status of some Indian soils. J Sci Indus Res 21(B), 597–598
20. Chavan DP, Bangar AR and Shingte AK (1980) Zinc, manganese, boron, and molybdenum distribution in soil profiles of different agroclimatic zones of Maharashtra. J Maharashtra Agricultural Univ 5(3), 182–189
21. Chavan DP, Kulkarni PG and Patil ND (1971) Response of wheat to foliar application of molybdenum. Indian J Agric Chem 5, 9–12
22. Chew WY, Joseph KT and Ramli K (1979) Influence of applied copper and other micronutrients on groundnut (*Arachis hypogaea*) and sorghum (*Sorghum bicolor*) on Malaysian Oligotrophic peat. Trop Agric (Trinidad) 56, 25–32
23. Chowdhury MY, Ali S, Zaman W, and Altamas SV (1978) Effect of phosphorus and zinc sulphate on the yield and the protein contents of rice grains. Indian J Agric Chem 11, 69–76
24. Coulter JK (1958) Mineral nutrition of the oil palm. Malaysian Agric J 41, 131
25. Dakshinamurti C, Satyanarayana KVS and Singh B (1955) Preliminary studies on the micronutrient status of Delhi soils. Proc Nat Acad Sci India A-24, 566–572
26. Dargan KS and Sahni VM (1965) Studies on the effect of micronutrients on the yield and economic character of American cotton. Indian Cotton J 19, 373–375
27. Das MC, Bora PK, Sharm SC and Sarmah KL (1971) Manganese status of Assam soils. Fertilizer News 16(2), 42–44
28. Das Gupta DK and Basuchaudhuri P (1974a) Effect of molybdenum on the nitrogen metabolism of rice. Expe Agric 10, 251–255

29. Das Gupta DK and Basuchaudhuri P (1974b) A method to increase protein content of wheat. Curr Sci 43, 495–496
30. Das Gupta DK and Basuchaudhuri (1978) Molybdenum nutrition in rice. International Bioscience Monograph, 69 p
31. Das Gupta DK and Bera GS (1972) Effect of molybdenum on nitrogen utilization in rice. Fertilizer News, 17(6), 89–90
32. Dastur RH and Singh K (1953) A study of the effect of trace elements on the growth and yield of American cotton. Indian Cotton Growers Review. 7(1), 57–66
33. De NK and Chatterjee BN (1976) Effect of trace elements on the growth and yield of groundnut in leached sandy loam soil. Indian J Agron 21, 209–216
34. De NK and Chatterjee BN (1978) Effect of trace elements on rice in the leached soils of Indian sub-tropics. Riso 27, 243–252
35. Deshmukh VA, Deshpande TL and Ballal DK (1974) Response of hybrid jowar (CSH-1) to the application of zinc and manganese. J Indian Soc Soil Sci 22, 201–202
36. Duarte UM, Leley VK and Narayana N (1961) Micronutrient status of the Bombay state soils. J Indian Soc Soil Sci 9, 41–53
37. Food and Agriculture Organization of the United Nations (1977) FAO-UNESCO soil map of the world. 1:500 000 Volume, South Asia, United Nations Educational Scientific, and Cultural Organization, Place de Fontemoy, 75, Paris
38. Food and Agriculture Organization of the United Nations (1979) FAO-UNESCO soil map of the world. 1:500 000 Volume, South Asia, United Nations Educational, Scientific, and Cultural Organization, Place de Fontemoy, 75, Paris
39. Food and Agriculture Organization of the United Nations (1982) FAO Production Yearbook (1981). FAO, Rome, Italy, Vol. 35
40. Ganjir BL, Sinha SB and Bhargava BS (1973) Zinc status of some soils of Madhya Pradesh. J Indian Soc Soil Sci 21, 447–454
41. Ghani MO and Haque AKMF (1945) Studies on the boron status of some West Bengal soils. Indian J Agric Sci 15, 257–262
42. Glinski J and Thai VC (1971) Soluble trace elements (Mn, Cu, B, Zn, Mo) in the soils of North Vietnam. Polish J Soil Sci 4, 125–130
43. Gopala Rao HG (1956) Effect of green manuring to red loamy soils freshly brought under swamp paddy cultivation with particular reference to availability of iron and manganese. J Indian Soc Soil Sci 4, 225–231
44. Haldar MP and Mandal LN (1979a) Distribution of Zn and Cu in lowland rice soils of West Bengal. Indian Agriculturist 23, 31–42
45. Haldar MP and Mandal LN (1979b) Influence of soil moisture and organic matter application on the extractable Zn and Cu contents in rice soils. Plant Soil 53, 203–213
46. Hidayal A, Ayub WG and Ismunadji M (1979) Copper and zinc status of wetland rice soils of Central Java of Indonesia. Progress report, Phys Div Bogor Research Institute of Food Crops
47. Hidayal A, Sudarman O and Ismunadji M (1981) Nutrient status of Sitiung transmigration area. Penilitian Pertanan 1, 2 (in Indonesian)
48. IAEA 1981 Zinc fertilization of flooded rice. IAEA-TECDOC 242, Vienna, Austria
49. Ismunadji M, Hidayat A and Fathan R (1982) Micronutrient problems in upland soils in Indonesia. Tropical Agriculture Research Series No. 15, 289–296
50. Iyer JG (1958) Copper status of the grassland soils of western India. J Biol Sci (Bombay) 1, 13–21
51. Iyer CRH and Rajagopalan R (1936) Determination of manganese in soils. J Indian Inst Sci A-19, 57–66
52. Iyer JG and Satyanarayan Y (1958) Trace elements in soils. I. Boron J Univ Bombay, B-26 (Part V), 18–25
53. Jha KK (1964) Review of work on micronutrient elements in Bihar. J Indian Soc Soil Sci 12, 235–241
54. Jones US, Katyal JC, Mamaril CP and Park CS (1980) Wetland rice-nutrient deficiencies other than nitrogen. Rice research strategies for the future, pp. 327–378. International Rice Research Institute, Los Banos, Philippines

55. Joshi NV and Joshi SG (1952) Effect of copper sulphate on rice in Bombay state. Sci Cult 18, 96–107
56. Joshi NV and Joshi SG (1957) Copper as fertilizer. J Indian Soc Soil Sci 5, 21–29
57. Juang Tzo-Chuan, Ming-nuh Kao and Chin-hua Chang (1976) The effect of zinc application on yield and micronutrient content of sugarcane. Nung Lin Hsueh Pro. 25, 103–112
58. Kabeerathumma S and Patnaik S (1978) Effect of submergence on the availability of toxic and deficient nutrients in acid sulphate soils of Kerala. Agric Res J Kerala 16, 181–187
59. Kalpage FSCP (1967) Manganese in soils and tea under Grevillea shade. Trop Agric Trinidad 44, 209–214
60. Kalpage FSCP and Silva CG (1968) Studies of the manganese status of the rubber soils of Ceylon. Rubber Research Institute of Ceylon, Quarterly J 44, 8–15
61. Kanapathy K (1972) Copper requirement and residual effect with maize on a peat soil. Malaysian Agric J 48, 249–263
62. Kanwar JS (1982) Managing soil resources to meet the challenge to mankind: presidential address. 12th Int Congress of Soil Sci, New Delhi, India
63. Katyal JC (1972) A study of zinc equilibria in flooded soils and amelioration of zinc deficient soils of Agusan-del-Norte. Terminal Report, International Rice Research Institute, Los Banos, Philippines, 115 p
64. Katyal JC (1977) Influence of organic matter on the chemical and electrochemical properties of some flooded soils. Soil Biol Biochem 9, 259–266
65. Katyal JC and Agarwala SC (1982) Micronutrient research in India. Fertilizer News 27(2), 66–86
66. Katyal JC and Ponamperuma FN (1974) Zinc deficiency: a widespread nutritional disorder of rice in Agusan-del-Norte. Philippines Agriculturist 58, 79–89
67. Katyal JC and Sharma BD (1979) Role of micronutrients in crop production. Fertilizer News, 24(9), 33–50
68. Katyal JC, Sharma BD and Mehta SK (1981) 13th annual report of the ICAR's all India coordinated scheme of micronutrients in soils and plants for the year 1979/80, 66 p
69. Katyal JC, Sharma BD and Mehta SK (1982) 14th annual report of the ICAR's all India coordinated scheme of micronutrients in soils and plants for the year 1980/81, 63 p
70. Kavimandan SK, Badhe MN and Ballal DK (1964) Available copper and molybdenum in Vidarbha soils. J Indian Soc Soil Sci 12, 281–282
71. Kene DR and Deshpande TL (1980) Effect of application of zinc, manganese and iron on the biological quality of grain of hybrid sorghum grown in black soils. J Indian Soc Soil Sci 28, 199–202
72. Khamparia RS, Gupta GP, and Rathove GS (1977) Relative response of zinc sulphate and trace as sources of zinc to paddy grown in black soils of Jabalpur (M.P.) JNKVV Res J 11 (3 and 4), 173–176
73. Koch DEV (1946) The manganese content of some Ceylon soils. Trop Agriculturist 102, 219–223
74. Krishnamurthy KK, Rajagopal CK, Sheriff MM and Selvakumari G (1975) Micronutrient status of Tamil Nadu soils. SIISTA Sugar J S.J.-1, 1–6
75. Krishnamoorthy CH, Venkateswarlu J, Reddy MG, Ramakrishna and Rao GV Murli Mohan (1971) Zinc deficiency in rice in Andhra Pradesh. Proc Int Symp Soil Fert Evaluation, New Delhi, 1, 955–967
76. Lal F and Biswas TD (1973) Factors affecting the distribution and availability of micronutrient elements in major soil groups of Rajasthan, I. Surface soils. J Indian Soc Soil Sci 21, 455–466
77. Lal F and Biswas TC (1974) Factors affecting the distribution and availability of micronutrient elements in major soil groups of Rajasthan. II. Soil Profiles. J Indian Soc Soil Sci 22, 333–346
78. Lal BM, Sahu D and Das NB (1959) Studies on available copper on some Indian soils. Curr Sci 28, 494

79. Lal BM, Sahu D and Das NB (1960) Available zinc status of some Indian soils. Curr Sci 29, 316
80. Lantin RJ, Cayton MTC and Ponnamperuma FN (1980) Boron toxicity in wetland rice and dryland crops on some soils of volcanic origin. 11th Annual Scientific Meeting, Crop Science Soc, Phil, VISCA, Baybay, Leyte
81. Liu Z, Zhu Q and Tong L (1980) Boron deficient soils and their distribution in China. Tu Jang Hsuch Pao. 17, 228–239
82. Lodha PS and Baser BL (1971) Available copper, boron, and iron status of Rajasthan soils. J Indian Soc Soil Sci 19, 407–413
83. Malewar GU and Randhawa NS (1978) Clay mineralogical makeup of Marathwada soils and their relationship with the content of zinc, iron, manganese, and copper. J. Maharashtra Agricultural Univ 3(1), 1–4
84. Mali CV and More SD (1977) Distribution of molybdenum and zinc in the profiles of various soil types. Research Bull Marathwada Agricultural Univ 1(2), 19–20
85. Mamaril CP (1983) Zinc and sulfur deficiencies in wetland rice in Asia. Paper presented at the International Rice Research Conference held at IRRI, Los Banos, Philippines, April 1983
86. Mandal LN (1961) Transformation of iron and manganese in waterlogged rice soils. Soil Sci 91, 121–126
87. Mandal LN and Nandi SN (1971) Influence of intensity of soil reaction on the availability of iron, manganese and phosphorus and the growth and nutrition of rice. J Indian Soc Soil Sci 19, 237–242
88. Mathur CM, Moghe VB and Talati MR (1964) Distribution of boron in soils of western Rajasthan irrigated with high boron waters. J Indian Soc Soil Sci 12, 319–324
89. Mazumdar DK (1973) A note on response of wheat variety Kalyan 227 to micronutrients. Indian Agriculturist. 17(1), 141–142
90. Mehta BV, Dangarwala RT, Trivedi BS, Meisheri MB and Rama S (1973) Response of wheat to Zn application in North Gujarat. Fertilizer News 18(10), 32–35
91. Mehta BV and Patel NK (1967) Forms of manganese and their distribution in soil profiles of Kaira district in Gujarat. J Indian Soc Soil Sci 15, 41–47
92. Mehta BV, Reddy GR, Nair GK, Gandhi SC, Neelakantan V and Reddy KG (1964) Micronutrient studies in Gujarat soils and plants. J Indian Soc Soil Sci 12, 329–342
93. Misra SG and Pandey G (1976) Zinc in saline and alkali soils of Uttar Pradesh. J Indian Soc Soil Sci 24, 336–338
94. Moghe VB and Mathur CM (1966) Status of boron in some acid soils of western Rajasthan. Soil Sci Plant Nutr 12, 11–14
95. Mudahar MS (1979) Issues in the evolution of fertilizer price policy. 17th Int Conf of Agric Econ, Banff, Canada
96. Murthy KSN and Mehta BV (1974) Studies on the fixation of zinc. Plant Soil 41, 215–221
97. Nair GGK and Mehta BV (1959) Status of zinc in soils of western India. Soil Sci 87, 155–159
98. Nandi S and Mandal LN (1979) Effect of application of phosphorus, iron and manganese under different moisture regimes on the yield and nutrition of rice. J Indian Soc Soil Sci 27, 150–157
99. Nayar PK, Misra AK, Rao AVS and Patnaik S (1980) Effect of nitrogen rates with and without foliar application of molybdenum on the yield, micronutrient content and uptake by rice plant. Riso 29, 35–41
100. Neelakantan V and Mehta BV (1961) Copper status of soils of western India. Soil Sci 91, 251–256
101. Nene YL (1965) Symptoms, cause and control of Khaira disease of paddy. Bull Indian Phytopath Soc 3, 97–101
102. Orticio MR and Ponnamperuma FN (1977) Zinc deficiency: a widespread nutritional disorder of rice in the Philippines. 8th Annual Scientific Meeting, Crop Science Soc of Philippines, La Trinidad, Benguet
103. Papadakis J 1966 Climates of the world and their agricultural potentialities. The Author, Buenos Aires

104. Patel MS, Mehta PM and Pandya HG (1972) Study of manganese distribution and availability in South Gujarat soils. J Indian Soc Soil Sci 20, 79–90
105. Pavanasasivam V (1973) Manganese studies in some soils with a high organic matter content. Plant Soil 38, 245–257
106. Pavanasasivam V and Kalpage FSCP (1969) Dithizone extractable zinc in rubber soils of Ceylon. Trop Agriculturist 125, 15–20
107. Pavanasasivam V and Kalpage FSCP (1974a) Status of zinc and copper in the wet-patana soils of Sri Lanka. Trop Agriculturist 130, 191–200
108. Pavanasasivam V and Kalpage FSCP (1974b) Molybdenum status of some organic matter rich montane soils of Sri Lanka. J Indian Soc Soil Sci 22, 352–356
109. Pillai KM (1967) Response of paddy to application of micronutrients. Indian J Agron 12, 151–155
110. Ponnamperuma FN (1955) The chemistry of submerged soils in relation to the growth and yield of rice. Unpublished Ph D thesis, Cornell Univ., Ithaca, New York, 208 p
111. Ponnamperuma FN (1965) Dynamic aspects of flooded soils and the nutrition of the rice plant. Pages 295–328 in Proc of Symp. The Mineral Nutrition of the Rice Plant held at IRRI, John Hopkins Press, Baltimore, Maryland, USA
112. Ponnamperuma FN (1972) The chemistry of submerged soils. Adv Agron 25, 29–96
113. Ponnamperuma FN (1974) Micronutrient limitations in acid tropical rice soils. Pages 330–347 in Soil Management in Tropical America (Eds. E. Bornemisza and A Alverado). North Carolina State University, Raleigh, North Carolina, USA
114. Ponnamperuma FN (1977) Behaviour of minor elements in paddy soils. IRRI Research Paper Series No. 8, International Rice Research Institute, Los Banos, Laguna, Philippines, 15 p
115. Rai MM, Dighe JM and Pal AR (1972a) Availability of copper in deep black soils of Madhya Pradesh. J Indian Soc Soil Sci 20, 135–142
116. Rai MM, Pal AR, Chimania BP, Shitoley DB and Vakil P (1972b) Available micronutrient status of shallow black soils of Madhya Pradesh. J Indian Soc Soil Sci 20, 129–134
117. Rai MM, Pal AR, Sharma RB, Khamparia RS, Tomar RAS, and Dighe JM (1979) Zinc and iron status of the Vertisols (medium black soils) of Madhya Pradesh, JNKVV Res J 10, 248–250
118. Rai MM, Shitoley DB, Pal AR, Vakil P and Gupta SK (1970) Available micronutrient status of deep black soils of Madhya Pradesh. J Indian Soc Soil Sci 18, 383–389
119. Rajagopal CK, Sheriff MM, Selvakumari G and Jabarani W (1977) Status of available micronutrient cations in the soils of Kerala. Agric Res J Kerala 15, 165–171
120. Rajagopal CK, Sheriff MM, Selvakumari G, Madappan K and Devarajan R (1974) Relation between organic carbon and available micronutrients in the soils of the Nilgiris. J Indian Soc Soil Sci 22, 347–351
121. Raju S, Shivappa TG, Sadashivaiah T and Kulkarni KR (1978) Response of Madhu variety of paddy to nitrogen, phosphorus, potash and zinc on farmers' fields in Mysore district. Mysore J Agric Sci 12, 63–68
122. Ramakrishnan S and Kaliappa R (1976) Methods and rates of application of Zn in relation to NPK fertilization in maize. Madras Agric J 63, 269–271
123. Ramanathan G and Nagarajan r 91980) A note on response of CBS 156 cotton to Zn application. Madras Agric J 67, 481–482
124. Ranadive SJ, Naik MS and Das NB (1964) Copper and zinc status of Maharashtra soils. J Indian Soc Soil Sci 12, 243–248
125. Rao ALS (1937) Studies on the physical and chemical properties of some sugarcane soils. Proc Indian Acad Sci B-6, 91–97
126. Rastogi SK and Rai MM (1978) Bioassayed and organic zinc status of some of the medium black soils of Madhya Pradesh. Food Farming Agriculture. 10(1), 12–13
127. Rathore GS, Khamparia RS, Gupta GP and Sinha SB (1980) Availability of micronutrients in some alluvial soils and their effect on wheat. J Indian Soc Soil Sci 28, 248–250

128. Raychaudhuri SP and Datta Biswas NR (1964) Trace element status of Indian soils. J Indian Soc Soil Sci 12, 207–214
129. Reddy GR (1964) Molybdenum status of western India soils. Indian J Agric Sci 34, 219–233
130. Samui RC and Bhattacharya AK (1973) A preliminary investigation on the foliar application of micronutrient fertilizers and soil application of calcium sulphate on wetland rice. Indian Agriculturist 17, 211–218
131. Samui RC, Das NR and Bhattacharya P (1979) Grain, straw, and dry matter yields of the late sown wheat as affected by micronutrients and varieties. Indian J Agron 24, 432–434
132. Satyanarayan Y (1958) Trace element status of the cotton soils of Gujarat. Indian Cotton Congress Review 12, 138–141
133. Savithri P and Sree Ramulu US (1980) Effect of continuous application of Zn, Cu and Fe on yield and availability of nutrients in cropping systems. J Indian Soc Soil Sci 28, 371–374
134. Saxena NP, Sheldrake AR (1980) Iron chlorosis in chickpea (*Cicer arietinum* L.) grown on high pH calcareous Vertisol. Field Crops Research 3, 211–214
135. Sharma SG and Motiramani DP (1964) Manganese status of soils of Madhya Pradesh. J Indian Soc Soil Sci 12, 249–254
136. Sharma RB and Motiramani DP (1969) Zinc status of the soils of Madhya Pradesh. J Indian Soc Soil Sci 17, 19–26
137. Sharma OP and Shinde BA (1968) Manganese status of black soils of Indore district. J Indian Soc Soil Sci 16, 65–69
138. Shinde PH, Khilari JM, Kale SP and Khanyilkar GS (1977) Effect of graded levels of zinc compounds applied through two sources on yield of wheat. J Maharashtra Agricultural Univ 2(3), 214–216
139. Shinde PH, Kale SP, More DA and Zende GK (1980a) Effect of soil and foliar application of molybdenum on yield of four varieties of wheat. J Maharashtra Agricultural Univ 5(2), 140–142
140. Shinde PH, More DA and Zende GK (1980b) Status of available zinc, copper, and molybdenum in soils from the sugarcane growing areas of Pune district (Maharashtra). J Maharashtra Agricultural Univ 5(1), 1–4
141. Shorrocks VM (1981a) Micronutrient problems in Southeast Asia. Fertilizer International, 143 (May 1981) 43, 45, 53
142. Shorrocks VM (1981b) Micronutrient problems in Asia – Part II. Fertilizer International, 144 (June 1981) 9, 11
143. Sillanpää M (1982) Micronutrients and the nutrient status of soils. FAO Soils Bull 48, FAO, Rome, Italy
144. Singh M (1970) Distribution of boron in relation to soil properties. J Indian Soc Soil Sci 18, 141–146
145. Singh D, Dogra RS and Dikshit (1969) Copper status of medium black soils (Indore district) Madhya Pradesh. Indian J Agric Chem 2, 66–73
146. Singh S and Singh RS (1972) Studies on water soluble boron in manganese rich saline alkali soils of southwest tracts of Bihar. J Indian Soc Soil Soc 20, 143–149
147. Singh KP and Sinha H (1975) Fixation of boron in relation to certain soil properties. J Indian Soc Soil Sci 23, 227–230
148. Sinha H and Singh SP (1966) Boron status of Bihar soils. Ranchi Univ J Agric Res 1, 47–52
149. Snitwongse P (1978) Isotope-aided micronutrient studies in rice production with special reference to zinc deficiency. IAEA Cooperators Meeting. Bogor Agric Univ Bogor, Indonesia
150. Soepardi G (1981) The zinc status in Indonesian agriculture, Department of Soil Science, Fac of Agric, Bogor, Agric Univ (mimeograph)
151. Soepardi G, Idris K, Siswore WH and Suwadji E (1977) Zinc deficiency in paddy soils in West Java, Indonesia. I. Preliminary study. II. The effect of Zn uptake in rice production. At Indones, 3(2), 15–20
152. Soepartini MS, Widjik IM, Sudjadi M (1980) Copper and zinc status of Indonesian soils. Soil Research Institute, Bogor, Indonesia (mimeograph)

153. Solanky BS, Sinha SB and Mahadik ON (1973) Response of groundnut to foliar application of Mg, Mn, and Zn application in medium black soils of Indore (Madhya Pradesh). JNKVV Res J 7(1), 2–3
154. Sreedharan C and George CM (1969) Effect of micronutrients on paddy in a red loam soil of Kerala. Agric Res J Kerala 7(2), 61–66
155. Subbarao IV (1975) Nutritional disorders of crops in Andhra Pradesh. Technical Bulletin No. 1, Andhra Pradesh Agricultural Univ, Hyderabad, India, 52 p
156. Subramanyam AV and Mehta BV (1974) Effect of Zn and Fe application on the yield and the chemical composition of rice. Indian J Agric Sci 44, 602–607
157. Talati NR and Agarwal SK (1974) Distribution of various forms of boron in North-west Rajasthan soils. J Indian Soc Soil Sci 22, 262–268
158. Tambhare BR and Rai MM (1967) Effect of pH, calcium carbonate, texture and organic matter on the availability of manganese. J Indian Soc Soil Sci 15, 251–256
159. Tanaka A and Yoshida S (1970) Nutritional disorders of rice plant in Asia. IRRI Tech Bull 10, Los Banos, Laguna, Philippines, 51 p
160. Tekale RR and Ghonsikar CP (1977) A note on the copper status of some soils of Prabhani district. Research Bulletin, Marathwada Agricultural Univ 1(10), 143–145
161. Tricart J (1972) The landforms of the humid tropics, forests and savannas. St. Martin's Press, New York
162. Troll C (1966) Seasonal climates of the earth. IN Rodenwalt, E and JH Jusatz (Ed.). World maps of climatology. Heidelberger Akademie Der Wissenschaften. Springer-Verlag Berlin-Heidelberg, New York, 28 p
163. Vamadevan VK and Mariakulandai A (1972) Influence of forms and levels of manganese on rice. Riso 21, 247–251
164. Van Breemen N and Castro RU (1980) Zinc deficiency in wetland rice along a toposequence of hydromorphic soils in the Philippines. II. Cropping Experiment. Plant and Soil 57, 215–221
165. Van Breemen N and Moormann FR (1978) Two toxic soils. In Int Rice Research Inst Soils and Rice, pp 781–800. IRRI, Los Banos, Philippines
166. Van Breemen N, Quijano CC and Sen Le Ngoc (1980) Zinc deficiency in wetland rice along a toposequence of hydromorphic soils in the Philippines. I. Soil conditions and hydrology. Plant Soil 57, 203–214
167. Verma KP and Jha KK (1970) Studies on soil molybdenum of Bikar. J Indian Soc Soil Sci 18, 37–40
168. Weeraratna CS (1980a) Studies on the molybdenum application to soybean. Beitrage trop. Landwirtsch. Veterinarmed 18, 131–134
169. Weeraratna CS (1980b) Studies on molybdenum application to soybean. In World Soybean Research Conference (Ed. F T Corbin), p 14–15. II Westview Press, Boulder, Colorado, USA
170. Yoshida S, Ahn JS and Forno DA (1973) Occurrence, diagnosis and correction of zinc deficiency of lowland rice. Soil Sci Plant Nutr 25, 121–134
171. Zende GK and Pharande KS (1964) Distribution pattern of soil manganese in major soil types on different canals of Bombay Deccan. Indian Sugarcane J 9 (Part I), 46–51