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Geographical Distribution of Potential Problem Areas with Micronutrient Anomalies in Tropical Asian Paddy Soils

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The geographical distribution and patterns of occurrence of trace element deficiency and toxicity have been reported for many areas of the world [Brogan *et al.* 1973; Department of Scientific and Industrial Research 1967; Kubota and Allaway 1972; Thornton and Webb 1980]. Maps outlining the areas of reported trace element problems have been prepared.

In most cases, the assessment of the problem areas was based on the effects of trace elements on plant growth and animal health and the analysis of stream sediments from a few locations, together with a large degree of geographical extrapolation.

In Tropical Asia, there has as yet been no systematic appraisal of the regional distribution of trace element problems in soils, although some reports point out the existence of trace element problems. These have been recognized in certain rice-growing areas and have been demonstrated under controlled conditions of nutrition [*IRRI* 1971; 1972; 1976; Ponnamperuma 1974; Tanaka and Yoshida 1970; Yoshida and Forno 1971].

Although there are no maps showing the distribution of trace elements in soils, the results of this study will provide valuable baseline data that may be used for the regional assessment of the trace element status of the soils in Tropical Asia.

This paper discusses the extractable trace element status of Tropical Asian paddy soils. Since many of these paddy soils might also be utilized for upland crops and foliage crops for fodder, the following essential trace elements were examined: boron, cobalt, copper, manganese, molybdenum, and zinc. In addition, this study was performed to provide information about the areas where deficiency and toxicity problems may arise in crops, and at the same time to delineate areas of critical trace element levels.

Materials and Methods

The soils used for the study have been described in earlier works [Kawaguchi and Kyuma 1977; Kyuma 1976; 1977; 1978]. They were chosen as being representative

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of various regions and materials in Tropical Asia. A total of 407 paddy soil samples were analyzed for the extractable trace elements by inductively coupled argon plasma atomic emission spectroscopy (ICAP-AES). The extractants used were 0.1N hydrochloric acid (HCl), 2.5% acetic acid (HAc), and water (H_2O). The methods of extraction were based on those of Mitchell [1964], Martens and co-workers [1966], and Lowe and Massey [1965].

Statistical Treatment

To obtain information on areas containing threshold levels of trace elements, the values for all the extractable trace elements were presented in histograms. Data showing positively skewed distributions were log-transformed to approximate them to a normal distribution. Means and the standard deviations were computed, and values deviating from the means by two standard deviations or more were considered to be abnormal.

Locating the Problem Areas

To locate the problem areas, HAc-extractable data were used. Values falling outside the normal range were plotted on maps.

Results and Discussion

Extractable Trace Elements by Countries

The amounts of trace elements extracted from Tropical Asian paddy soils by the three extractants are given in Figs. 1–6, which show the mean and its range of variation (plus or minus one standard deviation with log-transformed data).

1. Extractable Boron Contents

In general, values for the three extractable forms are high in the soils of Burma, India, Indonesia, and the Philippines. Low values were seen in Cambodia, Thailand, and West Malaysia. The soils

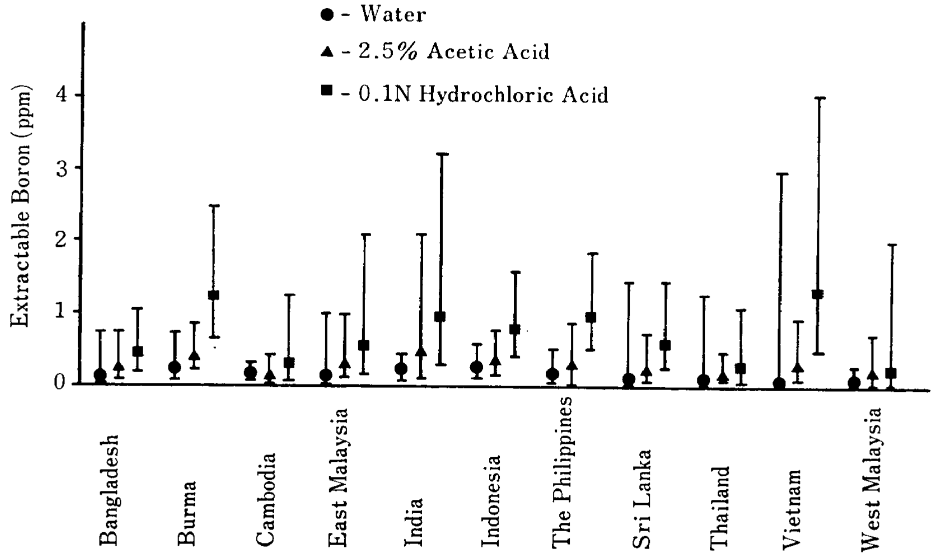

Fig. 1 Extractable Boron in Tropical Asian Paddy Soils (The range shows mean plus or minus one standard deviation for log-transformed data.)

of Bangladesh, East Malaysia, and Sri Lanka are similar in their contents of the three extractable forms. Vietnamese soils had high amounts of the HCl and HAc-extractable forms but a low amount of the H_2O-extractable form.

2. Extractable Cobalt Contents

Similar patterns of distribution of the three extractable forms were found in Burma, India, Indonesia, the Philippines, and Vietnam on the one hand, and in Bangladesh, Cambodia, East Malaysia, and Sri Lanka on the other. West Malaysian soils contained the lowest amounts of the three extractable forms.

It is interesting to note that, in general, soils with high amounts of the three extractable forms of boron had low amounts of the three extractable forms of cobalt, and *vice versa*. Though not shown here, correlation analysis revealed generally low but significant negative correlations among the different extractable forms of boron and cobalt.

3. Extractable Copper Contents

With the exception of West Malaysian soils, the HCl-extractable copper values in Tropical Asian paddy soils ranged from 1–4 ppm. West Malaysian soils had the lowest values for the three extractable

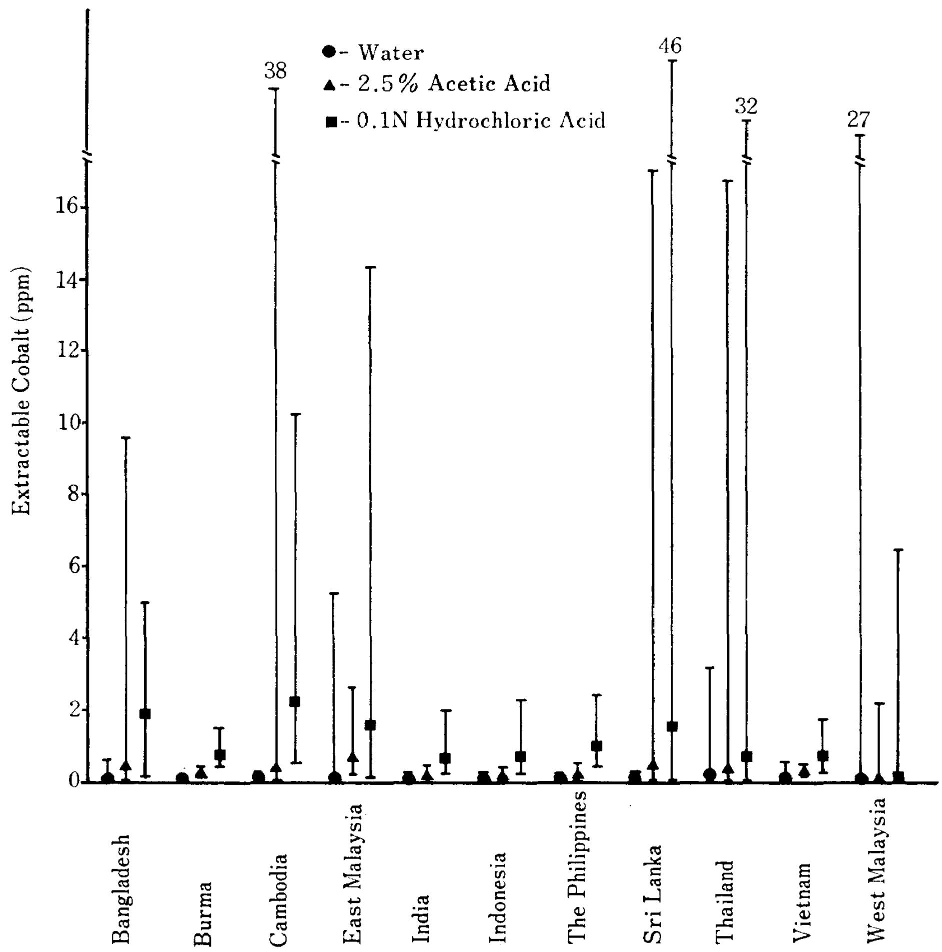

Fig. 2 Extractable Cobalt in Tropical Asian Paddy Soils (The range shows mean plus or minus one standard deviation for log-transformed data.)

forms, probably owing to their high organic matter content. Values for the HAc and H_2O-extractable copper are of more or less the same magnitudes. Bangladeshi soils contained high amounts of HCl and HAc-extractable copper, whereas the H_2O-extractable form was not detected.

4. Extractable Manganese Contents

Among the trace elements studied, manganese was extracted in highest amounts by HCl and HAc. The highest values were observed in Philippine and Indonesian soils. Burmese and Indian soils also contained high amounts of HCl and HAc-extractable manganese. East and West Malaysian soils had appreciably low values of the three extractable forms. The same patterns of distribution for HCl and HAc-extractable forms were observed in the soils of Bangladesh, Cambodia, and Sri Lanka.

Contents of H_2O-extractable manganese varied little in most of the soils of Tropical Asia, with the exceptions of Cambodian and Burmese soils, where they were low. The highest value was found in Sri Lanka, followed by Thailand.

5. Extractable Molybdenum Contents

The contents of HCl-extractable molybdenum were of almost the same magnitude in practically all the Tropical Asian paddy

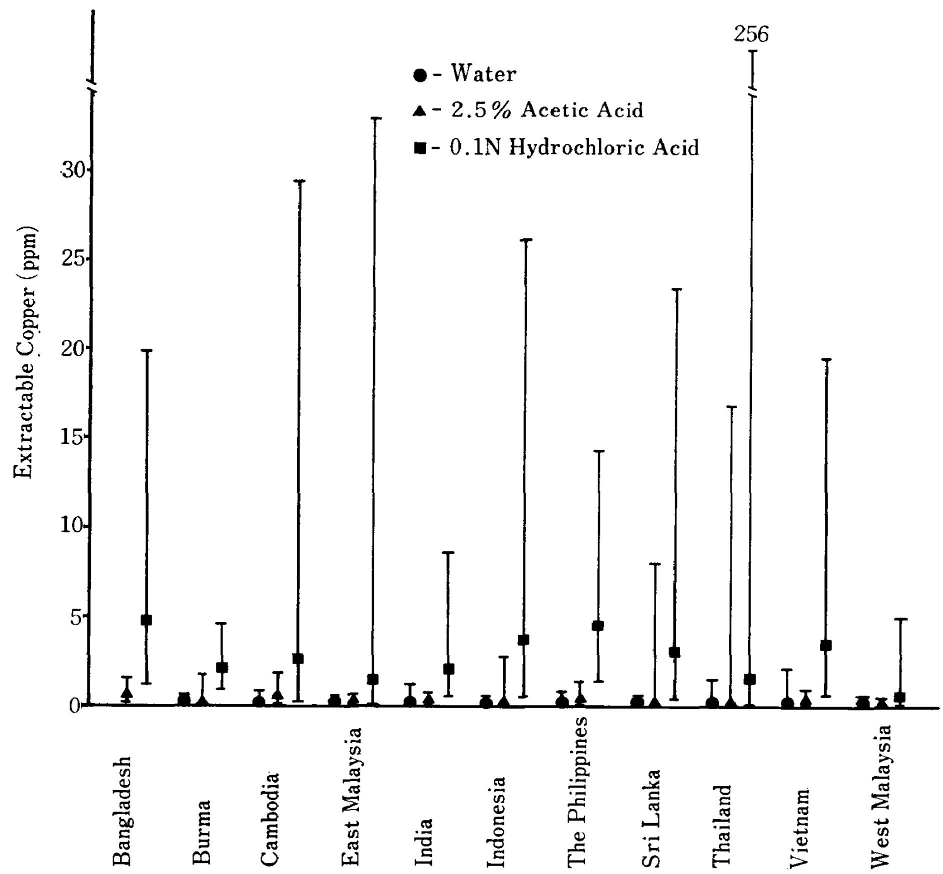

Fig. 3 Extractable Copper in Tropical Asian Paddy Soils (The range shows mean plus or minus one standard deviation for log-transformed data.)

soils, ranging from 1.34 to 1.84 ppm. HAc and H_2O-extractable molybdenum contents were for the most part the same. Indonesian soils had the lowest amount of HAc-extractable molybdenum, with lower values than the H_2O-extractables. Reasons for the low values can not be readily given, but the amount of iron oxide in the soils and the pH of the extracting solutions have some relevance.

Wells [1956] in a study of molybdate ion fixation in New Zealand soils considered amorphous iron and aluminum oxides to be responsible for molybdate "retention". Much of this "fixed" molybdate ion could be released by moderately alkaline solutions [Stout *et al.* 1951]. The pH range of maximum adsorption as determined experimentally is 3 to 6. Above pH 6 adsorption falls off rapidly, and practically none is adsorbed above pH 8 [Ishibashi *et al.* 1958; Jones 1957].

6. Extractable Zinc Contents

The soils of Burma, India, Indonesia, and the Philippines on the one hand, and of Bangladesh, Sri Lanka, Thailand, Vietnam, and West Malaysia on the other, had almost the same contents of the three extractable forms. Cambodian soils contained the lowest amounts. East Malaysian soils had a high amount of the HCl-extractable form but low amounts of the

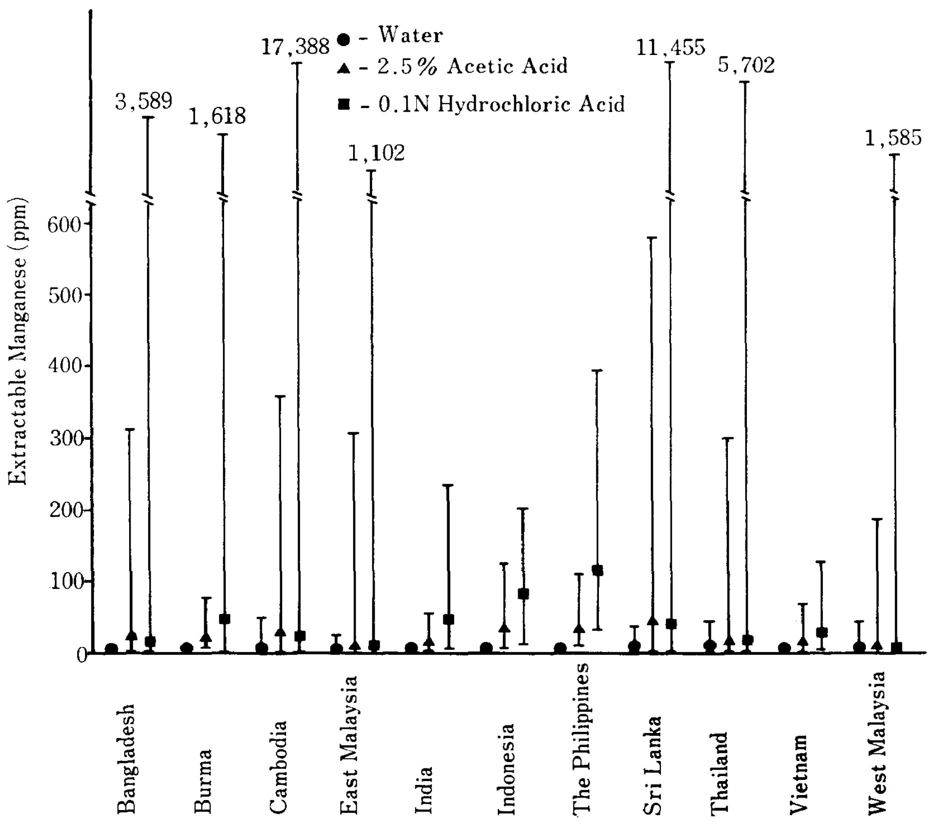

Fig. 4 Extractable Manganese in Tropical Asian Paddy Soils (The range shows mean plus or minus one standard deviation for log-transformed data.)

HAc and H_2O-extractable forms.

Geographical Distribution of Trace Element Abnormalities

To locate problem areas, as mentioned earlier, the HAc-extractable data were used. Although our findings indicated that 0.1N HCl was the best of the three extractants in that it extracted the largest amounts of the trace elements, it was felt that this method might not provide a reliable index of the trace elements available to plants. Being a strong acid, it would be expected to remove considerably more trace elements than would be available for plant uptake in one growing season.

Alternatively, the H_2O-extraction seems to be a fairly reliable method of determining the available trace elements at a given instant. However, it does not give indication of the soil's ability to supply additional soluble trace elements when those initially present are removed [Lowe and Massey 1965].

It is reasonable to assume that HAc method provides a good measure of the plant-available trace elements for the present purpose, since the values generally fall between those of HCl and H_2O.

As a preliminary step in the assessment of potential problem areas with micro-

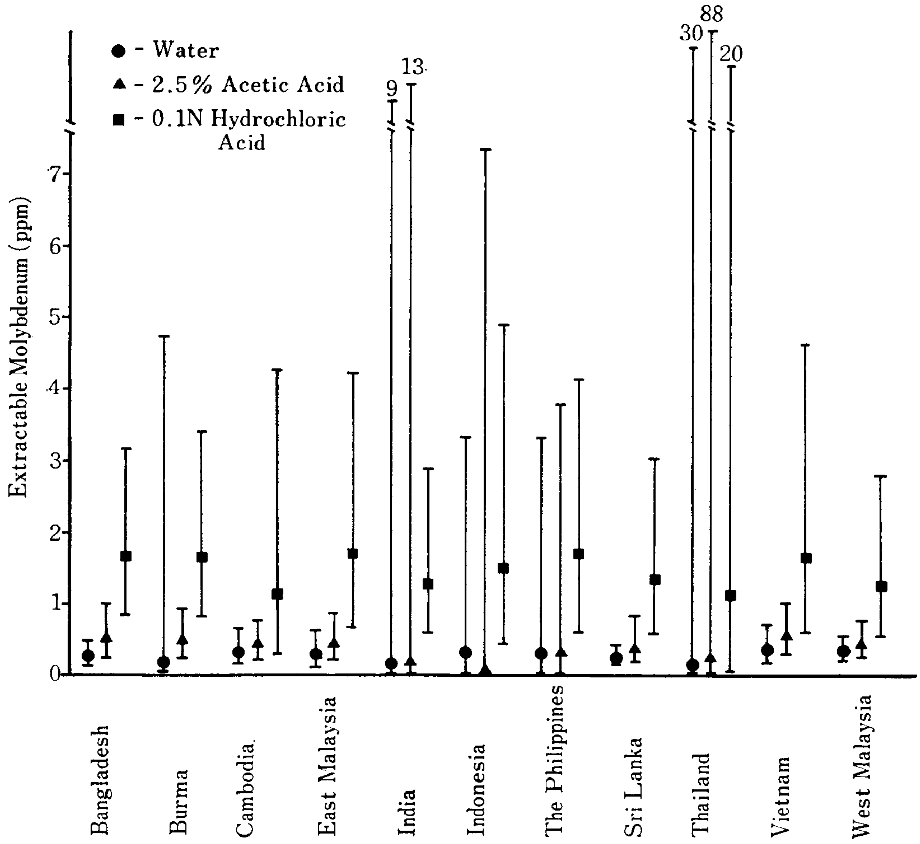

Fig. 5 Extractable Molybdenum in Tropical Asian Paddy Soils (The range shows mean plus or minus one standard deviation for log-transformed data.)

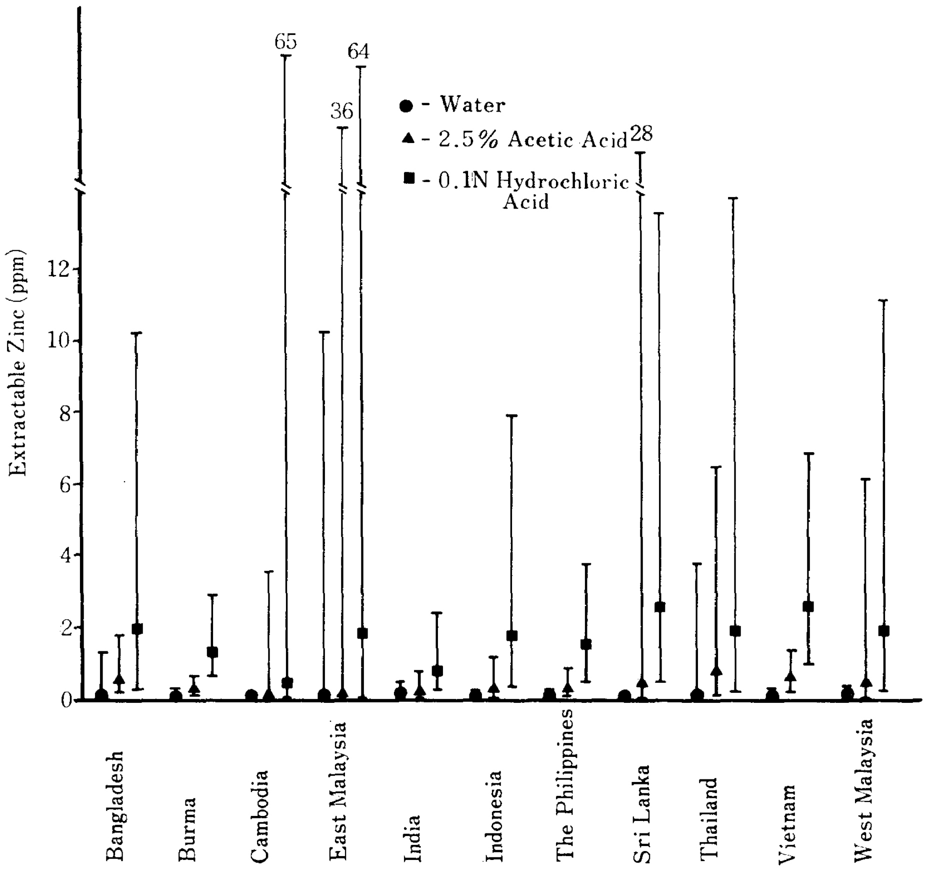

Fig. 6 Extractable Zinc in Tropical Asian Paddy Soils (The range shows mean plus or minus one standard deviation for log-transformed data.)

nutrient anomalies, the HAc-extractable trace element data were plotted in histograms, shown in Figs. 7–12, to determine the distribution pattern of each element.

The histograms reveal that, with the exception of molybdenum, the distributions of the extractable trace elements show a positive skew. Cobalt, manganese, and zinc have maximum occurrences in classes 2 and 3, boron and copper in classes 3 and 4. Molybdenum showed a more or less uniform distribution with the mode occurring in class 8.

The overall means for boron, copper, manganese, and zinc (0.37, 0.36, 29.64, and 0.57 ppm, respectively) fall in class 5, while those of cobalt (0.39 ppm) and molybdenum (0.46 ppm) fall in classes 4 and 6, respectively.

The data for boron, cobalt, copper, manganese, and zinc were log-transformed to approximate them to a normal distribution. The molybdenum data, on the other hand, were assumed to exhibit a normal distribution, and log-transformation was therefore not done. The means and the standard deviations were computed, and values deviating from the means by two standard deviations or more were considered to be abnormal. Values falling outside the normal range were plotted on maps, as shown in Figs. 13–15.

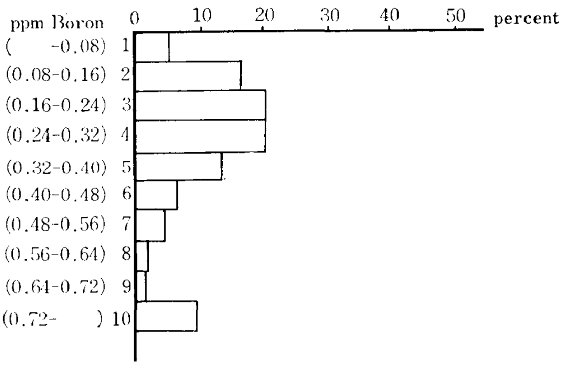

Fig. 7 Histogram of Acetic Acid-extractable Boron Content of Paddy Soils in Tropical Asia

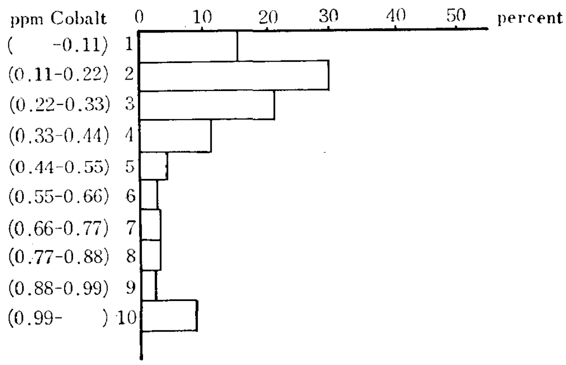

Fig. 8 Histogram of Acetic Acid-extractable Cobalt Content of Paddy Soils in Tropical Asia

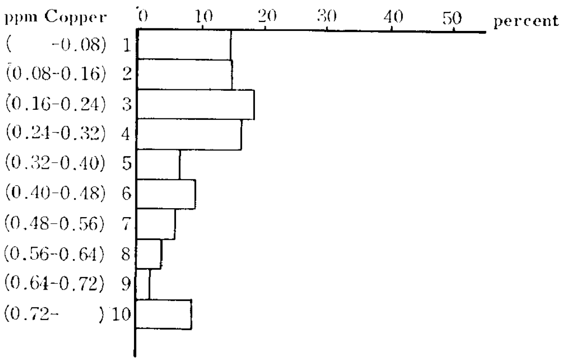

Fig. 9 Histogram of Acetic Acid-extractable Copper Content of Paddy Soils in Tropical Asia

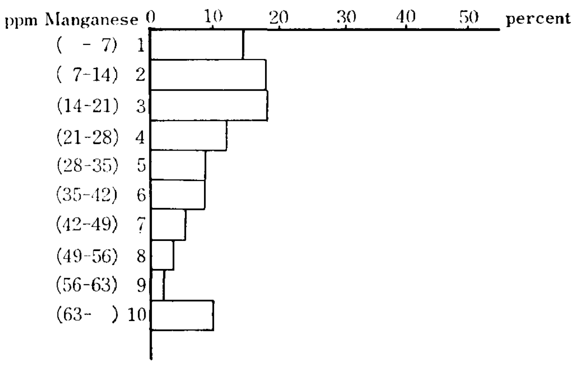

Fig. 10 Histogram of Acetic Acid-extractable Manganese Content of Paddy Soils in Tropical Asia

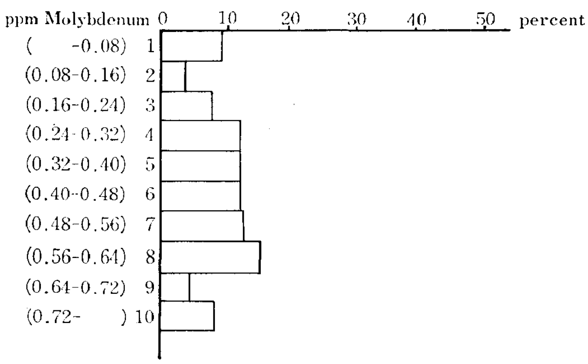

Fig. 11 Histogram of Acetic Acid-extractable Molybdenum Content of Paddy Soils in Tropical Asia

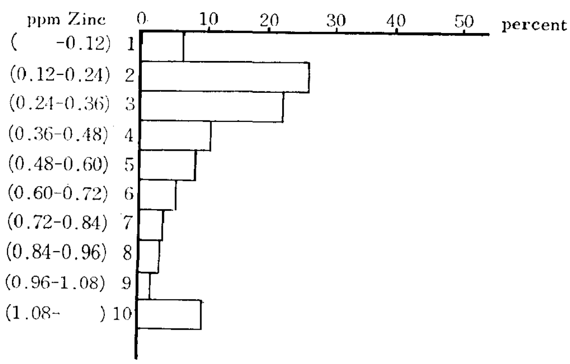

Fig. 12 Histogram of Acetic Acid-extractable Zinc Content of Paddy Soils in Tropical Asia

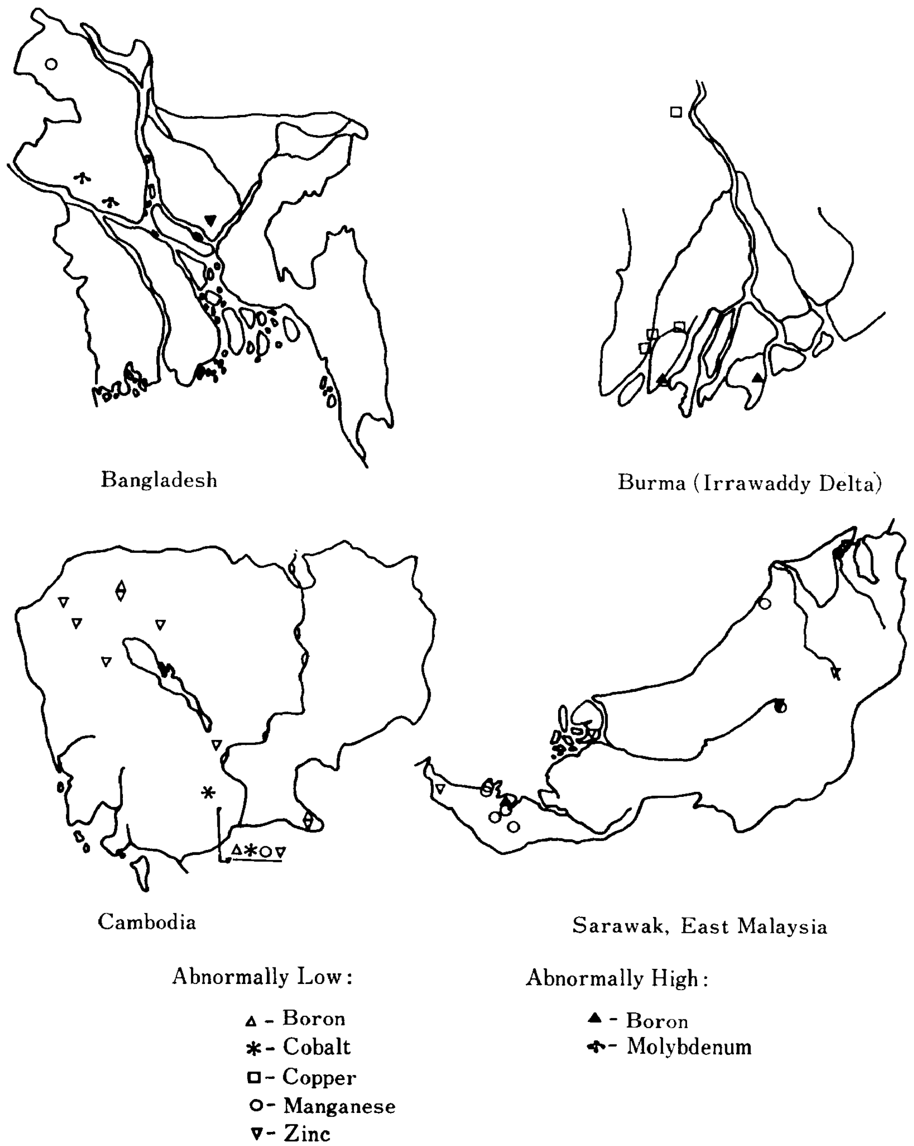

Fig. 13 Geographical Distribution of Trace Element Abnormalities in Bangladesh, Burma (Irrawaddy Delta), Cambodia, and the State of Sarawak, East Malaysia

These give an overview of the geographical distribution of the trace element abnormalities in Tropical Asia.

The results revealed that the most prevalent toxicity problems are abnormally high boron and molybdenum contents.

The geographic pattern of excess boron is most often associated with soils derived from marine alluvia. In India, where a fair number of samples were found to contain abnormally high amounts of boron, deltaic sediments and basin soils on local alluvia have been implicated.

Abnormally high molybdenum contents were principally found in India and Thailand, with a spotted distribution in Bangladesh and Indonesia. This problem is often associated with soils derived from calcareous materials.

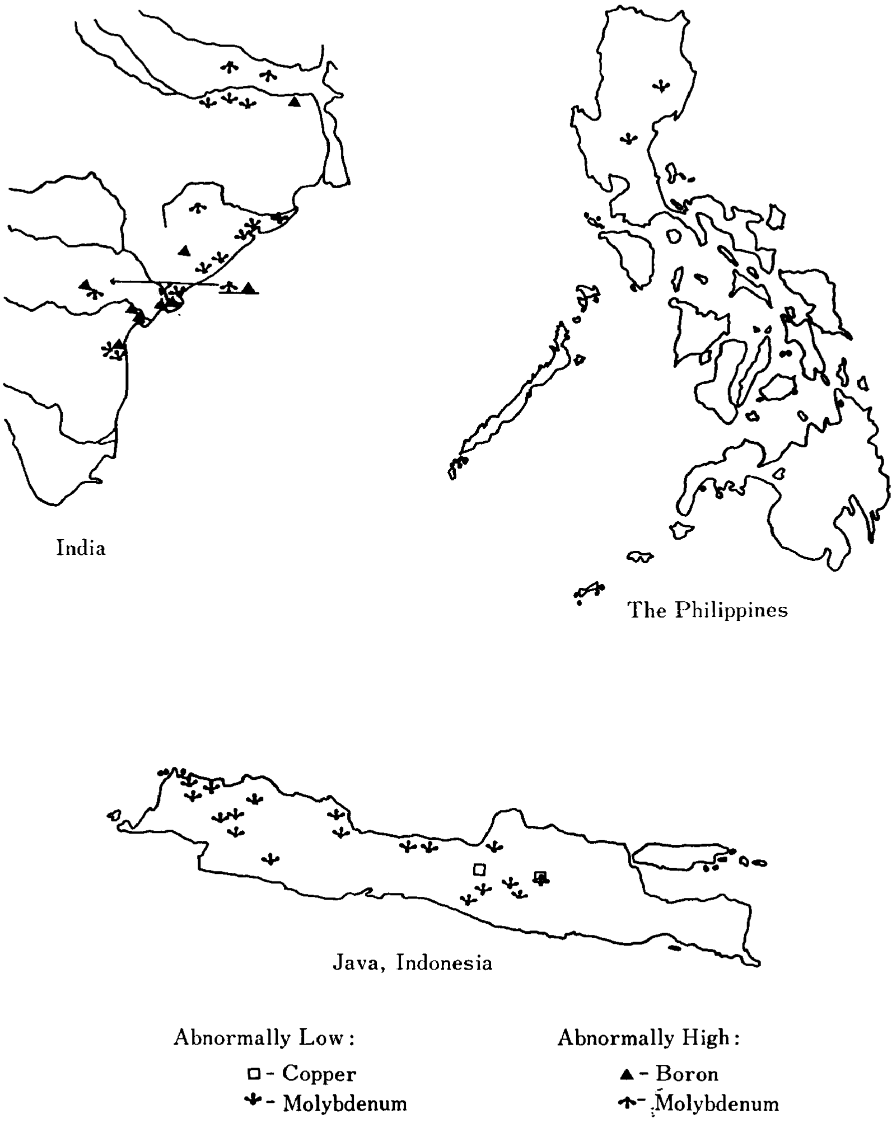

Fig. 14 Geographical Distribution of Trace Element Abnormalities in India (Eastern States), the Philippines, and Indonesia (Java)

About 24% of the paddy soils studied in Tropical Asia contained abnormally low levels of various trace elements. In the case of molybdenum, this included soils with either zero or trace levels of molybdenum below the detection limit of the instrument, in spite of the fact that the mean minus two standard deviations gave a negative value on the assumption of normal distribution.

The high frequency of abnormally low levels of trace elements is accounted for partly by the fact that some soils exhibited deficiencies in one or more trace elements. The most widely recognized problems were molybdenum and copper deficiencies.

A geographical pattern of abnormally low molybdenum values was evident in Indonesian soils derived from weathered volcanic ejecta. The soils can be grouped

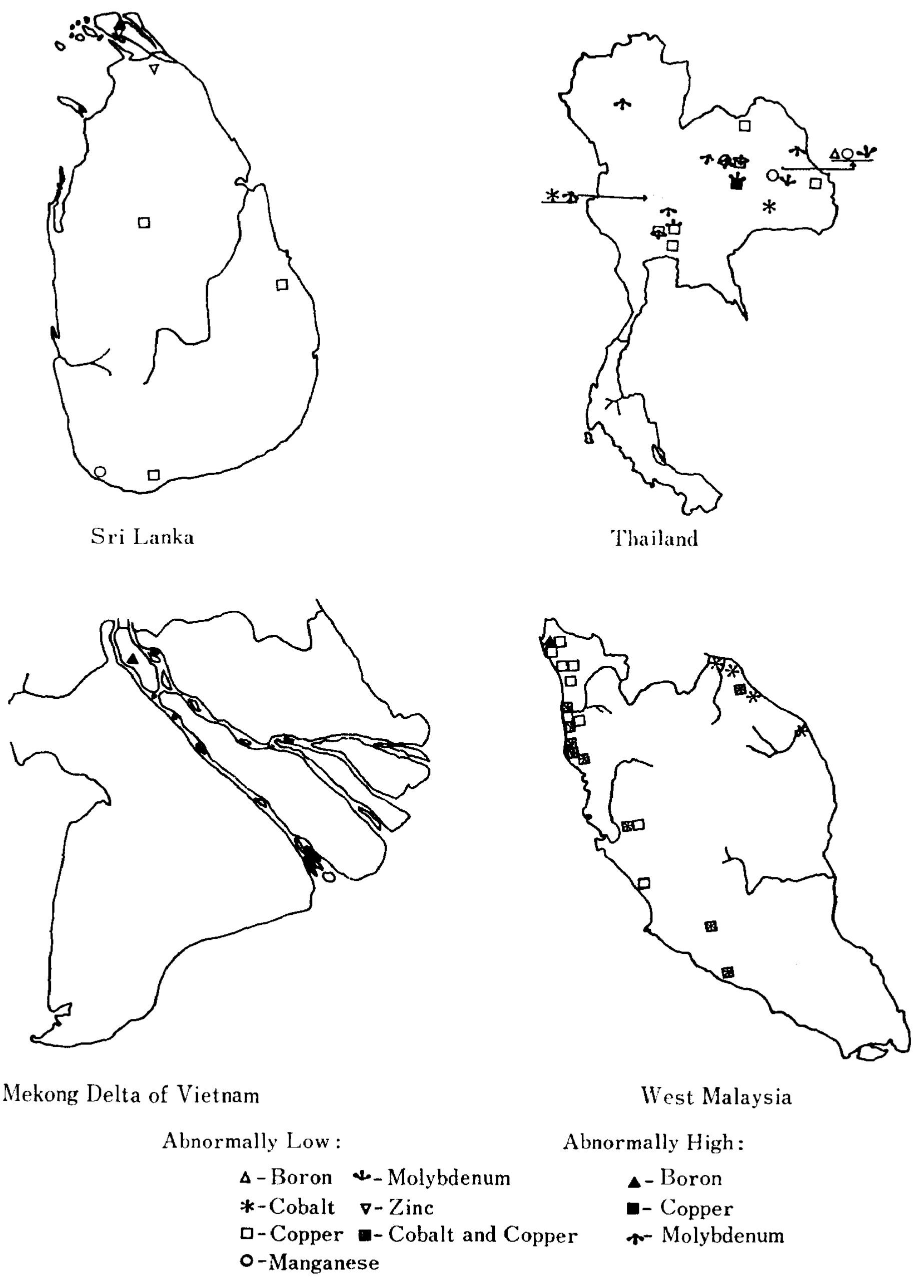

Fig. 15 Geographical Distribution of Trace Element Abnormalities in Sri Lanka, Thailand, Vietnam (Mekong Delta), and West Malaysia

into latosols, gray hydromorphics, regurs, regosols, mediterranean, and alluvial soils. The same disorder was also found in Gangetic and marine alluvia of India, and sandy, severely depleted alluvia of Thailand.

Abnormally low copper values were widespread in West Malaysian soils derived from organic matter-rich freshwater and brackish swamp sediments. In Sri Lanka and Thailand, the low values were often associated with sandy depleted soils.

The frequencies of cobalt, manganese, and zinc-deficient soils in Tropical Asia were of the same degree. Characteristically low zinc values were seen in Cambodian soils. These soils were typically associated with coarse-textured parent materials of low total zinc content. East Malaysian soils also showed very low values of zinc. This problem is associated with soils derived from Tertiary sandstone, marine and brackish alluvia, and alluvia derived from granite.

A geographic pattern of abnormally low levels of manganese was evident in East Malaysian soils derived from marine, estuarine, and riverine alluvia, and Tertiary sandstone. In Thailand and Cambodia, the problem is associated with strongly weathered and leached alluvia.

In addition to abnormally low copper values, West Malaysian soils showed very low cobalt values. In Cambodia and Thailand, low cobalt values were found in coarse-textured soils.

Boron deficiency was the least common problem in Tropical Asian paddy soils. It was confined to coarse-textured soils of Cambodia and Thailand.

One striking observation of interest is that the soils of East and West Malaysia, Cambodia, and Thailand showed very low levels of more than one trace element. In other words, the soils of these countries are prone to exhibit combined deficiencies of trace elements.

In general, trace element abnormalities in Tropical Asia characteristically occur on the following soils: soils high in organic matter in peaty depressions; highly weathered sandy mineral soils typically found in Northeast Thailand and Cambodia; and soils derived from weathered basic volcanic ejecta found in Indonesia and the Philippines.

Summary

A total of 407 paddy soil samples were analyzed for the extractable essential trace elements, boron, cobalt, copper, manganese, molybdenum, and zinc, by inductively coupled argon plasma atomic emission spectroscopy (ICAP-AES). The extractants used were 0.1N hydrochloric acid, 2.5% acetic acid, and water.

Results showed that considerably higher amounts of trace elements were extracted by 0.1N hydrochloric acid than 2.5% acetic acid, which in turn extracted more trace elements than water.

To obtain information on areas with threshold levels of trace elements, the acetic acid-extractable values deviating from the means by two standard deviations or more after log-transformation were considered to be abnormal. In the case of molybdenum, the same criterion was applied to the original data without log-transformation. Values falling outside the normal range were plotted on maps.

The most prevalent toxicity problems were found to be abnormally high boron and molybdenum contents. The former abnormality was principally recognized in India, the latter in Thailand and also in India.

About 24% of the paddy soils examined in Tropical Asia contained abnormally low levels of various trace elements. Abnormally low levels of molybdenum, zinc, and copper and cobalt are re-

spectively evident in Indonesian, Cambodian, and West Malaysian soils. East Malaysian soils contained abnormally low levels of manganese and zinc, Thai soils, abnormally low levels of copper, molybdenum, and manganese. Abnormally low levels of molybdenum were also found in Indian soils.

The findings in this study have provided valuable baseline information that may be used for further assessment of the geographical distribution of trace element abnormalities in other parts of Tropical Asia. Moreover, this study has delineated areas where trace element problems are evident.

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