STUDIES ON COPPER AND ZINC STATUS OF KERALA RICE SOILS AND THE RESPONSE TO THESE ELEMENTS BY IR-8

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CERTIFICATE

This is to certify that the thesis submitted contains the results of bonafide research work carried out by Shri C. Balakrishnan Nayar under my supervision. No part of the work embodied in this thesis has been submitted earlier for the award of any degree.

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INTRODUCTION

INTRODUCTION

Unlike the major plant nutrients, micronutrients have generally received very little attention in our country in the past. However, with the adoption of improved agricultural practices and greater use of major plant nutrients consequent on popularization of high yielding varieties of rice, more attention towards the supply of micronutrients is essential. The hidden hunger for micronutrients is manifested to a greater extend when major elements are supplied in optimum quantities.

Our contry has embarked on an ambitious agricultural development programme and use of fertilizers for crop yields has been intensified. Under conditions of intensive fertilizer use it is likely that physiological nutrient imbalance may arise due to lower uptake of trace elements resulting in reduced crop yields. It is therefore imperative that a proper assessment of trace element status of our soils comprising total and available fractions should be made.

It may be mentioned in this connection that the phenomena of trace element disorders are more often due to insufficient availability rather than due to deficiency in soil.

Very little information is available regarding the trace element status, more particularly of copper and zinc of Kerala rice soils. The Onattukara and Kuttanad regions are two of the major rice tracts of Kerala. With the popularization of high yielding varieties such as IR-8, many deficiency symptoms and physiological disorders in rice have been reported in these areas. The need for adequate information regarding the status of micronutrients especially that of copper and zinc in view of their important role in the nutrition of rice, has therefore been keenly felt in recent years.

It was therefore felt necessary that a study should be initiated primarily with the following objectives:-

1) To assess the status of copper and zinc in the soils of Onattukara and Kuttanad, and

2) to study the influence of application of copper and zinc to these soils on the yield and growth of paddy variety IR-8.

The present investigation is aimed at the aforesaid objectives.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The role of copper and zinc in the nutrition of plants, has been well recognised in recent years. In the following pages the literature pertaining to copper and zinc as essential micronutrients for plants, are briefly reviewed.

A. COPPER

The essentiality of copper as a plant nutrient was first established by Sommer (1931); and Lippman and Mackinney (1931). Since then considerable work has been done on different aspects of copper nutrition such as its enzymatic functions, the effects of its deficiency on plants and animals, inter-relationship between copper and other nutrients and responses of different crops to the application of copper.

According to Grewal et al. (1967) copper occurs in soils mainly in clay minerals and organic complexes. Clay minerals hold copper because of their cation exchange capacity arising partly from excessive negative charges owing to substitution in the silicon tetrahedron layer lattices and partly few negative charges of the terminal $O^{=}$ ions in the lattice edges.

1. Total and available copper in soils

Mc Murtrey and Robinson (1938) have found that the copper content of normal agricultural soils ranged from one to over fifty ppm. Holmes (1943) studied the copper content of a large number of U.S.soils and obtained similar results. His range was from two to sixty seven ppm. Swaine (1955) has quoted several workers who have found the total copper to range from one to hundred ppm in normal agricultural soils of the world. According Lal et.al.(1959) samples of peat soil collected from Kuttanad contained fifty ppm of total copper. It has been reported by Raychaudhry and Datta Biswas (1964) that copper content of shale, limestone and igneous rocks averaged about 192,20 and 70 ppm respectively.

Studies conducted by Randhawa and Kanwar(1964) revealed that total copper of soils of Punjab ranges from 6.6 to 36.4 ppm. Rajani(1965) estimated the copper content of soils of Gujarat and found the value ranging from 2.4 to 285.0 ppm with an average of 46.1 ppm.

According to Kanwar and Randhawa (1967) the amount of total copper in a soil is determined by the type of parent material, degree of weathering and leaching, intensity, acidity and texture of the soil.

Available copper in soils

Gilbert (1952) reported the fact that the total quantity of copper in a soil does not generally indicate the amount available to plants. Most Indian workers used normal ammonium acetate, 0.1N HCl and *Aspergillus niger* method for determining the available copper content of soils.

Lal *et al*. (1959) from their analysis of samples of peat soil from Kuttanad found that these contain 9 ppm of available copper. Some rice soils of Vidharbha, according to Kavimandan *et al*. (1964) contained 0.21 to 1.50 ppm of available copper. Recently in some soils of Punjab, Hariyana and Himachal Pradesh, Grewal *et al*. (1969) extracted the available copper by normal neutral ammonium acetate and determined colorimetrically as carbamate. The available copper content in these soils was found to vary from 0.30 to 1.05 ppm.

2. Factors affecting available copper content of soils

According to Kanwar and Randhawa (1967) the availability of copper in a soil depends upon a number of factors of which pH, organic matter, calcium carbonate, amount of clay and the effect of other elements are the important ones.

a. pH and availability of copper

Most workers report that copper availability lowers with decreased acidity in soils. Peech (1941) and Piper (1942) found that a decrease in acidity for any given level of copper reduced the availability somewhat when measured either chemically or by total copper absorbed by plants. Harmer (1946) reported that in soils of high organic matter content, such as peat soils, the more acid the peat, the greater may be the relative response to copper and greater the number of crops that are likely to benefit by the Copper application. However, Piper and Beckwith (1949) and French *et. al.* (1957) considered that no difference in copper uptake could be observed with variation in soil pH.

Delas et al.(1960) reported lower availability of copper at higher pH. Zagorka et.al. (1961) found that a decrease in copper content in the samples to be accompanied by an increase in pH, which indicates a constant relationship between copper content and pH. Neelakantan and Mehta (1961)also found a similar relationship between copper content and pH of soils. Many factors alter the dependency of the availability of copper on pH so that pH response does not always conform to that depicted. Hodgson (1963) was of the opinion that in addition to moderating the absorption or precipitation of micronutrients in soils, pH may alter the plant uptake of an element through a number of factors such as its effect on microbial activity, to cause change in the ability of plant roots to absorb ions or to transport them to the tops, effecting variations in the stability of soluble and insoluble organic complexes, or through an alteration of many rhizosphere effects that may be present.

Agarwala et.al. (1964) and Grewal et.al. (1969) have also obtained a significant negative relationship between available copper and pH of the soil.

b. Organic matter and availability of copper

Allison (1930) observed that the sawgrass peat of Florida, an almost useless soil could be made to produce good crops by copper fertilization. Harmer(1941), Comin (1944) and Browne (1950) have also concluded that many highly organic soils can be made profitable only after large amount of copper have been applied to them. Lees (1948) reported that the depressing effect of organic matter on the availability of copper may be pronounced only at higher levels of organic matter sufficient for the formation of less soluble organometallic complexes. Lundblad et al. (1949) have found that when copper is applied as a top dressing to a peat soil, it may remain in the top two inches for atleast six years and appears to organically bound in a form available to plants. Kanwar (1954) observed that copper fixation in soils was associated with the formation of organometallic complexes.

Iyer (1959) obtained a negative correlation between organic matter and the copper content of the virgin grass land soils of Western India. Misra and

Tiwari (1962) showed that 36.5 per cent copper was so strongly retained by compost that it could not be desorbed even with 0.I N HCl. According to Hodgson (1963) the presence of organic matter may promote the availability of a given nutrient presumably by supplying soluble complexing agents that interfere with their fixation; at the same time, the soils that are commonly deficient in copper and fix its greatest quantities, are in organic forms. Analysis carried out by Kavimandan et al. (1964) showed that available copper was higher in soils with more than one per cent organic matter than in soils containing less organic matter. Misra and Misra (1969) obtained a positive relationship between organic matter content and the availability of copper. But this effect was not seen in soils containing organic matter above one per cent. Grewal et al. (1969) arrived at a significant possitive correlation between available copper and organic carbon content in Punjab, Haryana and Himachal Pradesh soils. A possitive correlation between organic matter and total copper content was obtained by Misra et al. (1969) in some soils of Uttar Pradesh.

b. Calcium carbonate and copper availability

Calcium carbonate has been reported to decrease the availability of copper by bringing about a change in soil reaction. Hodgson (1963) reported that the availability of naturally occurring forms of copper was affected to a lesser degree than that of the added copper by application of $CaCO_3$, whereas Neelakantan and Mehta (1961 b) and Kavimandan et. al.(1964) reported that there was no significant relationship between available copper and $CaCO_3$ content. From the results of the later investigators, there appears to be a strong indication of an increase in available copper with an increase in calcium carbonate content. Recently, however Misra et al. (1969) found a significant negative correlation between available copper and calcicum carbonate content of some soils of Uttar Pradesh.

c. Clay content and copper availability

It has been reported that copper deficiency usually occurs on sandy and gravelly soils. Neelakantan and Mehta (1961 a), and Kavimandan et al. (1964) reported an increase in available copper with an increase in finer fraction of the soil, although the relationship was not statistically significant. Neelakantan and Mehta (1962) further reported that although this relationship was not significant on calcarious and goradu profiles of Gujarat, it was found to be significant in the medium black and black soil profiles. They further stated that a significant possitive relationship exists between total and available copper content of some Gujarat soils.

3. <u>Copper retention by soils</u>

Gibbs and Marshall (1952) found that copper bearing minerals including oxides, are weathered in the presence of clay surfaces, copper being adsorbed into the silicates from its original form. They considered the binding of copper to clay to be as strong as that of copper to organic matter. Heydemann (1959) reported that absorption of copper by clays and quartz follow the Freundlich absorption isothern.

Misra and Sharma (1961), and Misra and Tiwari (1962 a, 1962 b, 1964) studied the effect of soil reaction, cations and fertilizer amendments on the retention of Cu by the soils. They found that the presence of Ca^{++} and Na^{++} in soils hindered the entry of Cu^{++} ions in exchange complex when the latter was applied as copper sulphate. The decrease was of much greater magnitude in acid soils while it was insignificant in normal soils. These authors further reported that the presence of nitrogenous and potassic fertilizers decreased appreciably the adsorption of copper by soils. The amount of fixed copper increased while exchangeable copper decreased as the dose of N and K fertilizers was increased.

The accumulation of available microelements in the humus and illuvial horizon of soils is the result of biological accumulation of clayminerals. Mitchell (1965) has observed that most of the biologically important cations are very readily adsorbed by the exchange active clay minerals and are correspondingly difficult to displace; the order of difficulty of displacement is approximately Cu $>$ Pb $>$ Ni $>$ Co $>$ Zn $>$ Ba $>$ Rb $>$ Sr $>$ Ca $>$ Mg $>$ Na $>$ Li, but the relative positions in such a series varies with concentration in the solution and the nature of the exchange active material.

4. Importance of copper in rice nutrition

In Japan, Ishizuka (1942) found that copper was easily absorbed by rice plants in solution culture and a large amount of the element accumulated at the growing point of the root. Sommer (1945) had reported that copper has some function in chlorophyll formation although the chlorophyll molecule contain no copper. This function he assumed to be indirect, since plants may cease to grow as a result of copper deficiency, and still show no signs of chlorosis. Gilbert (1952) pointed out that all plants contain copper and the amount of copper in a plant varies depending on species, soil, the amount of fertilizer used, and other factors. From a physiological point of view, copper is important as a constituent of atleast three enzymes: ascorbic acid oxidase, laccase and tyrosinase. Lal and Subba Rao (1953) have described the role of copper in crop production. They worked out optimum requirements of copper for rice in sand culture and concluded that rice crop required 6.25 ppm Cu. For rice in water culture Patnaik (1953) has found that the optimal requirement of copper was 0.001 ppm.

Russell (1961) pointed out that copper has two separate functions: one directly concerned with plant nutrition, and other with the condition of soils. Its function as a nutrient lies in its being a constituent of some enzymes such as the oxidation reduction enzyme polyphenol oxidase.

It has been observed by Rao (1962) that rice takes much of its copper requirements at the flowering time.

5. Influence of copper on yield, growth and other characteristics of rice plant

In pot culture experiments Harrison and Aiyer (1917) observed that copper applied to rice plants has beneficial effects in increasing yield of grains, the yield increases varied from 9.1% to 24%. Tokuoka and Gyo (1938) found that the growth and yield of rice increased when 0.005 ppm of copper was added to the culture solution. A set of experiments on copper sulphate was conducted in Denmark primarily on cereals by Steenbjerg and Boken (1950). Out of the six hundred and forty trials conducted over a period nineteen years 87 per cent of copper treated plots gave increased yields. Shyu (1952) also reported increases in rice yield due to Mn and Cu treatments in pot culture experiments. Joshi and Joshi (1952) recorded an increase of 37.7 per cent in yield as a result of application of 1 lb $CuSO_4$ to rice nurseries. Govindarajan (1954) obtained an yield increase of 15-20 per cent in rice by soil application of five pounds to copper sulphate. Dutta and Bains (1960), however, found no increase in rice yield at I.A.R.I. Delhi by the application of $CuSO_4$.

Kanwar (1962) and Bhumbla _et al._ (1964) observed a significant increase in yield of rice with boron and copper. Chao and Tsui (1963) showed that the application of copper stimulated the growth of shoots and roots of rice. In pot culture experiments Nagarajan and Vadivelu (1964) observed an imporved straw yield of rice by soil application of copper and manganese. In Mysore, Govindarajan and Gopala Rao (1964) obtained higher yields of rice by adding copper salts to slightly copper deficient soils.

6. <u>Copper deficiency and toxicity symptoms in rice</u>

The effect of copper deficiency in plants varies from slightly reduced growth to disease symptoms so severe that death may eventually occur. At the same time copper toxicity can be expected in soils which receive heavy application of Bordeaux mixture for a considerably larger period of time. Piper (1940) found that copper deficiency symptoms were accompanied by some chlorophyll defect and necrosis of the leaves in rice. Ishizuka (1940, 1942) reported that copper was easily absorbed by rice plants in solution culture and large amount of the element accumulated at the growing point of the root, with the result nutrient uptake was greatly injured and with a concentration of above 50 ppm, the rice plants failed to grow. No inflorescence was produced in severe cases of copper deficiency, although secondary tillers continued to form. Ishizuka _et al._ (1961) found that the rice plants showed nearly normal growth with concentration below 1 ppm while severe toxicity resulted with more than 1 ppm concentration of copper. Karim and Vlamis (1962) observed that the deficiency of copper in rice seedlings affected the youngest leaves.

7. _Effect of copper on the uptake of other elements_

Malavolta _et al._ (1950) found that by the addition of copper, the zinc content of plants was severely reduced. Similar works by Dunne (1956) showed that the zinc level and yield of cereal grains were influenced by the copper level of the soil on which they were grown. As the copper level was increased, the zinc content of the tissues as well as yield were reduced.

Agarwala and Sharma (1961) observed that copper concentration in barley was doubled when the concentration of Mn in the nutrient solution was reduced from 0.55 to 0.0055 ppm. Gautam _et al._ (1964) observed that in the presence of NPK, foliar application of copper increased the nitrogen content of maize by 32.4 per cent over plants received NPK alone. Mehta et al. (1964) have reported an inverse Mo-Cu relationship. Dakhore et al. (1963) showed that copper application stimulated the uptake of phosphorus and potassium by wheat plants whereas nitrogen availability was not much affected.

B. ZINC

During the last forty years zinc has been recognised as an essential nutrient and its deficiencies in the field crops have been reported an extensive scale. Maze (1919) furnished first convincing evidence of the essentiality of zinc for higher plants. However, its essential nature was not generally accepted until Sommer and Lipman (1926), and Sommer (1928) showed that zinc is indispensible for plant growth.

According to Kanwar and Randhawa (1967), zinc deficiencies are more widespread in field and fruit crops in different parts of India. Despite this fact its distribution in soil and its role in plant nutrition has not so far received adequate attention.

1. Total zinc in soil

The content of total zinc in soils is generally low in comparison with other essential elements. However, Staker and Cummings (1942) found that peat soils of New York State contain from traces to as high as 23,600 ppm of zinc. Thorne et al. (1942) reported that zinc content of a number of Utah soils ranges from 30 to 250 ppm. The data on zinc and other trace elements have been rather thoroughly reviewed by Swaine (1950). He gives an average value of 80 ppm in the lithosphere.

In the soils of Gujarat, Nair and Mehta (1959) reported that zinc content ranges from 2 to 95 ppm. Raychaudhuri and Datta Biswas (1964) have reported that sandstone, limestone, shale and igneous rock contain 16,24,27 and 51 ppm respectively of zinc. Chatterjee and Dass (1964) analysed some Indian soils and found that zinc content ranged from 21.5 to 88.7 ppm. Ranadive et al. (1964) classified tho zinc in soils to be present as ions electrically bound in base exchange complex, as insoluble carbonates and phosphates, as chelates of organic compounds or as ions trapped in crystal lattice of clay minerals. Analysis carried out by Agarwala et.al. (1964) showed that the zinc content of most Indian soils lies in the range 10 and 300 ppm, except in some samples such as Bundlekhand series (Uttar Pradesh). Bundlekhand series have very high reserves of total zinc (ranges from 5.5 to 1204.9 ppm).

In a recent study in Bihar soils Prasad and Sinha (1969) found that the total zinc content varied from 69-1019 ppm, average being 497 ppm.

2. Available zinc content of soils

Available (1947 a,b) established tentative limits of zinc deficiency and toxicity in the case of available zinc as below 1 ppm and above 100 ppm, respectively.

Vlasyuk and Ziminia (1954) reported that the content of available zinc in soils of Russia to be related to the zinc content of the parentt rocks.

The value of available zinc content of soils varies depending on the type of extractant used. Nair and Mehta (1959) have used O.I N HCl while Durate *et al.* (1964) have used neutral normal ammonium acetate solution. Grewal *et al.* (1969) extracted available zinc with neutral normal ammonium acetate solution plus 0.01% dithizone in carbon tetrachloride. He obtained an available zinc content of 0.24 to 1 ppm in some soils of Punjab, Haryana and Himacnal Pradesh. In a recent study Tripathi *et al.* (1969) reported an available zinc content ranging from 0.9 to 8.8 ppm (5-15 per cent of total zinc) in soils of Uttar Pradesh.

3. Factors affecting available Zn content in soils

The availability of zinc in soils is dependent upon a number of factors like soil pH, organic matter content, $CaCO_3$ content etc.

a. Effect of pH on zinc availability

Numerous investigators have noted that zinc deficiencies usually occur on soils of pH 6.0 or higher. However, Alben and Boggs (1936) found some zinc deficiency on soils with pH below 5.5 and explained this on the basis of low total zinc content. Camp (1945) in a study concluded that the availability of zinc declines as the pH of the soil rises, the critical point being between the pH range 5.5 to 6.5.

Epstein and Stout (1951) analysed supernatant solution from a series of bentonite cultures of uniform total zinc content and found an increasing amount of soluble zinc with increasing H^+ ion concentration. Similarly several workers, among whom may be mentioned Greenwood and Hayform (1951), Shaw and Dean (1952), and Woltz et.al. (1953), have made observation on the occurrence of zinc deficiencies in soils in the range of pH 6.0 to 8.0. Thorne (1957) considered that the predominant occurrence of zinc deficiencies in the range of pH 6.0 to 8.0 to be favoured by conditions of minimum zinc solubility.

Nair and Mehta (1959), however, observed a significant positive correlation (+ 0.402) between pH and o.1 N HCl soluble zinc content of Gujarat soils. Chatterjee and Dass (1964) found that there was more ammonium acetate extractable zinc in soils with pH below

6.0 and its content decreased as pH rose above 7.0. Kanwar and Randhawa (1967) expressed the view that in addition to moderating the adsorption or precipitation of zinc, pH may alter the adsorption of zinc through an effect on microbial activity and change in the ability of the plant roots to absorb or to transport to the tops the adsorbed ions or variations in the stability of soluble and insoluble organic solvents of zinc or a change in the solubility of antagonistic ions or an alteration of any rhizosphere effects that may be present.

In a recent study, Tripathi *et al.* (1969) observed no correlation between available zinc and pH in some Uttar Pradesh soils.

b. Organic matter and zinc availability

Thorne and Wann (1950) have reported that in Utah, zinc deficient orchards were usually fertilized for many years with liberal applications of farm manure.

Baughman (1956) has furnished considerable support to the theory that organic matter may be a major soil factor in zinc fixation. De Mumbrum and Jackson (1956) also concluded in their studies, that peat holds Zn and Cu by a chelation type of reaction.

Nair and Mehta (1959) reported a positive significant relationship between organic matter and acid soluble zinc. De Remer and Smith (1964) found that decomposing plant residues can immobilize zinc in unavailable form. However, no significant relationship between available zinc and organic matter content of soil was observed by Tripathi et al. (1969) in soils of Uttar Pradesh.

c. Influence of calcicum carbonate content of soils on zinc availability

Zinc deficiencies are more common in calcarious soils. Leeper (1952) postulated that calcium carbonate may act as a strong adsorbent for heavy metals. Jurinak and Bauer (1956) reported that zinc was adsorbed on the crystal surfaces of dolomite and magnesite at sites in the lattice by replacing Mg; zinc was also adsorbed less strongly on calcite than magnesite and dolomite. Thorne (1957) quotes several workers who found that application of lime stone resulted in fixation of zinc in soil. Nair and Mehta (1959) observed that in a number of instances, the availability of zinc decreased as lime content increased. Tiwari and Misra (1964) studied the effect of $CaCO_3$ on retention of added zinc by three soils black, red and alkali soils of Uttar Pradesh. They found that with higher dose of CaCO3, the retention of applied zinc increased gradually in all soils due to the physical adsorption of ions at the colloidal surfaces and formation of some basic zinc carbonate.

Recently Tripathi et al. (1969) have shown that there is no significant relationship between available zinc and $CaCO_3$ content as regards some soils of Uttar Pradesh.

d. Adsorption of zinc by phosphates

From a study on zinc deficiency of tung trees in Florida, Mowry and Camp (1934) found that high phosphate in soils was an important factor in reducing available zinc. West (1938) reported that zinc deficiency symptoms of citrus occurred on super phosphate treated plots in Australia, apparently being induced by the phosphate ion. However, Brown *et al.* (1954) observed that appli ation of phosphate fertilizers for rice had no effect on the uptake of zinc from either applied or native zinc present in the soil.

Stuckenholz *et al.* (1966) concluded that translocation of zinc from roots to the tops was inhibited by elevated P concentration in corn. Paulson and Rotini (1968) found that high phosphorus levels decreased growth of P sensitive variety of soyabeans, but decreased zinc concentration in both the varieties.

e. Adsorption by colloids

Zinc has been found adsorbed in small amounts on the colloids in most soils. Elgabaly and Jenny (1943) investigated the adsorption and fixation of zinc on montmorillonite clays. These findings were further supported by the results obtained by Nelson and Melsted (1955). According to Basu *et al.* (1964) the adsorption of Mn^{++}, Cu^{++} and Zn^{++}, for H^{+} of humic acid takes place in the order, Zn > Mn > Cu. Chatterjee and Das (1964) reported a negative relationship between zinc content and cation exchange capacity of soils. Randhawa and Broadbent (1955) found a definite indication of the binding of the monovalent form of zinc by very acidic exchange sites on humic acid; weekly acidic site retaining zinc in the divalent form.

In a recent study of Bihar soils significant possitive correlation was observed by Prasad & Sinha (1969) between cation exchange capacity and acetic acid extractable zinc.

Value of zinc in Rice nutrition

a. Role of zinc

As regards the zinc requirements of rice Tokuoka and Gyo (1939) found that adding 1 ppm zinc in culture solution increased the yield of rice, while 5 ppm gave toxic effect. Retarded stem elongation, small narrow leaves and mishappen fruits associated with zinc deficiency led Skoog (1940) to investigate relation between the zinc deficiency and auxin production. Zinc plays a role in the production or functioning of several enzymes. Carbonic anhydrase which catalyses the reaction, $H_2CO_3 \longrightarrow H_2O + CO_2$, has been reported as containing zinc. Bradfield (1947) has reported its presence in leaves of several plants.

It was Tsui (1948) who ascertained that zinc is required directly for the synthesis of tryptophan and that auxin is produced from tryptophan. Bonner (1950) postulated that indole acetic acid is produced from tryptophan with indole acetaldehyde as an intermediate. Quinlam (1951) reported that aldolase was found to fall sharply with zinc deficiency. Lal and Subba Rao (1955) found that the efficiency of different plants to utilize zinc for dry matter production is of the order rice maize barley sugarcane. According to Naik and Asana (1961) zinc deficiency resulted in reduced rate of protein synthesis and increased accumulation of non-protein intermediates in cotton plants. Sadaphal and Dass (1961 a,b) have shown that soil as well as foliar application of zinc sulphate increased the protein content of wheat at I.A.R.I., New Delhi. According to Rao (1962), major portion of zinc by rice was required at the milk stage.

b. <u>Influence of zinc on the growth, yield and other characteristics</u>

Tokuoka and Gyo (1939) found that adding 1 ppm of zinc in culture solution increased the yield of rice. Hosoda (1942) found effective response when less than 75 ppm of zinc was added to the rice plant. In different parts of India substantial yield increases were reported by Kanwar (1952), Joshi and Joshi (1957) and Singh and Jain (1964) as a result of the application of zinc. Kanwar *et al.* (1958-62) and Bhumbla *et al.* (1963-65) have conducted a number of pot and field experiments on calcarious, neutral, non calcarious and acid soils of Punjab. The results are discussed in the following paragraph.

In seven experiments on calcarious soils significant increase in the yield of rice grain and straw were obtained by zinc sulphate sprays. In five field and pot experiments conducted on neutral and non calcarious soils with pH 7.2-7.5, the response to zinc sprays was observed only in one pot experiment. In case of two experiments on acid soils, significant yield increases were obtained by foliar sprays with zinc.

Replicated field experiments for studying responses to soil application of zinc were conducted by Kanwar and Joshi (1964) in acid soils for three years and the response was found to be significant. Singh and Jain (1964) reported that the application of 2.53 kg per hectare of zinc in the soil increased the production of dry weight and tillering, but when applied as sprays at higher levels an appreciably increased paddy yield was obtained.

Das Niranjan and Srivastava (1965) found that micronutrient treatments significantly affected the growth yield and leaf composition of barley. Zinc treatment led to an increase in the amount of total leaf chlorophyll. Pillai (1965) studied the response of rice to the application of Zn, Cu and Mn and found that the effect of Zn was more beneficial than Mn and this is followed by copper in increasing the yield of rice. Tanaka <u>et al</u>. (1967) reported that the foliar application of zinc and copper sulphates in some cases induced detectable increase in growth, height and foliar development of *Pinus strobus*. Grewal *et al.* (1967) indicated that crop responses to micronutrients, especially zinc was quite marked when NPK was applied as basal dose.

c. Zinc deficiency symptoms in rice

Viets *et al.* (1954) found that plants suffering from zinc deficiency were of poor growth and generally had intervenalchlorosis and necrosis of lower leaves. Thorne (1957) pointed out that lack of zinc results in distinctive plant symptoms associated with retardation of normal plant growth and lack of chlorophyll. Single and Holmberg (1957) reported that reddish or brownish spots often occurred in the older leaves as a result of zinc deficiency in several crops. Naik and Asana (1961) showed that typical chlorotic pattern of zinc deficient leaves appeared after fifty days in rice and that zinc content of deficient leaves after 28 and 52 days was 17 and 12 ppm respectively.

Karim and Vlamis (1962) reported that lack of zinc would affect root development, prevent maturation and fail to produce seed in rice.

Neen and Srivastava (1968) ascertained that Khaira disease in rice was caused by zinc deficiency and could be easily identified in field with discolouration in older leaves.

MATERIALS AND METHODS

MATERIAL AND METHODS

The investigation comprises (1) a survey of the status of copper and zinc in the two major rice tracts of Kerala, viz., Onattukara and Kuttanad; and (2) Pot culture experiments to study the effect of application of copper and zinc to the soils of Onattukara and Kuttanad, on the performance of Rice variety, IR-8.

I. Survey of Copper and Zinc status

(1) Collection of soil samples

For this purpose representative surface soil samples were collected from the rice fields of Onattukara and Kuttanad. Fifteen samples were collected from Onattukara and twenty samples from Kuttanad. The details regarding the selected places from which samples were collected are given in Tables A and B. The samples collected were kept in polythene bags and labelled.

(2) Laboratory studies

(a) Preparation of samples for analysis:

The samples of soil collected, were spread on white glazed sheets of paper, and then covered by sheets of paper to prevent contaminations. These were allowed

TABLE A

DETAILS OF SOIL SAMPLES FROM ONATTUKARA

Sample No.	Locality	Taluk
1	Theklumbhagam	Karunagapally
2	Panmana	..
3	Thondelipadam	..
4	Vavakavu	..
5	Krishnapuram	Karthikapally
6	Kayamkulam	..
7	Kareelakulangara	..
8	Muthukulam	..
9	Cheppad	..
10	Haripad	..
11	Karuvatta	..
12	Thottapally	..
13	Purakkad	..
14	Olakettiyambalam	..
15	Mavelikara	Mavelikara

TABLE B

DETAILS OF SOIL SAMPLES FROM KUTTANAD

Sample No.	Locality	Taluk
16	Kolarkode	Ambalapuzha
17	Karumadi	..
18	Punnapra	..
19	Pallathuruthi	Kuttanad
20	Tottuvathala	..
21	Ponnamkunnathusseri	..
22	Amichakari	..
23	Mampuzhakari	..
24	Ramankari	..
25	Narakathara	..
26	Chennankari	..
27	Kainady	..
28	Mangalam Kayal	..
29	Neelamperoor	..
30	Muttar	..
31	Neerattupuram	..
32	Thenadi	..
33	Thakazhi	..
34	Pandankari	..
35	Veliyanadu	..

to dry in air for one week after which periods the samples were ground separately using clean porcelain mortar and pestle.

A portion of each sample was sieved by a special cloth sieve made of mosquito net fitted into a wooden frame. These samples were then stored in clean Pyrex bottles and labelled; and used for estimation of copper and zinc.

The rest of the soil in each sample was passed through a 2 mm sieve and stored in ordinary sample bottles. These samples were used for the determination of mechanical composition, moisture, loss on ignition, organic carbon, total nitrogen, total phosphorus, total potassium, cation exchange capacity and calcium carbonate content.

(b) Methods of analysis:

Mechanical analysis of the soil samples was carried out by the International pipette method, following the procedure outlined by Sankaram (1960).

Moisture, Loss on ignition, organic carbon, total nitrogen, cation exchange capacity and calcium carbonate content were estimated by the methods described by Piper (1950).

Total potassium was estimated in the Hydrochloric acid extract of the soil photometrically using an EEL flame photometer.

Total phosphorus was determined in the Hydrochloric acid extract of the soil as suggested by Sankaram (1960).

Total copper and zinc in the soils were extracted by digestion of the samples by perchloric acid as outlined by Jackson (1958). Copper and zinc were estimated colorimetrically as carbamate and as dithizonate respectively, following the methods suggested by Jackson(1958)

For the determination of available copper in soils, the method of Cheng and Bray (1953) was followed.

Available zinc was determined by the method of Shaw and Dean (1952).

II. Pot culture experiments

The influence of different levels of copper and zinc applied singly and in combination, on the performance of rice variety IR-8, was studied by means of pot culture experiments using the soils of Onattukara and Kuttanad.

(a) Collection of soil

The soils used for the experiment were collected from the rice fields of Thakazhi, in Kuttanad and Kayamkulam in Onattukara; to represent the kari and sandy soils respectively. The mechanical and chemical composition of the soils were determined and the data are given in Tables C and D.

(b) Lay out of the experiment

The experiment was laid in Completely Randamised Design, with nine treatments and three replications. The treatments consisted of combinations of three levels of zinc and three levels of copper, in both the soils, as detailed below:

Treatments

1)	Zn_oCu_o	-	control				
2)	Zn_oCu_1	-	0 kg zinc/ha and 5 kg copper/ha				
3)	Zn_oCu_2	-	0 kg zinc/ha and 10 kg copper/ha				
4)	Zn_1Cu_o	-	5 kg	,,	and	0 kg	,,
5)	Zn_1Cu_1	-	5 kg	,,	and	5 kg	,,
6)	Zn_1Cu_2	-	5 kg	,,	and	10 kg	,,
7)	Zn_2Cu_o	-	10 kg	,,	and	0 kg	,,
8)	Zn_2Cu_1	-	10 kg	,,	and	5 kg	,,
9)	Zn_2Cu_2	-	10 kg	,,	and	10 kg	,,

TABLE C

MECHANICAL COMPOSITION OF THE SOILS USED FOR THE POT CULTURE EXPERIMENT

(Percentage, moisture free basis)

	Onattukara soil	Kuttanad soil
Coarse sand	50.1	1.0
Fine sand	32.0	3.1
Silt	6.5	18.4
Clay	11.1	57.5

TABLE D

CHEMICAL COMPOSITION OF THE SOILS USED FOR THE POT CULTURE EXPERIMENT

	Onattukara soil	Kuttanad soil
pH	5.7	3.7
Total Nitrogen	0.040%	0.410%
Total P_2O_5	0.180%	0.080%
Total K_2O	0.064%	0.520%
Organic carbon	0.289%	4.405%
Cation Exchange capacity	3.5 me/100 g	39.2 me/100g
Total Zn	85.00 ppm	60.00 ppm
Total Cu	58.00 ppm	62.00 ppm
Available Zn	1.98 ppm	1.12 ppm
Available Cu	2.59 ppm	0.96 ppm

(c) Preparation of pot and raising the crop

Glazed porcelain pots of 20 x 30 cm size were used for the experiment. The total number of pots were 54. Six kg of air dry soil was taken in each pot.

The quantity of micronutrients required for the different treatments were weighed out and incorporated into the soil by thorough mixing. All the pots received same levels of N,P and K. Nitrogen at the rate of 80 kg/ha was applied to each pot, as Ammonium sulphate (20%N). Half the dose of nitrogen was given as basal dressing, while the other half was applied in two split doses, one at the active tillering phase and the other at the primordia initiation stage. P and K were given as Superphosphate (16% P_2O_5) and Muriate of Potash (50% K_2O) at the rate of 50 kg P_2O_5/ha and 50 kg K_2O/ha respectively.

IR-8-288-3 seeds obtained from Central Rice Research Station, Pattambi, were sown on a well prepared nursery bed which received no manures or fertilizers. The seedlings were transplanted in the pots after 20 days of sowing, as two hills of one seedling each in every pot.

Redistilled water was used for puddling the soil before transplanting as well as for the periodical irrigation of the pots. Sprayings with insecticides free of micronutrients were done as and when required.

(d) Observations

The following observations were taken.

(i) Observations on growth performances:

(a) Plant height on 30th and 60th days after transplanting, and

(b) Number of tillers on 30th and 60th days after transplanting.

(ii) Observations on yield attributes:

(a) Percentage of productive tillers at harvest.

(b) 1000 grain weight, and

(c) Percentage of filled grains.

(iii) Observations on yield:

(a) Yield of grain, and

(b) Yield of straw.

e) Analysis of Plant samples

The grain and straw sample from all the 54 pots were analysed for the content of N, P, K, Cu and Zn.

Nitrogen was determined by digestion employing micro-kjeldahl method and distillation in micro-kjeldahl distillation set (Wagner-Parnar distillation unit).

The triple acid digestion of samples using ternary acid mixture were carried out for the analysis of P,K, Cu and Zn, as detailed by Jackson (1958).

Phosphorus was estimated colorimetrically by the 'chlorostannous - reduced molybdophosphoric blue color method' as outlined by Jackson (1958).

Potassium was estimated photometrically using an EEL flame photometer.

Zn and Cu were determined colorimetrically as dithizonate and carbamate respectively following the procedures detailed by Jackson (1958).

RESULTS

RESULTS

The results of the present study are given in Tables I to XXII.

1. Survey of copper and zinc status

A. Mechanical composition of the soil

The results of the mechanical analysis of the soils of Onattukara and Kuttanad are given in Table I and II.

The data show that the Onattukara soil is predominantly sandy whereas the Kuttanad soil is clayey. The clay content of the Onattukara soils varies from 8.0 per cent to 12.3 per cent. In Kuttanad soils the clay content varies from 51.9 per cent to 59.0 per cent.

The Onattukara soils are very low in their organic matter content whereas Kuttanad soils are rich in organic matter content. The organic matter content varies from 0.22 per cent to 0.54 per cent in Onattukara soils and 7.2 per cent to 9.2 per cent in Kuttanad soils.

B. Chemical composition

Data pertaining to the chemical composition

TABLE I

MECHANICAL COMPOSITION OF ONATTUKARA SOIL

Sample No.	Coarse sand %	Fine sand %	Silt %	Clay %	Organic matter %
1	52.5	32.9	5.0	8.4	0.32
2	54.9	30.1	5.9	8.0	0.50
3	52.7	32.3	5.1	8.8	0.38
4	52.8	30.9	5.8	9.4	0.42
5	54.6	29.3	5.7	9.3	0.48
6	49.8	31.6	6.2	11.2	0.24
7	50.8	33.4	5.8	8.9	0.28
8	48.9	34.2	5.4	10.4	0.28
9	52.8	29.4	6.2	10.5	0.22
10	49.7	30.6	6.3	12.3	0.52
11	52.8	32.0	5.3	8.7	0.48
12	52.2	29.3	6.8	10.6	0.38
13	50.0	32.0	6.0	10.8	0.54
14	50.0	34.6	5.9	8.4	0.52
15	54.0	29.7	5.9	9.3	0.38

TABLE II

MECHANICAL COMPOSITION OF KUTTANAD SOILS

Sample No.	Coarse sand %	Fine sand %	Silt %	Clay %	Organic matter %
16	2.0	2.1	24.0	51.9	7.9
17	1.0	3.7	23.1	52.5	8.5
18	0.8	4.1	20.6	52.7	7.9
19	0.8	3.5	20.2	56.1	7.7
20	1.4	4.0	21.0	55.1	7.9
21	1.1	2.6	22.1	54.2	8.3
22	1.0	2.5	17.5	59.0	8.3
23	1.2	2.5	23.2	54.3	9.5
24	1.2	3.1	21.9	54.7	8.9
25	1.3	3.2	22.0	54.6	8.7
26	1.7	2.2	20.0	57.2	8.3
27	0.5	3.5	19.8	56.5	8.9
28	0.8	2.6	23.1	53.1	8.1
29	1.0	2.3	22.5	53.1	9.1
30	1.1	3.6	20.5	55.9	8.1
31	0.7	2.2	20.0	57.2	8.3
32	1.4	4.0	21.0	55.1	9.3
33	0.9	3.1	18.2	58.2	8.3
34	1.3	3.3	20.2	55.0	9.7
35	1.3	3.3	21.5	54.6	8.5

of the soils are given in Tables III to VIII.

a. <u>Soil reaction</u>: The data show that the Kuttanad soils are highly acidic whereas the Onattukara soils are only slightly acidic. The pH values of Onattukara soils vary from 5.2 to 6.2 while that of Kuttanad soils vary from 3.2 to 4.0.

b. <u>Loss on ignition</u>: The loss on ignition is large in Kuttanad soils compared to Onattukara soils. It ranges from 3.3 per cent to 6.3 per cent in Onattukara soils and from 21.3 to 27.2 per cent in Kuttanad soils.

c. <u>Total nitrogen</u>: The Kuttanad soils have a very high reserve of total nitrogen compared to the Onattukara soils. The total nitrogen content in Kuttanad soils varies from 0.340 per cent to 0.410 per cent, and in Onattukara soils it ranges from 0.021 per cent to 0.070 per cent.

d. <u>Total phosphorus</u>: The total phosphorus content of Onattukara soils are slightly higher than that of Kuttanad soils. The content of total P_2O_5 varies from

TABLE III

CHEMICAL CHARACTERISTICS OF ONATTUKARA SOILS

Sample No.	pH	Moisture %	Loss on ignition %	CEC me/100g	N %	P_2O_5 %	K_2O %
1	6.0	1.31	3.5	3.0	0.032	0.05	0.120
2	5.5	1.60	4.8	4.0	0.027	0.04	0.096
3	5.7	1.32	4.0	3.6	0.025	0.09	0.084
4	5.6	1.42	4.6	3.7	0.021	0.10	0.122
5	5.4	1.41	5.0	3.9	0.048	0.18	0.064
6	5.6	1.23	3.2	2.0	0.030	0.04	0.140
7	5.7	1.32	3.6	3.2	0.042	0.12	0.072
8	6.0	1.32	3.5	2.8	0.040	0.04	0.084
9	5.6	1.56	3.3	1.9	0.039	0.13	0.120
10	5.4	1.62	5.8	4.2	0.040	0.21	0.084
11	5.4	1.39	5.0	4.1	0.052	0.08	0.132
12	5.9	1.36	4.2	3.6	0.063	0.07	0.168
13	6.2	1.42	3.9	3.2	0.070	0.04	0.108
14	5.3	1.72	6.1	3.9	0.058	0.07	0.072
15	5.2	1.69	6.3	3.9	0.058	0.05	0.060

TABLE IV

CHEMICAL CHARACTERISTICS OF KUTTANAD SOILS

Sample No.	pH	Moisture %	Loss on ignition %	CEC me/100g	N%	P_2O_5%	K_2O%
16	3.9	4.01	21.3	32.5	0.350	0.07	0.490
17	3.9	4.12	21.4	31.8	0.360	0.08	0.510
18	3.4	4.30	24.5	40.6	0.360	0.03	0.500
19	3.4	4.21	21.6	41.2	0.340	0.09	0.480
20	3.4	4.13	21.5	38.9	0.370	0.10	0.640
21	3.5	5.02	27.2	38.3	0.380	0.05	0.510
22	3.2	4.43	24.2	38.1	0.380	0.06	0.550
23	3.4	4.50	24.3	39.1	0.410	0.10	0.570
24	3.2	4.81	25.1	36.5	0.400	0.06	0.580
25	4.0	4.41	24.1	38.3	0.380	0.08	0.620
26	3.4	4.39	21.6	32.8	0.370	0.06	0.600
27	4.0	4.21	26.1	38.2	0.380	0.08	0.710
28	3.9	4.31	23.3	37.2	0.360	0.07	0.580
29	3.4	5.10	22.1	34.6	0.370	0.02	0.750
30	3.3	4.11	26.2	38.1	0.400	0.04	0.560
31	3.6	4.23	23.2	32.8	0.360	0.12	0.590
32	3.4	4.21	25.8	35.8	0.350	0.07	0.590
33	3.2	4.50	24.3	39.2	0.410	0.06	0.470
34	3.8	4.32	24.1	35.9	0.390	0.03	0.610
35	3.4	4.61	25.0	39.2	0.400	0.06	0.610

TABLE V

COPPER AND ZINC CONTENT IN ONATTUKARA SOILS

Sample No.	Copper		Zinc	
	Total Cu ppm	Available Cu ppm	Total Zn ppm	Available Zn ppm
1	27	1.68	82	2.21
2	60	3.38	121	5.01
3	30	2.93	31	0.81
4	45	3.33	158	4.40
5	60	3.43	41	1.25
6	62	2.63	49	1.25
7	85	3.38	52	0.54
8	51	2.08	51	0.51
9	49	2.03	54	1.25
10	86	4.58	137	4.81
11	130	4.48	118	3.21
12	136	5.13	68	3.21
13	56	2.08	68	2.71
14	108	5.50	98	4.25
15	125	5.00	118	3.45

TABLE VI

COPPER AND ZINC CONTENT IN KUTTANAD SOILS

Sample No.	Copper		Zinc	
	TotalCu ppm	Available Cu ppm	Total Zn ppm	Available Zn ppm
16	52	0.51	70	0.52
17	49	0.46	63	0.71
18	72	1.51	63	0.56
19	50	0.41	89	1.96
20	50	0.30	81	0.82
21	72	1.81	82	2.32
22	75	1.66	74	0.82
23	60	1.96	63	0.69
24	97	2.81	92	1.82
25	67	1.31	85	1.82
26	65	1.16	91	2.47
27	66	1.01	72	0.71
28	65	1.06	59	0.69
29	67	1.46	76	1.21
30	80	1.91	93	2.06
31	67	0.61	69	0.52
32	67	1.61	82	1.21
33	81	3.31	90	2.21
34	97	2.21	88	1.71
35	75	2.00	87	1.71

0.04 per cent to 0.21 per cent in Onattukara soils, while in the Kuttanad soils it varies from 0.02 per cent to 0.12 per cent.

e. Total potassium: The Kuttanad soil contain relatively high amounts of potash. The K_2O content ranges from 0.470 per cent to 0.750 per cent in Kuttanad soils and from 0.060 to 0.168 in Onattukara soils.

f. Cation exchange capacity: From Tables III & IV it is seen that Kuttanad soils have high cation exchange capacity compared to Onattukara soils. In Onattukara soils the c.e.c. ranges from 1.9 to 4.2 me/100g, while in Kuttanad soils it ranges from 31.8 to 41.2 me/100g.

g. Copper status of soils: The status total and available copper in Onattukara and Kuttanad soils are given in Tables V and VI.

(i) Total copper: The data show that the total copper content of Onattukara soils ranges from 27 ppm to 136 ppm, and that of Kuttanad soils ranges from 49 ppm to 97 ppm. The averages are 74.00 ppm and 66.65 ppm for Onattukara and Kuttanad soils respectively. Although the Onattukara soils have a higher average value compared to Kuttanad soils, the range of variation is wider in the former than in the latter.

(ii) Available copper: Tables V and VI give the available copper content of different soil samples.

The available copper content of Onattukara soils ranges from 1.68 ppm to 5.50 ppm and that of Kuttanad soils ranges from 0.30 to 3.31 ppm. The averages for available copper content are 3.443 ppm and 1.404 ppm for Onattukara and Kuttanad soils respectively.

Although the average content of available copper in Kuttanad soils is 1.404 ppm, a thorough perusal of the data shows that five out of the twenty samples studied, are having only less than 1 ppm of available copper in them. In Onattukara soils on the other hand, except one sample, all are having a content of available copper greater than 2 ppm; nine samples are having more than three ppm of available copper.

h) Zinc status of soils: The status of total and available zinc in different soils is given in Tables V and VI.

(i) Total zinc: Tables V and VI show that the total zinc content of Onattukara soils ranges from 31 ppm to 158 ppm and that of Kuttanad soils ranges from 59 ppm to 93 ppm. The averages are 83.067 ppm and 78.450 ppm respectively, for Onattukara and Kuttanad soils. Although Onattukara soils are higher in average content of zinc, the range of variation is wider in Onattukara soils whereas in Kuttanad soils it is more consistent.

In Onattukara soils six out of fifteen samples studied are having a total zinc content only less than 60 ppm, while in Kuttanad soils all samples except one have a total zinc content greater than 60 ppm. But in Onattukara soils there are five samples out of the 15 studied, having total zinc content above 100 ppm, whereas no sample in Kuttanad soils is having a zinc content above 100 ppm.

(ii) <u>Available zinc</u>: Reference of the Tables V and VI shows that in Onattukara soils the available zinc content ranges from 0.51 ppm to 5.01 ppm and in Kuttanad soils it ranges from 0.52 ppm to 2.47 ppm. The averages are 2.591 ppm and 1.342 ppm, for Onattukara and Kuttanad soils respectively. In Onattukara soils the range of variation of available zinc is comparatively wider than that in Kuttanad soils. Three out of fifteen samples of Onattukara, are having available zinc content less than 1 ppm. But in Kuttanad soils nine out of the twenty samples studied, are having their available zinc content less than 1 ppm.

C. <u>Relationship between Cu and Zn content and other characteristics of the soil</u>

Correlation between copper and zinc content of the soils and different soil characteristics namely, pH, organic matter content, clay content, total nitrogen content, total P_2O_5 content, total K_2O content and cation exchange capacity were worked out. The values of correlation coefficients are given in Tables VII and VIII. The regression equations and the straight lines

TABLE VII

VALUES OF CORRELATION COEFFICIENTS

(KUTTANAD SOIL)

	Total Cu	Av.Cu	Total Zn	Av.Zn.
Av.Cu	0.820*	----	----	----
Av.Zn	----	----	0.667*	----
pH	-0.052	-0.4863*	-0.406	-0.340
Organic matter	0.490*	0.3270	0.337	0.338
Clay content	0.248	0.284	0.346	0.361
N %	0.156	0.091	-0.125	-0.083
P_2O_5%	-0.003	0.008	-0.089	-0.121
K_2O %	0.099	-0.083	0.026	0.084
CEC	0.136	0.296	0.214	0.308

* significant

TABLE VIII

VALUES OF CORRELATION COEFFICIENTS (ONATTUKARA SOIL)

	Total Cu	Av.Cu	Total Zn	Av.Zn
Av.Cu	0.858*	----	----	----
Av.Zn	----	----	0.881*	----
pH	-0.303	-0.648*	-0.410	-0.387
Organic matter	0.493*	0.362	0.402	0.411
Clay content	0.036	-0.083	0.077	-0.063
N %	0.079	-0.036	-0.007	0.009
P_2O_5 %	0.156	0.207	0.243	0.183
K_2O %	0.098	-0.115	0.056	0.116
CEC	0.428	0.697*	0.581*	0.711*

* significant

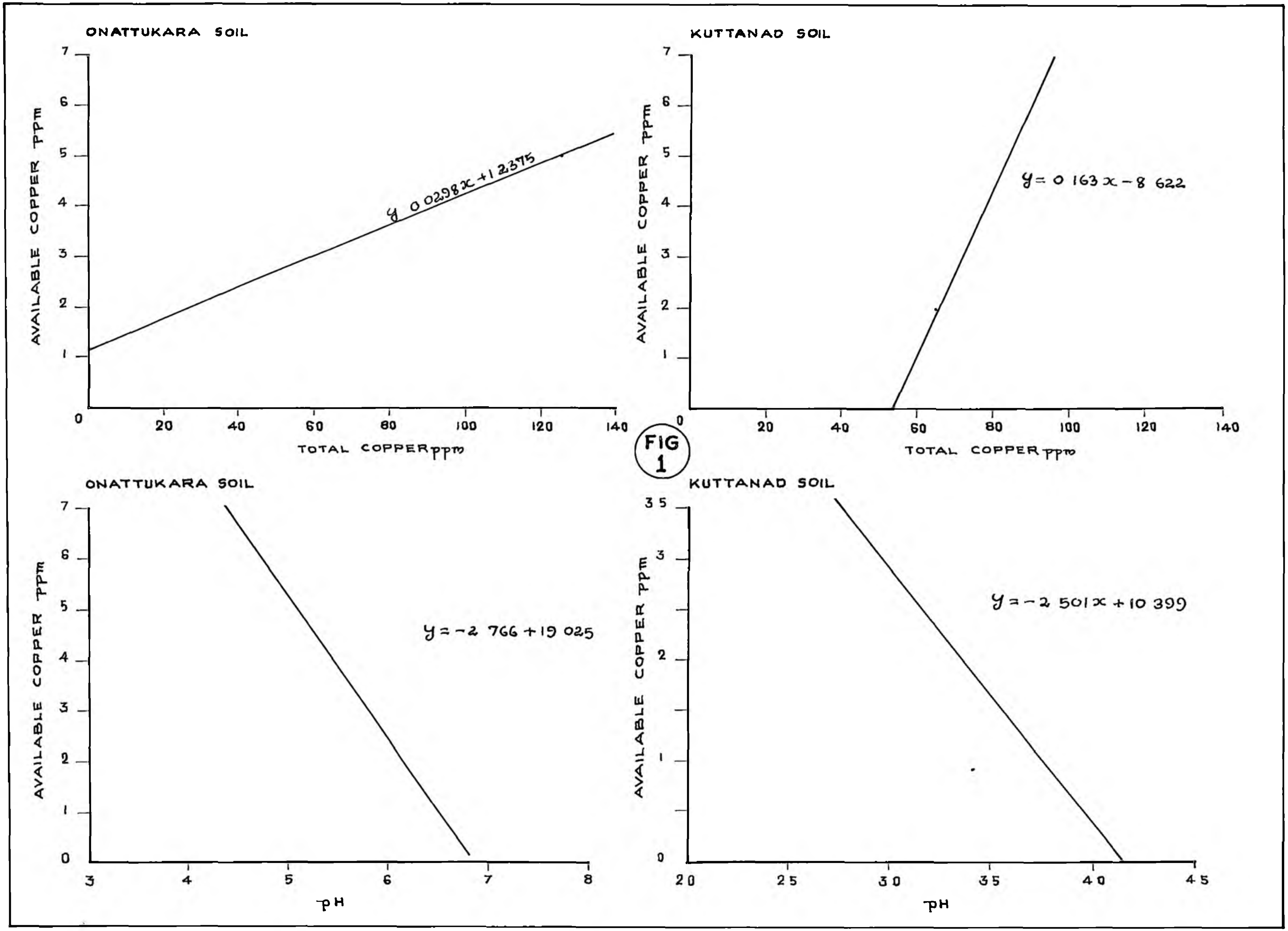
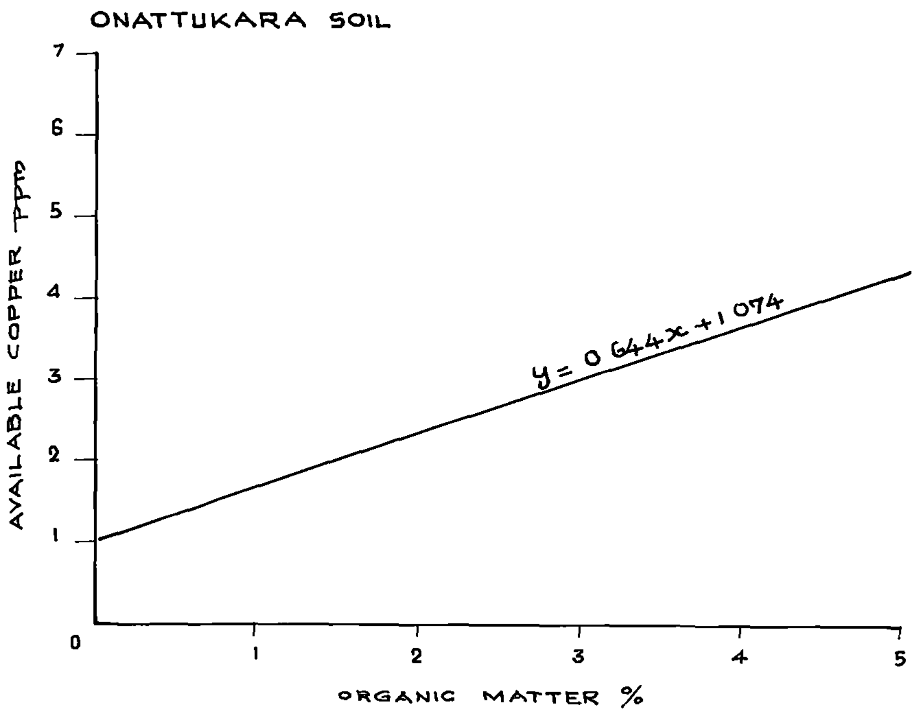
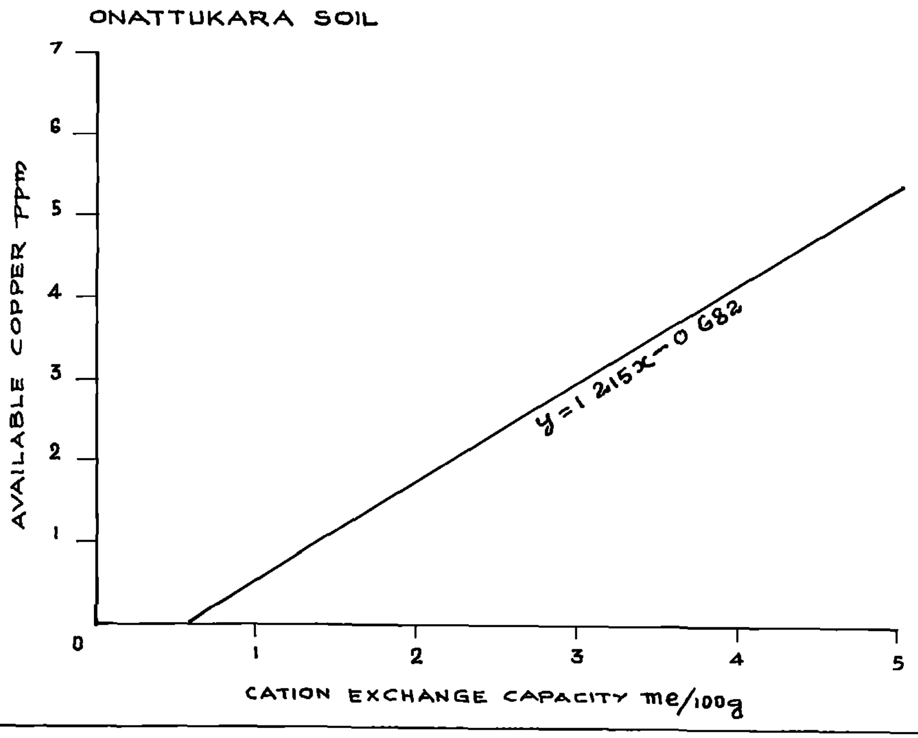

ONATTUKARA SOIL
AVAILABLE COPPER ppm
TOTAL COPPER ppm
y 0 0298x + 1 2375
KUTTANAD SOIL
AVAILABLE COPPER ppm
TOTAL COPPER ppm
y = 0 163 x − 8 622
ONATTUKARA SOIL
AVAILABLE COPPER ppm
pH
y = −2 766 + 19 025
KUTTANAD SOIL
AVAILABLE COPPER ppm
pH
y = −2 501x + 10 399

FIG 1



ONATTUKARA SOIL
AVAILABLE COPPER ppm
0
1
2
3
4
5
6
7
y = 0 644x + 1 074
ORGANIC MATTER %



ONATTUKARA SOIL
AVAILABLE COPPER ppm
0
1
2
3
4
5
6
7
y = 1 215x − 0 682
CATION EXCHANGE CAPACITY me/100g

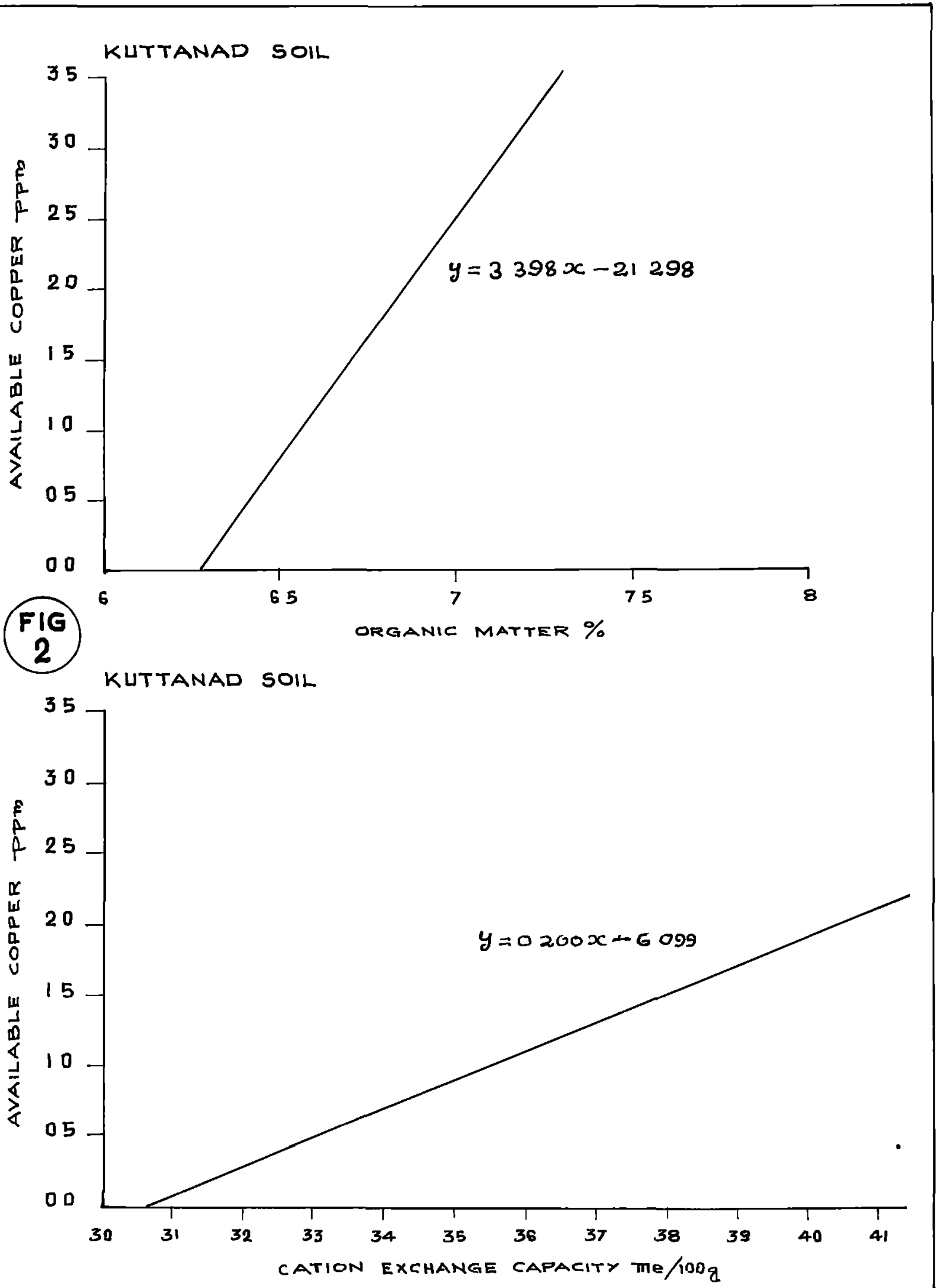
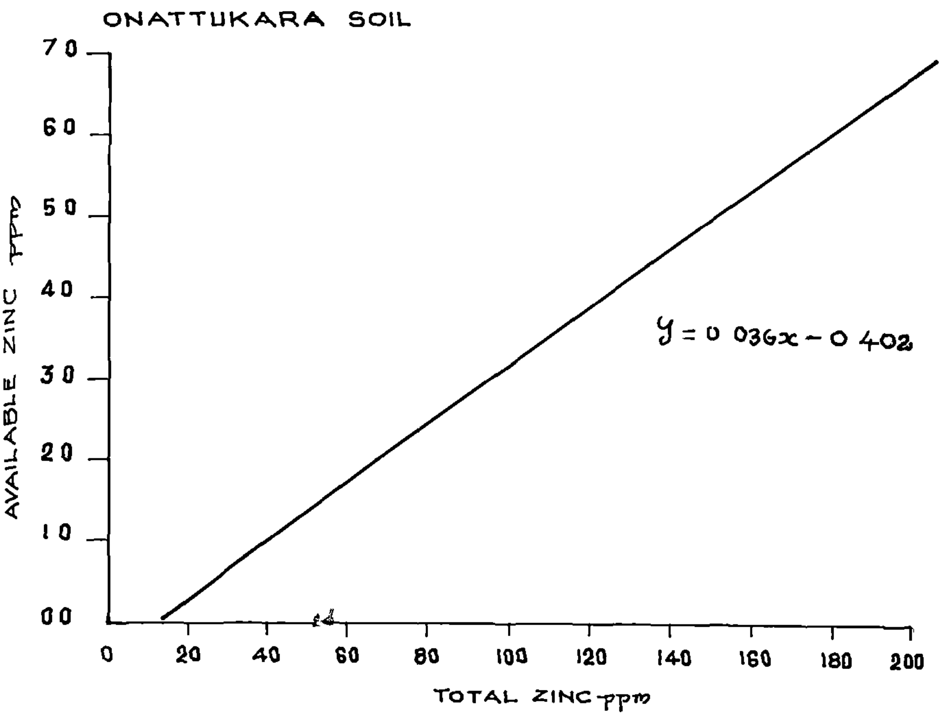
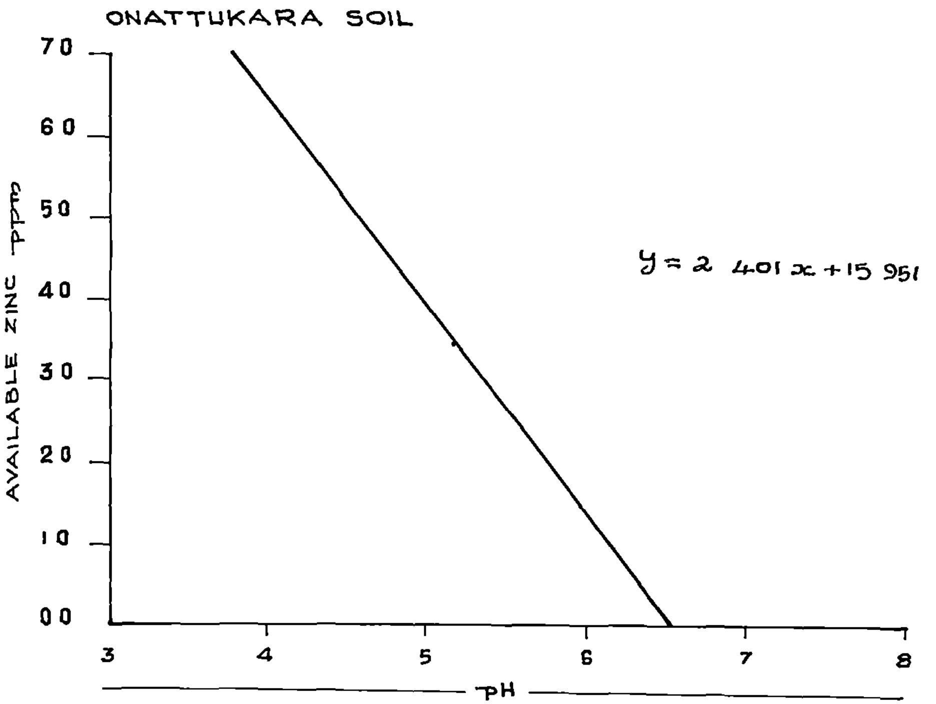

KUTTANAD SOIL
AVAILABLE COPPER ppm
35
30
25
20
15
10
05
00
y = 3 398 x − 21 298
6
6 5
7
7 5
8
ORGANIC MATTER %
KUTTANAD SOIL
AVAILABLE COPPER ppm
35
30
25
20
15
10
05
00
y = 0 200 x − 6 099
30
31
32
33
34
35
36
37
38
39
40
41
CATION EXCHANGE CAPACITY me/100g

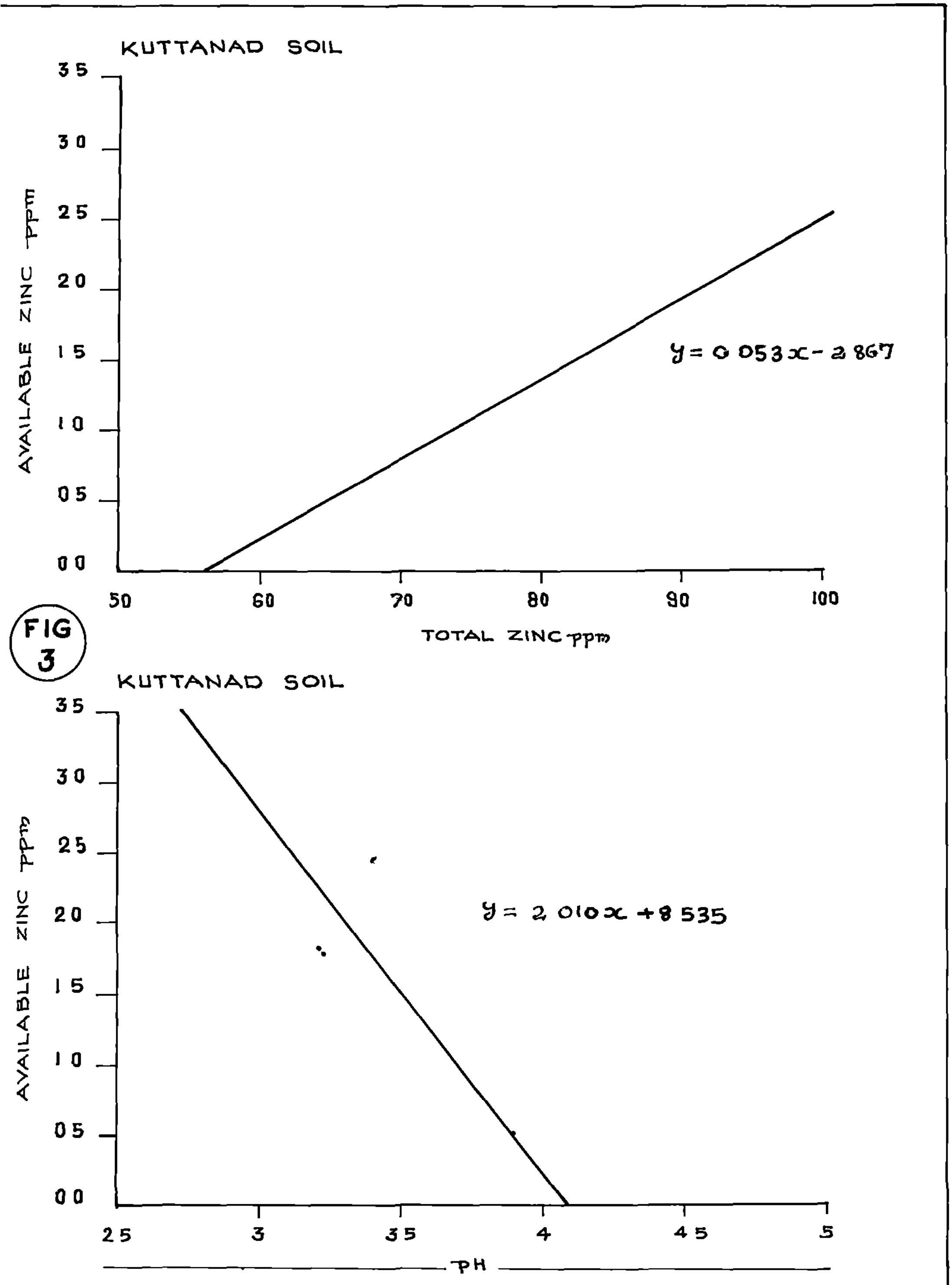
FIG 2



ONATTUKARA SOIL
70
60
50
40
30
20
10
00
AVAILABLE ZINC ppm
0
20
40
60
80
100
120
140
160
180
200
TOTAL ZINC-ppm
y = 0 036x - 0 402

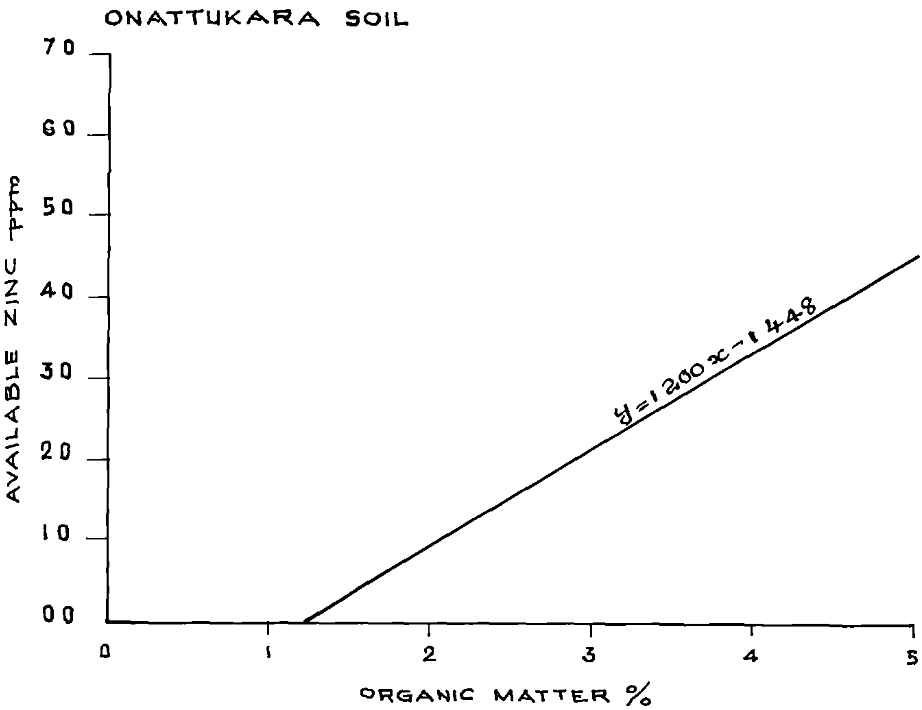


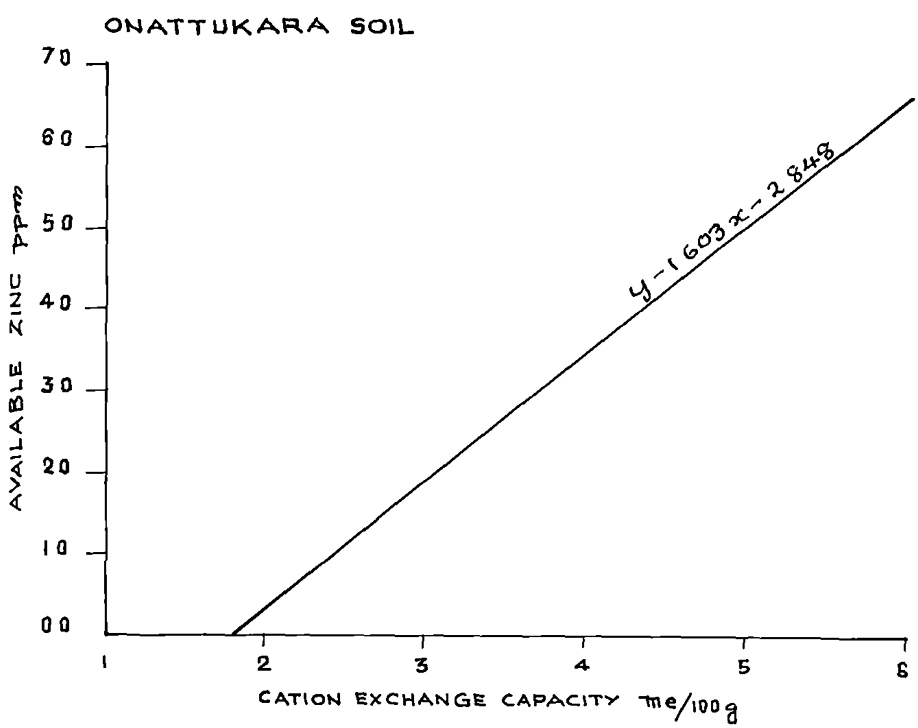
ONATTUKARA SOIL
70
60
50
40
30
20
10
00
AVAILABLE ZINC ppm
3
4
5
6
7
8
pH
y = 2 401 x +15 951



KUTTANAD SOIL
AVAILABLE ZINC ppm
35
30
25
20
15
10
05
00
y = 0 053x - 2 867
50
60
70
80
90
100
TOTAL ZINC ppm
KUTTANAD SOIL
AVAILABLE ZINC ppm
35
30
25
20
15
10
05
00
y = 2 010x + 8 535
25
3
35
4
45
5
PH

FIG 3


ONATTUKARA SOIL
AVAILABLE ZINC ppm
70
60
50
40
30
20
10
00
0
1
2
3
4
5
ORGANIC MATTER %
y=1200x-1448


ONATTUKARA SOIL
AVAILABLE ZINC ppm
70
60
50
40
30
20
10
00
1
2
3
4
5
6
CATION EXCHANGE CAPACITY me/100g
y-1603x-2848

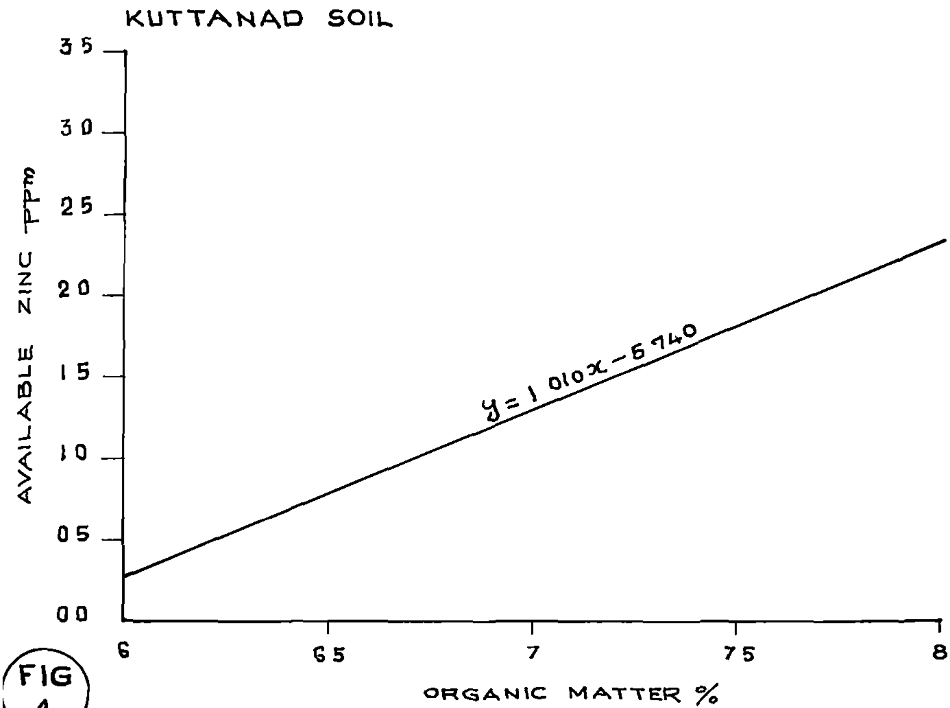
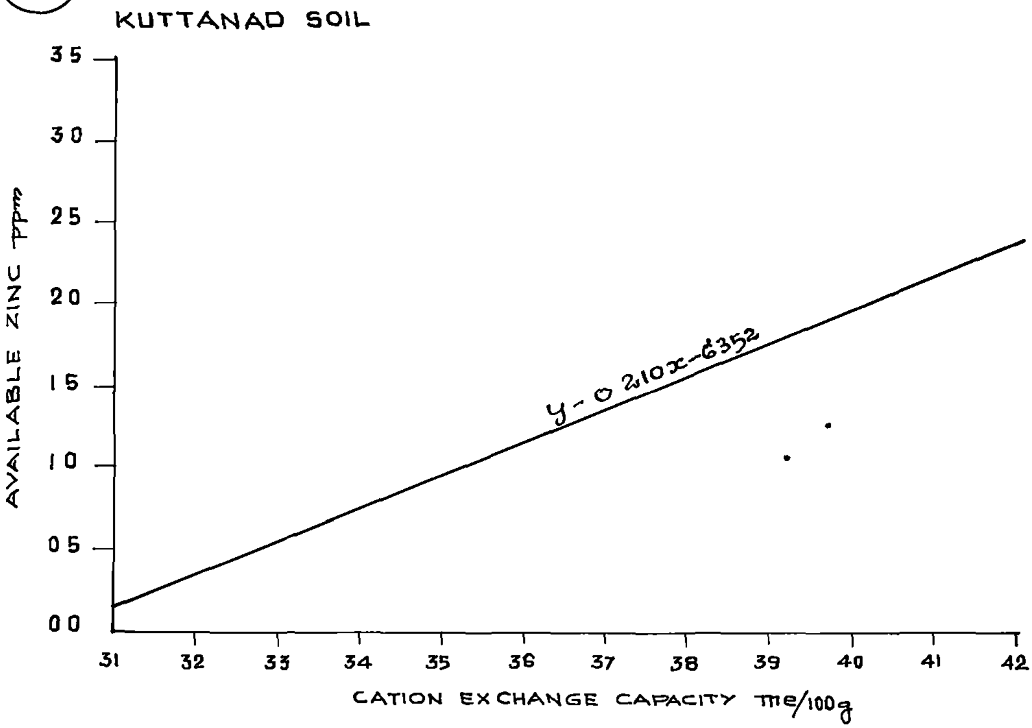

KUTTANAD SOIL
3 5
3 0
2 5
2 0
1 5
1 0
0 5
0 0
AVAILABLE ZINC ppm
y = 1 010x − 5 740
6
6 5
7
7 5
8
ORGANIC MATTER %

FIG 4


KUTTANAD SOIL
3 5
3 0
2 5
2 0
1 5
1 0
0 5
0 0
AVAILABLE ZINC ppm
y - 0 210x - 6352
31
32
33
34
35
36
37
38
39
40
41
42
CATION EXCHANGE CAPACITY me/100g

fitted using the relationships are presented in Figures 1 to 4.

The data show that there is a significant positive correlation between available copper content and total copper content in both Onattukara and Kuttanad soils. Similarly a significant positive correlation is observed between available zinc and total zinc content in both the soils.

Significant negative relationship is observed between pH and copper content of soils. A similar negative relationship is observed between pH and zinc content of the soils also. However, the relationship is not significant at 5% level of significance. But the values of correlation coefficients in both the soils are very close to the critical value.

In both the soils a significant positive correlation is observed between organic matter and total copper content.

A positive relationship is observed between zinc content and organic matter content of soils. The relationship, however, is not significant in both the soils.

The cation exchange capacity and zinc and copper content of soils are found to have a positive correlation. The relationship, however, is statistically significant only in Onattukara soils, and it is not significant in Kuttanad soils.

Zinc and copper content of both Kuttanad and Onattukara soils are found to have no significant relationship with the contents of total N, total P_2O_5 and total K_2O.

II. Pot culture experiment

The results of the pot culture experiment are presented in Tables IX to XXII.

A. Growth characteristics

The average growth characeristics of rice for the various treatments in the two soils are presented in Tables IX and X.

1. Height of the plant: Considerable differences exist among the two soils in their response to micronutrient application. In Onattukara soil the mean

TABLE IX

EFFECT OF COPPER AND ZINC ON THE GROWTH CHARACTERISTICS OF IR-8 IN ONATTUKARA SOIL

Treatments		Growth characteristics					
Copper kg/ha	Zinc kg/ha	Plant height cm			No.of tillers		No. of productive tillers
		30th day	60th day.	At harvest	30th day	60th day	
0	0	50.43	73.63	94.53	12.67	12.67	10.00
	5	51.43	73.80	94.70	12.33	12.00	11.00
	10	51.53	76.40	96.17	11.33	11.67	10.00
	Mean	51.13	74.61	95.13	12.11	12.11	10.33
5	0	48.23	75.03	94.63	13.67	14.00	11.33
	5	53.33	76.70	96.77	14.00	13.33	12.00
	10	56.30	76.13	95.80	13.67	13.67	11.00
	Mean	52.95	75.95	95.73	13.78	13.67	11.44
10	0	49.90	73.80	96.33	13.33	12.67	11.00
	5	52.76	76.00	99.67	14.00	13.67	12.33
	10	53.57	76.87	99.33	15.00	13.67	11.33
	Mean	52.08	75.56	98.44	14.11	13.34	11.55
All levels	0	49.52	74.15	95.16	13.22	13.11	10.78
	5	52.84	75.50	97.05	13.44	13.00	11.78
	10	53.80	76.47	97.10	13.33	13.00	10.78
L.S.D. copper & zinc means							
95 per cent level		1.7648	N.S.	N.S.	N.S.	N.S.	N.S.
Copper X zinc							
95 per cent level		3.0674	N.S.	N.S.	N.S.	N.S.	N.S.

TABLE X

EFFECT OF COPPER AND ZINC ON THE GROWTH CHARACTERISTICS OF IR-8 IN KUTTANAD SOIL

Treatments		Growth characteristics					
Copper kg/ha	Zinc kg/ha	Plant height			No.of tillers		No. of productive tillers
		30th day	60th day	At harvest	30th day	60th day	
0	0	50.37	73.43	93.37	13.00	12.33	9.33
	5	51.23	73.80	93.67	11.67	11.67	10.33
	10	51.17	76.00	95.17	12.00	11.33	9.33
	Mean	50.92	74.41	94.07	12.22	11.78	9.66
5	0	48.13	74.67	93.80	13.67	13.67	10.33
	5	53.87	76.40	96,03	13.00	13.00	10.67
	10	56.17	75.90	94.47	14.00	13.67	9.33
	Mean	52.72	75.66	94.77	13.56	13.45	10.11
10	0	49.77	73.67	94.27	12.00	12.33	10.00
	5	52.67	75.67	98.17	13.67	13.33	11.67
	10	53.17	76.67	98.53	14.33	13.33	10.67
	Mean	51.87	75.34	96.66	13.33	13.00	10.78
All levels	0	49.42	73.92	93.81	12.89	12.73	9.87
	5	52.59	75.29	95.96	12.78	12.67	10.89
	10	53.50	76.19	96.06	13.44	12.78	9.78
L.S.D. copper & zinc means							
95 per cent level		1.6808	1.5703	2.0674	N.S.	N.S.	N.S.
Copper x zinc							
95 per cent level		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

height of plant increased significantly at the initial stages of growth by increased doses of both copper and zinc. The maximum mean plant height in Onattukara soil is observed for the treatments 5 kg Cu/ha and 10 kg Zn/ha. In the later stages, however, the increases in plant height due to micronutrient application in Onattukara soil, are not statistically significant.

In Kuttanad soil, the increase in plant height is found to be significantly influenced by application of micronutrients, at all stages of growth. At the early stages of growth copper at 5 kg/ha and zinc at 10 kg/ha is found to exert the maximum influence in increasing the mean plant height. But at later stages of growth higher level of copper also found to have significant influence in increasing plant height.

2. Number of tillers: As seen from the tables, the various treatments did not have a significant influence on the number of tillers at both the stages studied. However, in both the soils the higher levels of copper

treated pots gave maximum tiller count.

3. Number of productive tillers: The various treatments found to have no significant influence on the number of productive tillers in both the soils. However, higher levels of copper and zinc found to produce the maximum number of productive tillers. In Kuttanad soils when the 0 level of copper produced a mean number of 9.66 productive tillers, the highest level of copper (10 kg/ha) produced a mean number of 10.78 productive tillers.

B. Yield

The average yield of rice per plot for various treatments of the soils are presented in Tables XI & XII, and the data are graphically represented in Figure (5).

1. Yield of grain: In both the soils, the micronutrient application significantly increased the yield of grain. The highest total yield in Onattukara soil is observed for copper and zinc fertilization at the highest level, viz, 10 kg/ha each. At copper 10 kg/ha the mean yield per pot is 22.54 g as against 17.70 g for control.

TABLE XI

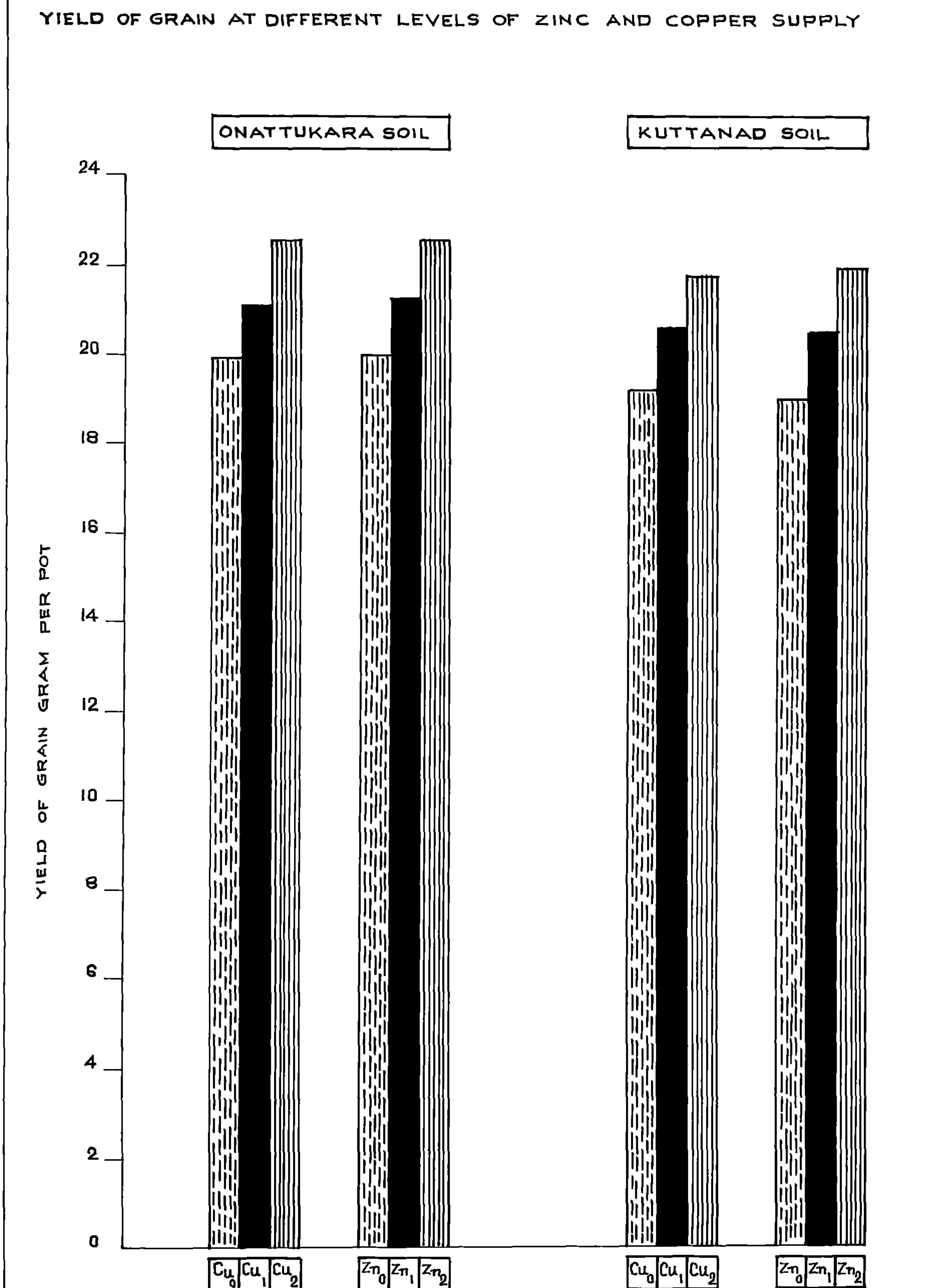
EFFECT OF COPPER AND ZINC ON YIELD AND YIELD ATTRIBUTES OF IR-8 IN ONATTUKARA SOIL

Treatments					
Copper kg/hect.	Zinc kg/hect.	Yield of grain gm	Percentage filled grains	1000 grain weight gm	Yield of straw gm.
0	0	17.70	87.53	28.37	23.57
	5	20.23	89.17	29.13	25.60
	10	22.00	90.00	29.03	26.43
	Mean	19.98	88.90	29.01	25.20
5	0	20.10	89.93	28.93	26.30
	5	21.47	88.17	28.57	27.07
	10	22.40	89.50	29.17	27.80
	Mean	21.32	88.87	28.89	27.06
10	0	22.33	89.60	29.10	27.70
	5	21.93	89.67	29.00	26.73
	10	23.30	88.87	29.03	28.93
	Mean	22.52	89.38	29.04	27.79
All levels	0	20.04	89.02	28.97	25.86
	5	21.21	89.00	28.90	26.47
	10	22.57	89.12	29.08	27.42
L.S.D. copper & zinc means 95 per cent level		0.9455	N.S.	N.S.	1.1976
Copper X zinc 95 per cent level		N.S.	N.S.	N.S.	N.S.

TABLE XII

EFFECT OF COPPER AND ZINC ON YIELD AND YIELD ATTRIBUTES OF IR-8 IN KUTTANAD SOILS

Treatments					
Copper kg/hect.	Zinc kg/hect.	Yield of grain gm.	Percentage filled grain	1000 grain weight gm.	Yield of straw gm.
0	0	16.70	87.53	28.20	23.00
	5	19.33	87.43	28.47	25.27
	10	21.50	88.50	28.33	25.87
	Mean	19.18	87.52	28.33	24.71
5	0	19.10	88.93	28.93	28.97
	5	20.83	88.13	27.90	26.50
	10	21.73	88.17	27.83	27.23
	Mean	20.56	88.41	28.22	27.57
10	0	21.33	88.77	28.43	27.03
	5	21.27	87.77	28.33	26.17
	10	22.63	89.10	28.03	28.37
	Mean	21.74	88.55	28.26	27.19
All levels	0	19.04	88.41	28.52	26.33
	5	20.48	87.78	28.23	25.98
	10	21.96	88.59	28.06	27.16
L.S.D. copper & zinc means 95 per cent level		0.9707	N.S.	N.S.	N.S.
Copper X zinc 95 per cent level		N.S.	N.S.	N.S.	N.S.



YIELD OF GRAIN AT DIFFERENT LEVELS OF ZINC AND COPPER SUPPLY
ONATTUKARA SOIL
KUTTANAD SOIL
YIELD OF GRAIN GRAM PER POT
24
22
20
18
16
14
12
10
8
6
4
2
0
Cu_0 Cu_1 Cu_2
Zn_0 Zn_1 Zn_2
Cu_0 Cu_1 Cu_2
Zn_0 Zn_1 Zn_2

FIG 5

zinc fertilization at 10 kg/ha gave a mean pot yield of 22.58 g as against 17.70 g for control. The interaction between copper and zinc is not significant.

In Kuttanad soils also invariably there is a positive significant influence for application of micronutrients, on yield of rice. Higher doses of both copper and zinc increased the yield significantly. Pots received copper at the rate of 10 kg/ha gave a mean yield of 21.74 g as against 16.70 g for control. Zinc application at the rate of 10 kg/ha gave a mean yield of 21.96 g/pot as against 16.70 g/pot for control.

However, Onattukara soils gave better total yields when compared to Kuttanad soils.

2. Yield of straw: Considerable differences exist among the two soils in their response to micronutrient fertilization as regards the yield of straw.

In Onattukara soil the yield of straw is significantly increased due to both zinc and copper fertilization, whereas in Kuttanad soil, the treatments did not have a significant influence on straw yield. In Onattukara soil copper at both higher levels increased the straw yield significantly over the control. However, the 10 kg/ha level of copper is not significantly superior to 5 kg/ha level of copper. Zinc at the rate of 10 kg/ha also gave significant increases in straw yield over control in Onattukara soils.

3. <u>1000 grains weight and percentage of filled grain</u>

The different treatments are found to have no significant influence on thousand grain weight and percentage of filled grains in both the soils.

C. <u>Mineral composition of the plants</u>

Data pertaining to the mineral composition of plants for the various treatments of the two soils are given in Tables XIII to XXII.

1. <u>Nitrogen</u>: The percentage of nitrogen in grain and straw are found to be not significantly influenced by the various treatments in both the soils. The percentage of nitrogen in grain observed to have only a narrow variation ranging from 1.17 to 1.24. Similarly

TABLE XIII

NITROGEN CONTENT OF GRAIN AND STRAW (ONATTUKARA SOIL)

Treatments			
Copper kg/hect.	Zinc kg/hect.	N % grain	N % straw
0	0	1.23	0.73
	5	1.20	0.72
	10	1.22	0.70
	Mean	1.217	0.717
5	0	1.19	0.72
	5	1.23	0.75
	10	1.21	0.72
	Mean	1.210	0.730
10	0	1.23	0.68
	5	1.17	0.71
	10	1.21	0.68
	Mean	1.203	0.690
All levels	0	1.217	0.710
	5	1.200	0.727
	10	1.213	0.700
L.S.D. copper & zinc means 95 per cent level		N.S.	N.S.
Copper X zinc 95 per cent level		N.S.	N.S.

TABLE XIV

NITROGEN CONTENT OF GRAIN AND STRAW (KUTTANAD SOIL)

Treatments			
Copper kg/hect.	Zinc kg/hect.	N % grain	N % straw
0	0	1.23	0.74
	5	1.21	0.72
	10	1.24	0.70
	Mean	1.227	0.720
5	0	1.24	0.72
	5	1.23	0.75
	10	1.21	0.72
	Mean	1.227	0.730
10	0	1.20	0.69
	5	1.17	0.71
	10	1.22	0.68
	Mean	1.197	0.693
All levels	0	1.223	0.717
	5	1.203	0.727
	10	1.223	0.700
L.S.D. copper & zinc means 95 per cent level		N.S.	N.S.
Copper X zinc 95 per cent level		N.S.	N.S.

TABLE XV

PHOSPHORUS CONTENT OF GRAIN AND STRAW (ONATTUKARA SOIL)

Treatments			
Copper kg/hect.	Zinc kg/hect.	P_2O_5 per cent of grain	P_2O_5 per cent of straw
0	0	0.0662	0.0228
	5	0.0652	0.0221
	10	0.0642	0.0214
	Mean	0.0652	0.0221
5	0	0.0631	0.0228
	5	0.0639	0.0211
	10	0.0611	0.0206
	Mean	0.0627	0.0215
10	0	0.0636	0.1094
	5	0.0609	0.0186
	10	0.0621	0.0189
	Mean	0.0622	0.0190
All levels	0	0.0643	0.0217
	5	0.0633	0.0206
	10	0.0625	0.0203
L.S.D. copper & zinc means			
95 per cent level		N.S.	N.S.
Copper X zinc			
95 per cent level		N.S.	N.S.

TABLE XVI

PHOSPHORUS CONTENT OF GRAIN AND STRAW (KUTTANAD SOIL)

Treatments			
Copper kg/hect.	Zinc kg/hect.	P_2O_5 % of grain	P_2O_5 % of straw
0	0	0.0661	0.0225
	5	0.0636	0.0222
	10	0.0644	0.0214
	Mean	0.0647	0.0220
5	0	0.0631	0.0222
	5	0.0640	0.0223
	10	0.0613	0.0207
	Mean	0.0628	0.0217
10	0	0.0652	0.0196
	5	0.0609	0.0187
	10	0.0624	0.0190
	Mean	0.0628	0.0191
All levels	0	0.0648	0.0214
	5	0.0628	0.0211
	10	0.0627	0.0204
A.S.D. copper & zinc means			
95 per cent level		N.S.	N.S.
Copper X zinc			
95 per cent level		N.S.	N.S.

TABLE XVII

POTASSIUM CONTENT OF GRAIN AND STRAW (ONATTUKARA SOIL)

Treatments			
Copper kg/hect.	Zinc kg/hect.	K_2O % grain	K_2O % straw
0	0	0.613	1.42
	5	0.627	1.47
	10	0.607	1.40
	Mean	0.616	1.430
5	0	0.607	1.47
	5	0.603	1.38
	10	0.607	1.52
	Mean	0.606	1.457
10	0	0.630	1.40
	5	0.607	1.43
	10	0.617	1.47
	Mean	0.618	1.433
All levels	0	0.617	1.430
	5	0.612	1.427
	10	0.610	1.463
L.S.D. copper & zinc means 95 per cent level		N.S.	N.S.
Copper X zinc 95 per cent level		N.S.	N.S.

TABLE XVIII

POTASSIUM CONTENT OF GRAIN AND STRAW (KUTTANAD SOIL)

Treatments			
Copper kg/hect.	Zinc kg/hect.	K_2O % grain	K_2O % straw
0	0	0.617	1.40
	5	0.617	1.45
	10	0.600	1.40
	Mean	0.611	1.417
5	0	0.603	1.48
	5	0.603	1.40
	10	0.607	1.52
	Mean	0.604	1.407
10	0	0.633	1.43
	5	0.603	1.45
	10	0.613	1.43
	Mean	0.616	1.437
All levels	0	0.618	1.437
	5	0.608	1.433
	10	0.607	1.450
L.S.D. Copper and zinc means 95 per cent level		N.S.	N.S.
Copper X zinc 95 per cent level		N.S.	N.S.

percentage of nitrogen in straw varied from 0.68 to 0.75.

2. <u>Phosphorus</u>: The various treatments found to have no influence on the percentage of P_2O_5 in grain and straw in both the soils. However, the percentage of P_2O_5 in the plant found to decrease slightly as higher doses of micronutrients are applied. For samples from the control pots the mean P_2O_5 content of grain is observed to be 0.0662 per cent and at the highest level of micronutrient application the content of P_2O_5 in grain decreased to 0.0622 per cent. Similarly mean P_2O_5 content of straw for highest levels of copper and zinc is found to be 0.0190 per cent where as that of control is 0.0228 per cent.

3. <u>Potassium</u>: The different treatments found to have no significant influence on the K_2O content of grain and straw of both the soils. The content of K_2O in grain is found to range from 0.600 per cent to 0.630 per cent and the content of K_2O in straw ranged from 1.400 per cent to 1.52 per cent.

4. <u>Micronutrient composition</u>

Data showing micronutrient composition of plants are presented in Tables XIX to XXII.

a. Copper and zinc content of grain

The various treatments are found to have significant influences on the micronutrient composition of grain.

The content of copper in grain, showed a wide variation, ranging from 20.3 ppm to as high as 58.0 ppm the maximum being nearly three times the minimum. In all cases, the copper content in grain increased significantly with increased doses of copper application. In both the soils the maximum content of copper in grain is obtained for the highest level of copper application. It can be noted, however, that the total content of copper in grain in Onattukara soils are slightly more than that for Kuttanad soils at all levels of copper application.

The zinc content of grain showed a wide variation ranging from 23.7 ppm to as high as 83.3 ppm., the maximum being 4 times the minimum. In all cases zinc content of grain increased as doses of zinc applied increased. Maximum zinc content is obtained for highest level of zinc application in both the soils.

TABLE XIX

COPPER CONTENT OF RICE PLANT GROWN IN ONATTUKARA SOIL

Treatments				
Copper kg/hect.	Zinc kg/hect.	Cu content in grain ppm	Cu content in straw ppm	Cu uptake mgm/pot
0	0	21.0	7.7	0.591
	5	22.7	10.3	0.726
	10	24.0	9.0	0.767
	Mean	22.56	9.00	0.694
5	0	40.7	18.0	1.290
	5	42.0	15.3	1.319
	10	42.0	18.0	1.451
	Mean	41.56	17.11	1.353
10	0	55.3	26.7	1.980
	5	58.0	25.0	1.944
	10	52.7	31.7	2.144
	Mean	55.33	27.78	2.023
All levels	0	39.00	17.44	1.267
	5	40.89	16.89	1.329
	10	39.56	19.56	1.454
L.S.D. copper & zinc means 95 per cent level		4.5214	3.1305	0.1555
Copper X zinc 95 per cent level		N.S.	N.S.	N.S.

TABLE XX

COPPER CONTENT OF RICE PLANT GROWN IN KUTTANAD SOIL

Treatments				
Copper kg/hect.	Zinc kg/hect.	Cu content in grain ppm	Cu content in straw ppm	Cu uptake mgm/pot
0	0	20.3	8.7	0.544
	5	23.0	10.3	0.707
	10	24.0	10.3	0.785
	Mean	22.44	9.78	0.679
5	0	40.3	16.3	1.097
	5	42.3	15.3	1.293
	10	35.7	15.7	1.206
	Mean	39.44	15.78	1.232
10	0	55.3	25.7	1.848
	5	58.0	25.0	1.893
	10	46.7	29.0	1.548
	Mean	53.33	26.55	1.885
All levels	0	38.67	16.89	1.207
	5	41.11	16.89	1.298
	10	35.44	18.33	1.291
L.S.D. copper and zinc means 95 per cent level		6.5341	3.0549	0.1370
Copper X zinc 95 per cent level		N.S.	N.S.	N.S.

TABLE XXI

ZINC CONTENT OF RICE PLANT GROWN IN ONATTUKARA SOIL

Treatments				
Copper kg/hect.	Zinc kg/hect.	Zn content of grain ppm	Zn content of straw ppm	Zn uptake mgm/pot
0	0	23.3	14.0	0.832
	5	48.0	39.0	1.965
	10	78.0	59.0	3.295
	Mean	51.44	37.33	2.031
5	0	23.7	14.0	0.841
	5	45.7	32.3	1.859
	10	83.0	52.3	3.337
	Mean	50.78	32.89	2.013
10	0	29.3	11.0	0.954
	5	46.3	29.0	1.764
	10	83.3	55.3	3.519
	Mean	53.00	31.78	2.061
All levels	0	27.11	13.00	0.875
	5	46.67	33.44	1.362
	10	81.44	55.56	3.377
L.S.D. copper & zinc means 95 per cent level		9.5470	3.3406	0.3572
Copper zinc 95 per cent level		N.S.	5.7778.	N.S.

TABLE XXII

ZINC CONTENT OF RICE PLANT GROWN IN KUTTANAD SOIL

Treatments				
Copper kg/hect.	Zinc kg/hect.	Zn content of grain ppm	Zn content of straw ppm	Zn uptake mgm/pot
0	0	27.7	14.7	0.798
	5	44.0	39.7	1.857
	10	82.0	59.0	3.293
	Mean	51.22	37.8	1.983
5	0	24.7	14.3	0.838
	5	45.7	38.3	1.970
	10	80.0	57.3	3.305
	Mean	50.11	36.67	2.038
10	0	30.7	12.0	0.981
	5	46.3	30.7	1.800
	10	75.3	58.7	3.362
	Mean	50.78	33.78	2.048
All levels	0	27.67	13.67	0.873
	5	45.33	36.22	1.876
	10	79.11	58.33	3.320
L.S.D. copper & zinc means 95 per cent level		9.8012	3.9709	0.2193
Copper X zinc 95 per cent level		N.S.	N.S.	N.S.

The interaction between zinc and copper is not significant in both the soils showing that copper content of grain is not influenced by zinc application and vice versa.

b. Copper and zinc content of straw

The various treatments are found to exert significant influence on the micronutrient composition of straw in both the soils.

Mean copper content of straw showed a wide variation ranging from 7.7 ppm to as high as 31.7 ppm, the maximum being nearly 4 times the minimum. In all cases, the copper content of straw increases significantly with increased doses of copper fertilization. In both the soils the maximum content of copper in straw is observed for the highest level of copper application. It can also be seen that the content of copper in straw for Onattukara soils are slightly more as compared to that of Kuttanad soils, at all levels of copper application. Zinc fertilization in both the soils found to have no influence on copper content of straw.

The zinc content of straw also showed a wide variation, ranging from 11.0 ppm to as high as 59.0 ppm, the maximum being nearly 5.5 times the minimum. In all the cases the zinc content of straw increases significantly with increased levels of zinc application. Maximum content of zinc in straw is noticed for highest level of zinc application in both the soils.

In Kuttanad soil the interaction between copper and zinc is not significant. But in Onattukara soil copper fertilization significantly reduced the zinc content of straw.

D. Uptake of copper and zinc by rice plant

The data pertaining to the uptake of copper and zinc by rice plant grown in Kuttanad and Onattukara soils are presented in Tables XIX to XXII. The data are graphically represented in Figure 6.

In both the soils ~~of~~ copper uptake by rice is found to increase significantly with increases in level of copper application. In Onattukara soil the copper uptake for control is found to be 0.591 mg/pot, while that for highest level of copper application, i.e. 10 kg/ha, is found to be 0.023 mg/pot. In Kuttanad soil the copper uptake for control is found to be 0.544 mg/pot and for treatment of copper at the rate of 10 kg/ha, the uptake is found to be 1.885 mg/pot.

Zinc uptake by rice increased significantly by zinc application in Onattukara as well as Kuttanad soils. In Onattukara soil for control the uptake is found to be 0.832 mg/pot while that for treatment of zinc at the rate of 10 kg/ha is found to be 3.377 mg/pot. In Kuttanad soil the uptake of zinc for control is found to be 0.873 mg/pot while that for treatment at the rate of 10 kg Zn/ha, is found to be 3.320 mg/pot.

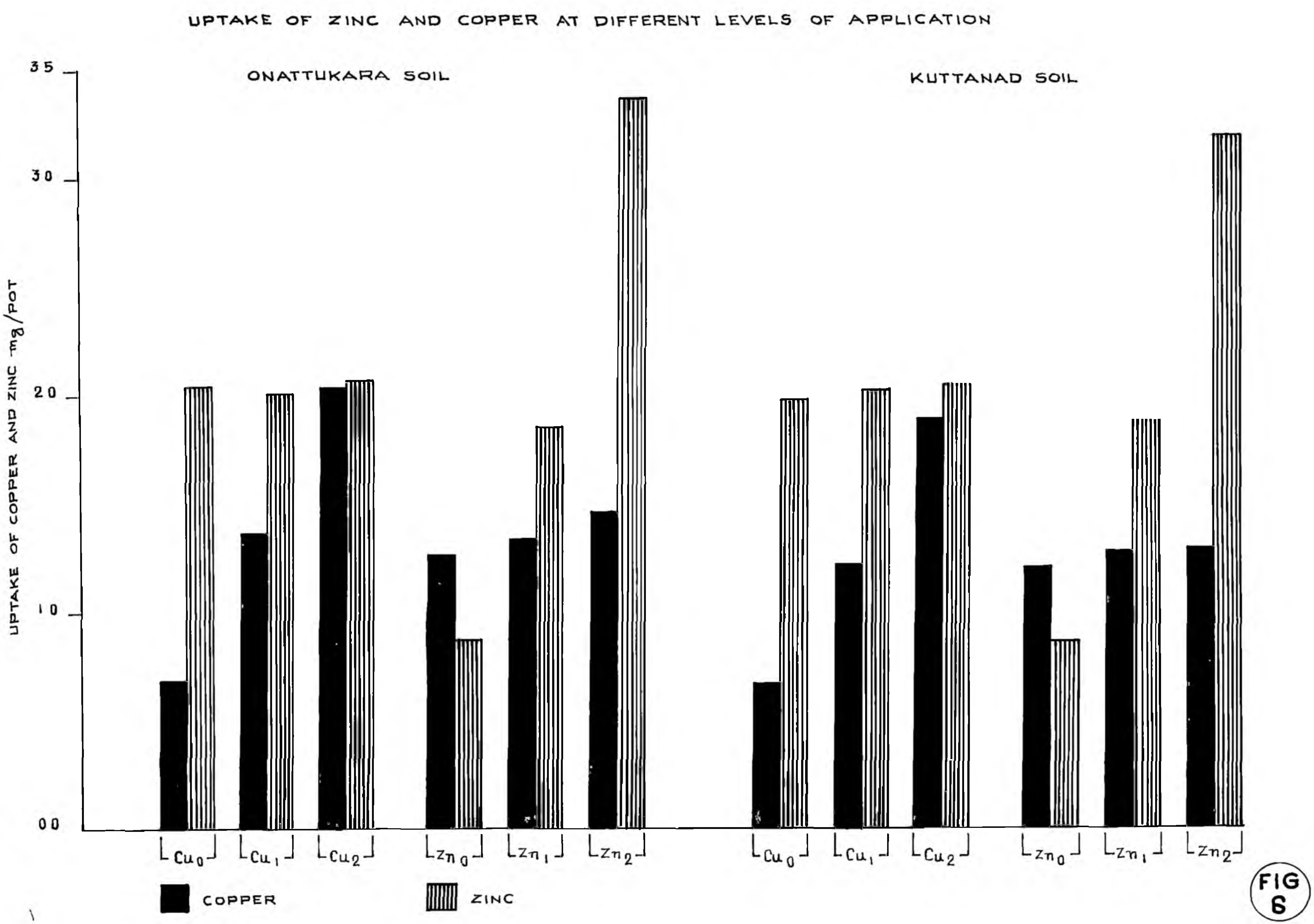

UPTAKE OF ZINC AND COPPER AT DIFFERENT LEVELS OF APPLICATION
ONATTUKARA SOIL
KUTTANAD SOIL
UPTAKE OF COPPER AND ZINC mg/POT
35
30
20
10
00
Cu0
Cu1
Cu2
Zn0
Zn1
Zn2
Cu0
Cu1
Cu2
Zn0
Zn1
Zn2
COPPER
ZINC

FIG 6

DISCUSSION

DISCUSSION

A study has been made regarding the status of copper and zinc in the two major rice soils of Kerala. Along with the study a pot culture experiment was also conducted to assess the effect of copper and zinc applied to these soils on the performance of paddy variety IR-8. The results obtained are discussed in the following pages.

Copper and zinc status of the soils of Onattukara & Kuttanad:

The two soil types chosen for the survey of copper and zinc status namely, the kari soils of Kuttanad and the sandy soils of Onattukara differ widely regarding their major characteristics. Predominance of clay fraction, high percentage of organic matter and nitrogen and a fairly good potash status are features which clearly distinguish the Kuttanad soils from the soils of Onattukara. The Onattukara soils are much less acidic than the Kuttanad soils and are far better placed with respect to the content of P_2O_5. As regards the content of copper and zinc also these two soil types exhibit marked differences.

The content of total copper is slightly higher in Onattukara soils than in Kuttanad soils; the averages being 74.00 ppm and 66.65 ppm respectively. While there are wide variations in the total copper content of the different samples of Onattukara, this is not very much in evidence in the samples collected from the Kuttanad region. It would therefore appear from the results that the distribution of total copper is more uniform in Kuttanad region than in Onattukara region. This may be due to the fact that the Kuttanad area lies as consolidated continuous belt and the soil was developed under similar environmental conditions and identical cropping patterns.

As regards the content of available copper wide variation is noticed in the two different soil types, available copper being higher in Onattukara soils than in Kuttanad soils. In both types of soils a positive correlation exists between total and available copper. A lower availability of copper in acid peaty soils have been reported by several workers. Allison (1930), Harmer (1941), Comine (1944) and Browne (1950) have noticed the lower availability of copper in highly organic soils. Less (1948) and Kanwar (1954) have concluded in their studies that the lower availability of copper in peat soils is due to the fixation of copper with the formation of organometallic complexes. The results of the present study are thus generally in agreement with the findings of these authors.

In each of the two regions there is a negative correlation between available copper content and pH of the soil. A significant negative relationship between available copper content and pH of the soils reported by Agarwala et al. (1964) and Grewal et al. (1969) therefore appears to be in agreement with the findings of the present study also. The existence of a constant relationship between copper content and pH suggested by Sagorka et al. (1961) and Neelakantan and Mehta (1961) might be true in the case of the two soil types included in the present investigation.

Considering each region it would appear from the results (vide Tables I,II,V & VI) that in those samples having a higher organic matter content, the total copper also is comparatively high. This indicates a positive correlation between organic matter and total copper content. A similar relationship between organic matter and total copper content has been reported in some soils of Uttar Pradesh by Mishra et al. (1969).

Considering the relationship between cation exchange capacity and the content of available copper it is seen that only in Onattukara soils, there is a significant positive relationship between cation exchange capacity and available copper. No such relationship is observed in the soils of Kuttanad. Results presented in Tables V and VI reveal that the Kuttanad soils have very high values for cation exchange capacity. In the case of Onattukara soils, the cation exchange capacity ranges between 2.0 and 4.2 meq/100g. While a significant positive relationship is in evidence in the case of Onattukara soils no such relationship is in evidence in the case of the Kuttanad soils. It is possible therefore that in soils of very high cation exchange capacity such positive relationship, as is noticed in the case of soils of low or medium cation exchange capacity, is not to be expected.

Considering the status of zinc in the two soils, results presented in Tables V and VI reveal that the two soils differ little as regards the total zinc content. However, a wide variation in the total zinc content is noticed between samples collected from Onattukara region, while such a variation is not conspicuous in the Kuttanad soils. It would therefore appear that the distribution of total zinc is more uniform in Kuttanad soils than in Onattukara soils.

Although the two soils are identically situated as regards the total zinc content, these differ considerably as regards the content of available zinc. A greater percentage of the total zinc is in the available form in the case of Onattukara soils while this is not the case regarding the Kuttanad soil. The fact that the Kuttanad soils contain a very high percentage of organic matter compared to Onattukara soils, may explain the cause of low availability of zinc in Kuttanad soils. Baughman (1956) has furnished considerable support to the theory that organic matter may be a major single factor in zinc fixation of soil. Further, decomposing plant residues also can immobilize zinc in unavailable form as has been suggested by DeRemer and Smith (1964).

As in the case of copper the existence of a positive significant relationship between cation exchange capacity and zinc content, both total and available, is indicated in Onattukara soils only. The results also reveal that the other factors such as the contents of nitrogen, phosphorus, and potassium in the soils do not influence the status of zinc in both the soils.

The results have shown that as regards the content of total copper the two soils differ considerably, whereas they do not differ appreciably as regards total zinc. But from the point of view of available copper and zinc, the Onattukara soils appear to be better placed than the Kuttanad soils.

Effect of application of copper and zinc on the performance of paddy:

The application of copper and zinc to the two types of soils namely that of Onattukara and Kuttanad have resulted in producing varying effects. In the case of plants grown in Onattukara soil the mean height of plants is increased only in the initial stages of growth as a result of application of copper and zinc, while in Kuttanad soils significant increase in height has been noticed at all stages of growth. Chao and Tsui (1963), and Das Niranjan and Srivastava (1965) have also reported the increases in plant height and growth of cereal crops due to application of copper and zinc as copper sulphate and zinc sulphate respectively. The greater response to application of zinc and copper in Kuttanad soils, however, can be attributed to the fact that Kuttanad soils are comparatively more-deficient in available copper and zinc.

Applicatiom of copper and zinc has not produced any significant effect of the number of tillers and productive tillers, but the yield of grain is found to be significantly increased by the application of these micronutrients. Results show that in Onattukara soil, the application of copper has recorded a grain yield increase ranging from 11 to 21 per cent whereas in Kuttanad soil, the increase in yield is from 14 per cent, for application of copper at 5 kg/ha, to 26 per cent for application of copper at 10 kg/ha. This shows that when the dose of copper is doubled the percentage yield increase was also almost doubled. A similar pattern in yield increase of grain is also noticed with the application of zinc to these soils. Similar yield increases for rice by application of copper has been reported by Govindarajan (1954) who has obtained an yield increase of 15 to 20 per cent by application of copper as copper sulphate at 6 pounds per acre. In their experiments on acid soils, Kanwar et al. (1958-'62) and Bhumbla et al. (1963-'65) have obtained significant yield increases by application of zinc as foliar spray. Similar results were obtained by Kanwar and Joshi (1964) when soil application of zinc was made to acid soils of Punjab. The results of the present study are thus in agreement with the findings reported by previous workers.

As regards the yield of straw it appears that application of the micronutrients, copper and zinc have produced different effects in the two soils. Significant increase in yield due to application of copper and zinc is observed in Onattukara soil whereas no such effect is indicated in Kuttanad soil. Nagarajan and Vadivelu (1964) have reported increases in straw yield of rice by application of copper and manganese, and Lal and Subba Rao (1955) have shown that rice has the maximum efficiency in the utilization of zinc for dry matter production. However, in the present study the results are in agreement with these observations only as regards rice grown in Onattukara soil.

Presumably the relatively high acidity of the Kuttanad soils have caused a generally less vigorous growth of plants resulting in a lesser yield of straw. That Onattukara soils are more productive may be seen from the fact that both yield of grain and straw are higher in Onattukara soils than in Kuttanad soils. However, the results have tended to show that in both soils the yield of grain could be increased by application of copper and zinc whereas significant increase in yield of straw is possible by the application of these elements only in Onattukara soil.

As regards the other yield characters such as thousand grain weight and percentage of filled grains the results have not furnished any significant influence for application of copper and zinc. Similarly the content of nitrogen, P_2O_5 and K_2O in the plant were also not influenced by the application of copper and zinc.

The uptake of copper and zinc by plants

are significantly increased by the application of copper and zinc respectively. Barring the fact that in Onattukara soils the copper content of straw is significantly reduced by the application of zinc, generally no interaction between copper and zinc in both the soil types is observed, thereby showing that the uptake of copper is not affected by zinc. Similarly the uptake of zinc also is not influenced appreciably by application of copper.

From the foregoing it is seen that the Onattukara soils and the Kuttanad soils being deficient in available copper and zinc have responded favourably by the application of these elements. Results of the present study therefore highlights the need for adequate copper and zinc fertilization of these soils to ensure maximum crop production and to prevent aberrant factors consequent on the application of high levels of major nutrients required by the high yielding varieties of rice.

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

A study has been made to survey the status of copper and zinc in the two major rice tracts of Kerala, viz., Onattukara and Kuttanad. A pot culture experiment was also conducted to assess the effect of application of copper and zinc to the soils of Onattukara and Kuttanad, on the performance of paddy variety IR-8. The main findings are summarised below:-

1) The soils of Onattukara are predominantly sandy, high in the content of phosphorus and are much less acidic than Kuttanad soils. The Kuttanad soils are highly acidic, rich in organic matter and total nitrogen, and the content of phosphorus is much less than that of Onattukara soils.

2) The content of total copper is slightly greater in Onattukara soils than in Kuttanad soils. While there is wide variation in the total copper content of the samples of Onattukara, this is not much in evidence in the samples collected from Kuttanad, thereby showing that the distribution of total copper is more uniform

in the Kuttanad soils.

3) A significant positive correlation exists between total and available copper in both the soils.

4) In each of the two regions a significant negative relationship is observed between available copper content and pH.

5) The content of available copper in Kuttanad soils is much less than that of Onattukara soils.

6) Cation exchange capacity and available copper are observed to have a positive correlation in Onattukara soils, while such a relationship is not seen in Kuttanad soils.

7) The Onattukara and Kuttanad soils differ little as regards their total zinc content. However, a wide variation in total zinc is noticed between the different samples collected from Onattukara region, while such a variation is not conspicuous in Kuttanad soils. With regards to the available zinc content in Onattukara soils are better placed than Kuttanad soils.

8) A positive significant relationship is

observed between total zinc and available zinc content in both the soils.

9) As in the case of copper, a positive significant relationship is observed between cation cation exchange capacity and available zinc content only in the case of Onattukara soils. As regards pH and available zinc a negative relationship is found to exist in both the soils.

10) The application of copper and zinc is found to exert a significant influence on plant height in both, Onattukara and Kuttanad soils.

11) With regard to the number of tillers and productive tillers, the application of zinc and copper is found to exert no significant influence, but the yield of grain is found to be significantly increased by the application of these micronutrients. The percentage yield increase was, however, more in Kuttanad soil than in Onattukara soil.

12) Increase in straw yield due to the application of micronutrients is observed only in Onattukara soil whereas no such effect was in evidence in Kuttanad soil.

13) As regards the yield components such as thousand grain weight and percentage filled grains the results have not furnished any significant influence for application of copper and zinc. Similarly the content of N, P_2O_5 and K_2O in plants are also found to have been not influenced by the application of copper and zinc.

14) The uptake of copper and zinc by the plants have increased significantly by the application of copper and zinc.

15) In general no interaction is observed between copper and zinc in both the soil types, thereby showing that the uptake of copper was not affected by zinc and vice versa.

The study has, thus, helped in making a proper assessment of the status of zinc and copper in the two major rice soils of Kerala and it has also highlighted the need for fertilizing these soils with adequate amounts of these micronutrients to ensure maximum crop production. However the need for further studies leading to information on the optimum doses of copper and zinc required by these soils is indicated from the results of the present study.

REFERENCES

REFERENCES

Agarwala, S.C.	1963	Annual Progress Report of the ICAR Scheme - "Micronutrient status of U.P. Soils" for the years 1962-63.
Agarwala, S.C.	1964	Annual Progress Report of the ICAR scheme - "Micronutrient status of U.P. soils" for the year 1963-64.
Agarwala, S.C. and Sharma, C.P.	1961	The effect of iron and manganese supply on the tissue concentration of macro and micronutrient elements in barley plants grown in sand culture - Naturwissenschaften 48: 506.
Agarwala, S.C., Sharma, C.P. & Sinha, B.K.	1964	Soil plant relationship with particular reference to trace elements in usar soil of U.P. Plant Physiol. 39: 343-53.
Alben, A.O. and Boggs, H.M.	1936	Soil Sci. 41: 329-332.
*Allison, R.V.	1930	Florida Agr. Expt. Sta. Ann. Rept. 129.
Basu, A.N., Mukherjee, D.C. & Mukherjee, S.K.	1964	Interaction between humic acid fraction of soil and trace element cations. J. Indian. Soc. Soil. Sci. 12: 311-8.

* Baughman, N.M. 1956 Dissertation Abstract 16: 839.

Berg, H. 1947a On Plant available zinc in soil. A comparison between chemically determined plant available zinc and the amount of zinc found in plant tissues in growth experiments.
K. norske vidensk -Selsk. Forh. 20: 41-4.

Berg, H 1947b Sink som plantenaering of plantagift (zinc as a plant nutrient and plant poison)
Nord. JordbrForskn. (121-130) (fide soils and Fer. 11:116)

*Berheim, P. and Quinton M. 1950 Compt.Rend. 230 : 380-384.

Bhumbla, D.R., Grewal, J.S & Randhawa, N.S. 1963-65 Annual Progress reports of the ICAR Scheme
"Distribution of micronutrients in Punjab soils and their effect on the yield of crops", for the years 1962-63, 1963-64 and 1964-65.

Bhumbla, D.R.& Dhingra, D.R. 1964 Micronutrient status of saline and alkaline soils of Punjab.
J.Indian.Soc.Soil.Sci. 12: 255-60.

Boawn, L.C. Viets, F.G. Jr. and Grawford, C.L.	1954	Effect of phosphorus fertilization on zinc nutrition of field beans Soil.Sci. 78: 1-7.
Bonner, J.S.	1950	"Plant Biochemistry" Academic Press, New Delhi.
*Bradfield, J.R.G.	1947	Nature 159 : 467-68.
Browne, F.S.	1950	Progress Rept.for 1934-38. Div.of Hort., Central Expt. Farm, Ottava.
Camp, A.F.	1945	Soil.Sci. 60: 157-64.
Chao, S.W. and Tsui, C.	1963	The effect of micronutrients on the growth and respiration of rice with special reference to the respiratory inhibitors. Act.Bot.Sci. 11: 67-75.
Chatterjee, R.K. & Dass S.C.	1964	Comparative studies on the determination of available zinc in soils of varying mineralogical composition. J.Indian.Soc.Soil.Sci. 12: 297-300.

Cheng, K.L., & Bray, R.H.	1953	Two specific methods of determining copper in soil and plant material. <u>Anal.Chem.</u> 25: 655-659.
*Comin, D.	1944	<u>Ohio Agr.Expt.Sta.Bimo.Bull.</u> 29: 144-147.
Datta, N.P.and Bains, S.S.	1960	Effect of soil application of fertilizer mixture alone and in conjunction with soil and spray application of micronutrients. <u>Indian J.Agron.</u> 4: 258-263.
*Delas J.,Delmas, J. and Demias, C.	1960	<u>Compt.Rend.</u>250: 2867-3869.
DeMumbrum, L.E. & Jackson, M.L.	1956	<u>Soil Sci.Soc.Am.Proc.</u> 20: 334-337.
DeRomer, A.D. & Smith, R.L.	1964	<u>Agron.J.</u> 56,67.
Dunne, T.C.	1956	A zinc copper antagonism affecting cereals - <u>Australian Plant Nutrient Conf.</u> 1: 278-283.

Durate, U.M., Leley, V.K. and Narayana, N. 1961 Micronutrient status of the Bombay State soils - J. Indian Soc. Soil. Sci. 9: 41-53.

*Elgabaly, M.M. & Jenny, H. 1943 J. Phys. Chem. 47: 399-408.

Epstein, E. and Stout, P.R. 1951 Soil Sci. 72: 47-65.

Gautam O.P., Ahuja, L.R., Mukhopadhyay, D. 1964 Response to hybrid maize to micronutrient elements. J. Indian. Soc. Soil. Sc: 12: 411-21.

*Gibbs, O.E. & Marsall, C.E. 1952 Missouri Agri. Expt. Sta. Res. Bull. 513.

Gilbert, F.A. 1952 Copper in nutrition Advanc. Agron. 4: 147.

Goldschmidt, V.M. 1954 "Geochemistry" (A Muir, ed.) pp.1-730. Oxford Univ. Press (Clarendon) London and New York.

Govindarajan, S.V. | 1954 | Role of micronutrients in (a) causing diseased condition in plants, (b) increasing crop production. Proc.10th meet.Crops Soil Bd.Agric.India. 103.

Govindarajan, S.V. & Gopala Rao, H.G. | 1964 | Effect of micronutrients on crop response and quality in Mysore State. J. Indian Soc.Soil.Sci. 12: 411-21.

*Greenwood, M. & Hayfron R.J. | 1951 | Empire J.Expt.Agri. 19: 73-86.

Grewal, J.S, Bhumbla, D.R. & Randhawa, N.S. | 1969 | Available Micronutrient status of Punjab, Haryana and Himachal Pradesh soils. J.Indian Soc.Soil.Sci. 17: 27.

Grewal, J.S. Chaman and Randhawa N.S. | 1967 | Evaluation of different methods for determination of available copper in soils of Ludhiana. Indian.J.Agri.Sci. 39: 877-885.

*Hamner, P.M. | 1941 | Michigan Agr.Expt.Sta. Special Bull. 314.

Harmer, P.M.	1946	Soil Sci.Soc.Amm.Proc. (1945) 10: 284-294.
Harrison, W.H. & Aiyer, P.A.S.	1917	Notes on copper sulphate as a stimulant for rice crop. Madras Dept.Agri.Year Book 55-62.
*Hey Demann, A.	1959	Geochim Cosmochin Acta. 15: 305-329.
Holmes, R.S.	1943	Soil sci. 56: 359-370.
Hodson, S.F.	1963	Chemistry of micronutrient element in soils. Advanc.Agron. 15: 119-59.
Ishizuka, Y.	1940	Casual nature of toxic action of copper ions on the growth of rice plants. 1. On the toxic action of copper ions on the growth of rice plant when a half of its root is placed in the solution of $CuSO_4$ with and without nutrients. (In Japanese, English abstract) Japan, 14(4): 248-63.

Ishizuka, Y. 1942 Casual nature of toxic action of cu ions on the growth of rice plants.
2. On the abnormal accumulation of copper ion near the growth point of root - (In Japanese);
J.Sci.Soil and Manure, Japan. 16(2): 43-45.

Ishizuka, Y., A. Tanaka and O. Fujita. 1961 Inorganic nutrients of rice plants 6.
Effect on iron, manganese and copper level in culture solution on yields and chemical composition of the plant (In Japanese)., J.Sci.Soil and Manure, Japan
32(3): 97-100.
(Cf. Soil Science and Plant Nutr. 7(1): 41-42. (Abstr.))

Iyer, J.G. 1959 Trace elements in soil and plants of West India.
Ph.D. Thesis, University of Bombay.

Iyer, J.G. and Satyanarayan, Y. 1958 Trace elements in soils.
J.Univ.Bombay 27(Part II) 74-82

Jackson, M.L. 1958 "The soil chemical analysis".
Prentice - Hall Inc. Englewood Cliffs, N.J.

Joshi, N.V. and Joshi, S.G. 1952 Effect of copper sulphate on rice in Bombay State.
Sci. and Cult. 18: 96.

Joshi, N.V. and Joshi, S.G. 1957 Copper as a fertilizer.
J. Indian. Soc. Soil Sci. 5: 21-9.

Jurinak, J.J. and Bauer, N. 1956 Thermodynamics of zinc absorption on calcite, dolomite and magnesite type minerals.
Proc. Soil. Soc. Amer. 20: 466-71.

Kanwar, J.S. 1954 Influence of organic matter on copper fixation in soil.
J. Indian. Soc. Soil. Sci. 2: 73.

Kanwar, J.S. 1962 Effect of micronutrient sprays on the chemical composition of citrus leaves and incidence of chlorosis.
Bull. nat. Inst. Sci. 33: 268-71.

Kanwar, J.S. and Joshi, M.D. 1964 Zinc deficiency in reddish clay tea soils of the Punjab.
Indian J. Agron. 9: 100-03.

Kanwar, J.S. and Randhawa, N.S. 1967 "Micronutrient research in soil and plants in India". An ICAR Bulletin, 1967.

Karim, A.Q.M.B. and Vlanis James 1962 Micronutrient deficiency symptoms of rice grown in nutrient culture solution. Plant and soil 16: 347-60.

Karunkar, P.D. 1952 Trace element studies on rice and other crop plants. I.R.C. Working Party on Fertilizer Bogor.

Kavimandan, S.K., Badhi, N.N. and Ballal, D.K. 1964 Available copper and molybdenum in Vidharbha soils. J.Indian Soc.Soil.Sci. 12: 281-8.

Lal, B.M., Sahu, D, and Dass N.B. 1959 Studies on available copper in some Indian soils. Curr.Sci.28: 494.

Lal, B.M., Sahu, D, and Dass N.B. 1960 Available zinc status of some Indian soils. Curr. Sci. 29: 316.

Lal, B.M. and Subba Rao, M.S.	1955	Studies on crop physiology, Effect of microelements on growth characteristic of certain Graminaceous crop Plants. Bull.nat.Inst.Sci.India. 8: 41.
Lal, K.N. and Subba Rao, M.S.	1953	Role of copper in crop production. Trop.Agriculture.Trin.28:117.
*Lees, H.	1948	Biochem.J. 43: 624.
Leeper, G.W.	1952	Factors affecting avaialability of inorganic nutrients in soils with special reference to micronutrient metals. Ann.Rev.Plant Physiol.3:1-16.
*Lingle, J.C. and Holmberg, D.M.	1959	California Agri.Expt.Sta. Bull. 10: 13-14.
Lippman, C.B. and Mackinney.	1931	Proof of the essential nature of copper for higher green plants. Plant.Physiol.6: 593-9.
Lundblad, K., Savenberg, O and Ekman, P.	1949	Plant and soil 1: 277-302.

Mason, B. 1960 "Principles of Geochemistry". 2nd ed.Wiley, New York.

*Maze, P. 1919 Recherche dune solution purement minerale capable d' assurer l' evolution complete due mai's culture a labri des microbes. Ann.Inst.Pasteur 33:139-73.

*McMurtrey, J.E. and Robinson, W.O. 1933 U.S.Dept.Agri.Yearbook Agri. 807-839.

Mehta, B.V., Reddy, G.R., Nair, G.K., Gandhi, S.C., Neelakantan, V and Reddy, K.G. 1964 Micronutrients studies on Gujarat soils and plants. J.Indian.Soc.Soil.Sci. 12: 329-42.

Misra, S.G. and Misra, M.K. 1969 Available copper status of some soils of Uttar Pradesh. J.Indian.Soc.Soil Sci. 17: 283.

Misra, S.G. and Sharma , M.D. 1961 Studies on the release of adsorbed copper by soils & composts. Soil & Plant Food 6: 103-5.

Misra, S.G and Tiwari, R.C. 1962a Studies on the adsorption and release of copper by soils. Effect of cation.I. Soil Sci.I.Plant Nutn.8:93-6.

Misra, S.G. and Tiwari, R.C. 1962b Effect of cations on the adsborption and release of Cu^{++} by compost. Proc.nat.Inst.Sci.28A:815-9.

Misra, S.G and Tiwari, R.C. 1964 Effect of fertilizers and pH on retention of copper by soils. J.Indian.Soc.Soil.Sci. 12: 289-95.

Misra, B., Tripathi, B.R. & Din Dayal. 1969 Copper status of soils of Uttar Pradesh. J.Indian Soc.Soil.Sci.17:379.

Mitchell, R.L. 1965 In. "Chemistry of the soil". (F.E.Bear, Ed.) ACS Monograph No.126, pp.253-286. Reinhold, New York.

Nagarajan, S.S. & Vadivelu, K. 1964 Studies on micronutrients on crop plants III. Micronutrient deficiency studies on rice. Madras Agri.J. 51: 75.

Naik, M.S. & Asana, R.D. 1961 Effect of zinc deficiency upon mineral uptake and nuclear activity in the cotton plants. Indian J.Plant Physiol. 4: 103-111.

Nair, G.G.K., and Mehta, B.V.	1959	Status of zinc of Western India. <u>Soil</u> <u>Sci</u>.87: 155-9.
Neelakantan, V, and Mehta, B.V.	1961 a	Copper status of soils of Western India. <u>Soil</u> <u>Sci</u>.91: 251-6.
Neelakantan, V and Mehta, B.V.	1961 b	Studies on copper deficiency and toxicity symptoms in some commoncrops of Gujarat. <u>J</u>.<u>Agri</u>.<u>Sci</u>.56: 295-6.
Neelakantan, V. and Mehta, B.V.	1962	Distribution of copper in typical soil profiles of Gujarat. <u>Indian</u> <u>J</u>.<u>Agri</u>.<u>Sci</u>.32:39-46.
Neen, Y.L. and Srivastava, S.L.	1967	Khaira disease of paddy. <u>Indian</u> <u>Farming</u> 17: 4-5.
*Nelson, J.L., and Melsted, S.W.	1955	<u>Soil</u> <u>Sci</u>.<u>Soc</u>.<u>Am</u>.<u>Proc</u>. 19: 439-443.
Patnaik, S.	1955	Role of micronutrients on the growth and metabolism of rice plants. <u>Bull</u>.<u>nat</u>.<u>Inst</u>.<u>Sci</u>.<u>India</u>.3: 65.

Paulson, G.M., and Rotini, O.A. 1968 Phosphorus - zinc interaction in two soyabean varieties differing in sensitivity to phosphorus nutrition. Proc.Soil.Sci.Soc.Amer. 32(1): 73-76.

*Peech, M. 1941 Soil Sci.51: 473-494.

Pillai, K.M. 1965 Response to paddy to application of micronutrients. Indian J.Agron.12(2):151-155.

Piper, C.S. 1940 The symptoms of diagnosis of minor element deficiencies in Agricultural and Horticultural crops - II, Cu, Zn, Mo. Empire J.Expt.Agr.8:199-206.

Piper, C.S. 1942 J.Agr.Sci.32: 143-178.

Piper, C.S. 1950 'Soil & Plant Analysis' Interscience Publishers, Inc., New York, N.Y.

Prasad, K.G and Sinha, H. 1969 Zinc status of Bihar soils. J.Indian.Soc.Soil.Sci. 17: 267-274.

Quinlan-Watson, T.A.F.	1951	Nature 167: 1033-1044.
Rajani, H.J.	1965	Private communications: Summary of the results of annual progress report of the scheme "Micronutrient status of Bombay State Soils" for the years 1955-56, 1956-57, 1957-58 and 1958-59.
Ranadive, S.T. Naik, M.S. and Dass, N.B.	1964	Copper zinc status of Maharastra soils - J.Indian.Soc.Soil.Sci. 12: 243-8.
Randhawa, N.S. and Broadbent, F.E.	1965	Soil organic matter- metal complexes - VI. Stability constants of zinc- humic acid complexes at different pH values - Soil Sci. 99: 295-300.
Randhawa, N.S. and Kanwar, J.S.	1964	Zinc, copper and cobalt status of Punjab soils - Soil Sci. 98: 403-7.
Rao, V.S.	1962	Andhra agri.J. 9: 225.
Raychaudhuri, S.P., & Datta Biswas, N.R.	1964	Trace element status of Indian soils. J.Indian.Soc.Soil.Sci. 12: 207-14.
Sadaphal, M.N. and Dass, N.B.	1961 a	The effect of microelement fertilizer on wheat. J.Indian.Soc.Soil.Sci. 9: 99-105.

Satyanarayan, Y. 1958 Trace element status of cotton soils of Gujarat.
Indian Cott.Gr.Rev.12:138-141.

Shaw, E. and Dean, L.A. 1952 Use of dithizone as an extractant to estimate the zinc nutrient status of soil.
Soil Sci.73: 341-347.

Shyu, S.C. 1952 Effects of some minor elements on rice nursery soils.
1. Effects of single application on the growth of rice seedlings.
Agric.Res.Taiwan. 3: 1-15.

*Skoog, F. 1940 Am.J.Botany 27: 939-951.

Singh, R.M. and Jain, G.L. 1964 Response of paddy to iron and zinc.
Indian J.Agron. 9: 273-6.

Sommer, A.L. 1928 Further evidence of the essential nature of zinc for the growth of higher green plants.
Plant Physiol. 3: 217-21.

Sommer, A.L. 1931 Copper as an essential element for plant growth.
Plant Physiol. 6(2): 339-45.

*Sommer, A.L. 1945 Soil Sci. 60: 71-79.

Sommer, A.L. & Lipman, C.B.	1926	Evidence for the indespensable nature of zinc and boron for higher green plants. <u>Plant Physiol</u>. 1: 231-49.
*Staker, E.V. and Cummings, R.W.	1942	<u>Soil sci.soc.Am.proc</u>. 6: 207-214.
Steenbjerg, F. and Boken, E.	1950	<u>Plant and soil</u> 2: 195-221.
Stuken Rolz, D.D. Oslen, R.J. and Gogen, G.	1966	On the mechanism of P-2 Zn interaction in corn nutrition. <u>Proc.Soil.Sci.Soc.Amer</u>. 6: 759-63.
Swaine, D.J.	1955	<u>The trace element contents of soils</u>. Commonwealth Bureau of soil science, Technical Communications No.48.
Tanaka, H. M. Yatazawa and J.G. Iyer.	1967	Supply of trace elements in nursery soils of Wisconsin. <u>Soil sci. & Plant Nutri.</u>(Tokyo) 13: 31.
Thorne, W.	1957	Zinc deficiency and its control. <u>Advanc.Agron</u>. 9: 31-65.

*Thorne, D.W., Laws, W.D. and Wallace, A.	1942	Soil sci. 54: 463-68.
*Thorne, D.W. and Wann, F.B.	1950	Utah Agr.Expt.Sta.Bull. 338.
Thorne, P.C.L. and Roberts, E.R.	1948	"Inorganic Chemistry" 5th ed.Interscience,New York.
Tiwari, R.C. and Misra, S.G.	1964	Studies on the retention of zinc in some soils of Uttar Pradesh. J. Indian.soc.soil.sci. 12: 301-9.
*Tokuoka, M. and Gyo, S.	1938	Effect of copper on the growth of paddy rice II. Water culture experiments. J.Soc.Trop.Agric.Taihoku Imp. Univ. 10: 9-15. C.A.33-5027.
Tripathi, B,R., Mishra, B. and Din Dayal.	1969	J.Indian.Soc.Soil.Sci. 17:471.
Tsui, C.	1961	Am.J.Botany 35: 172-79.
Viets, F.G.Jr., L.C. Boawn, and E.L. Crawford.	1954	Zinc deficiency in soil plant system. Soil.sci. 78: 305-16.

Vinogradov, A.P.	1959	"The Geochemistry of Rare and Dispersed chemical elements in soils" - Consultants Bur., New York. (translated from the Russian)
*Vlasyuk, P.A. and Ziminia, U.A.	1954	Pochvovedenie No. 5: 11-26.
West, E.S.	1938	Australian J. council sci. Ind.Research 11: 182-184.
Wilson, C.C.	1953	Science, 117: 231.
Woltz, S., Toth,S.J., and Bear, F.E.	1953	Soil sci. 76: 115-122.
Zagorka Filipovic, Bremslava, Stankovia and Zivka Dusic.	1961	Distribution of Cu, Pb, Zn, Ni. and Co in soil in relation to soil pH changes, soil sci. 91: 147-50.

* Originals not seen.

APPENDICES

Appendix I

Height of plants : 30th day (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	199.107	28		
Treatment	141.727	8	17.7160	5.5570*
Cu	13.390	2	6.7000	2.1070
Zn	89.390	2	44.7000	14.0100**
Cu x Zn	38.947	4	9.7620	3.0700*
Error	57.380	18	3.1880	

Appendix II

Height of plants : 60th day (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	118.661	26		
Treatment	43.331	8	5.4160	1.2975
Error	75.130	18	4.1740	

* significant at 0.05 level

** significant at 0.01 level

Appendix III

~~Table-III~~

Height of plant: at harvest (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	186.655	26		
Treatment	88.365	8	11.0450	2.0226
Error	98.290	18	5.4605	

Appendix IV

Numbers of tillers per plant: 30th day (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	84.000	26		
Treatment	28.000	8	3.5000	1.1250
Error	56.000	18	3.1111	

Appendix V

Number of tillers per plant : 60th day (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	49.960	26		
Treatment	16.290	8	2.0363	1.1951
Error	30.670	18	1.7039	

Appendix VI

Number of productive tillers (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	46.670	26		
Treatment	14.670	8	1.8340	1.0316
Error	32.000	18	1.7778	

Appendix VII

Plant height : 30th day (Onattukuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	190.950	26		
Treatment	138.910	8	17.3600	5.9862*
Cu	14.600	2	7.3000	2.5249*
Zn	82.460	2	14.2300	14.2610**
Cu x Zn	41.850	4	10.4600	3.6130
Error	52.040	18	2.8911	

Appendix VIII

Plant height : 60th day (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	123.410	26		
Treatment	97.850	8	12.230	2.5860*
Cu	19.421	2	9.710	2.0390
Zn	59.420	2	29.210	6.1420**
Cu x Zn	21.000	4	10.510	2.2116
Error	85.560	18	4.753	

* significant at 0.05 level
** significant at 0.01 level

Appendix IX

Plant height: at harvest (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	166.860	26		
Treatment	88.930	8	11.1160	2.5675*
Cu	41.900	2	20.9500	4.8395*
Zn	28.900	2	14.4500	3.3379*
Cu x Zn	18.130	4	4.5300	1.0410
Error	77.93	18	4.3294	

Appendix X

Number of tillers per plant: 30th day (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	52.963	26		
Treatment	21.296	8	2.6620	1.5131
Error	31.667	18	1.7593	

* significant at 0.05 level
** significant at 0.01 level

Appendix XI

Number of tillers per plant: 60th day (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	99.186	26		
Treatment	17.853	8	2.2320	1
Error	81.333	18	4.5185	

Appendix XII

Number of productive tillers (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	34.075	26		
Treatment	14.742	8	1.8430	1.7160
Error	19.333	18	1.0740	

Appendix XIII

Yield of grain : (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	84.540	26		
Treatment	68.180	8	8.5200	9.3740**
Cu	28.110	2	14.0550	15.5610**
Zn	30.060	2	15.0200	16.6690**
Cu x Zn	10.010	4	2.5005	2.7778
Error	16.36	18	0.9088	

Appendix XIV

Percentage filled grains (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	131.190	26		
Treatment	17.390	8	2.1740	0.3433
Error	114.000	18	6.3333	

* significant at 0.05 level
** significant at 0.01 level

Appendix XV

100 grain weight - - (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	2.021	26		
Treatment	0.794	8	0.0990	1.4516
Error	1.227	18	0.0682	

Appendix XVI

Yield of straw - (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	82.040	26		
Treatment	55.770	8	6.9700	4.7770*
Cu	30.770	2	15.3850	10.5324**
Zn	15.552	2	7.7760	5.3180**
Cu x Zn	10.448	4	2.6120	1.8590
Error	26.270	18	1.4590	

* significant at 0.05 level
** significant at 0.01 level

Appendix XVII

Yield of grain - (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	95.980	26		
Treatment	78.680	8	9.8300	10.2278**
Cu	29.700	2	14.8500	15.4516**
Zn	38.140	2	19.0700	19.8418**
Cu x Zn	10.840	4	2.4600	2.5595
Error	17.300	18	0.9611	

Appendix XVIII

Percentage filled grain (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	46.770	26		
Treatment	8.860	8	1.1750	1
Error	37.911	18	2.1050	

* significant at 0.05 level
** significant at 0.01 level

Appendix XIX

1000grain weight (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	14.856	26		
Treatment	2.709	8	0.3380	1
Error	12.147	18	0.6748	

Appendix XX

Yield of straw (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	172.590	26		
Treatment	54.090	8	6.7600	1.02683
Error	118.500	18	6.5833	

Appendix XXI

N per cent grain - (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.3497	26		
Treatment	0.0096	8	0.0012	1
Error	0.3401	18	0.0189	

Appendix XXII

N per cent straw : (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.0668	26		
Treatment	0.0135	8	0.0017	1
Error	0.0533	18	0.0029	

Appendix XXIII

N per cent grain : (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.3950	26		
Treatment	0.0115	8	0.00144	
Error	0.3835	18	0.02130	

Appendix XXIV

N per cent straw : (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.0604	26		
Treatment	0.0115	8	0.00144	1
Error	0.0489	18	0.00272	

Appendix XXV

P_2O_5 per cent grain - (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.000190	26		
Treatment	0.000078	8	0.00000973	1.5568
Error	0.000112	18	0.00000625	

Appendix XXVI

P_2O_5 per cent straw - (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.000177	26		
Treatment	0.000053	8	0.00000664	
Error	0.000124	18	0.00000689	

Appendix XXVII

P_2O_5 per cent grain - (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.000184	26		
Treatment	0.000071	8	0.00000889	1.4199
Error	0.000113	18	0.00000626	

Appendix XXVIII

P_2O_5 per cent straw - (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.000173	26		
Treatment	0.00056	8	0.00000707	1.0946
Error	0.000116	18	0.00000645	

Appendix XXIX

K_2O per cent grain (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.1778	26		
Treatment	0.0023	8	0.000284	1
Error	0.1755	18	0.009752	

Appendix XXX

K_2O per cent straw - (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.852	26		
Treatment	0.045	8	0.0056	0.1250
Error	0.807	18	0.0448	

Appendix XXXI

K_2O per cent grain - (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F- ratio
Total	0.0632	26		
Treatment	0.0027	8	0.00034	0.1012
Error	0.0605	18	0.00336	

Appendix XXXII

K_2O per cent straw - (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	0.805	26		
Treatment	0.039	8	0.0048	0.1126
Error	0.765	18	0.0426	

Appendix XXXIII

Copper content : grain (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	5310.080	26		
Treatment	4935.410	8	616.9260	29.6385**
Cu	4875.640	2	2437.8200	117.1184**
Zn	16.970	2	8.4900	1
Cu x Zn	42.800	2	10.7000	1
Error	374.670	18	20.8150	

Appendix XXXIV

Copper content : straw (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	1874.963	26		
Treatment	1693.633	8	211.7040	21.1549**
Cu	1596.520	2	798.2600	79.7673**
Zn	35.630	2	17.8200	1.7807
Cu x Zn	61.180		15.2900	1.5279
Error	181.330		10.0073	

* significant at 0.05 level
** significant at 0.01 level

Appendix XXXV

Copper uptake by rice (Onattukara soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	8.5335	26		
Treatment	8.0975	8	1.0122	41.7919**
Cu	7.9350	2	3.9675	163.8110**
Zn	0.1343	2	0.0674	2.7820
Cu x Zn	0.0278	4	0.0070	1
Error	0.4360	18	0.0242	

Appendix XXXVI

Copper content : grain (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	5396.520	26		
Treatment	4610.520	8	576.3150	13.1980**
Cu	4308.050	2	2154.0300	49.3279**
Zn	145.850	2	72.9300	1.6701
Cu x Zn	156.620	4	39.1600	1
Error	786.00	18	43.6667	

* significant at 0.05 level
** significant at 0.01 level

Appendix XXXVII

Copper content : straw (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	1502.297	26		
Treatment	1336.630	8	166.9540	18.0296**
Cu	12.490	2	6.2500	1
Zn	1300.940	2	650.4700	70.2451**
Cu x Zn	22.200	4	5.5500	1
Error	166.667	18	9.2600	

Appendix XXXVIII

Copper uptake by rice (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	7.3267	26		
Treatment	6.6742	8	0.8218	22.6703**
Cu	6.5660	2	3.2830	90.5655**
Zn	0.0504	2	0.0252	1
Cu x Zn	0.0578	4	0.0144	1
Error	0.6525	18	0.0362	

* significant at 0.05 level
** significant at 0.01 level

Appendix XXXIX

Zinc content : grain (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	15422.190	26		
Treatment	13749.190	8	1718.6500	18.4910**
Cu	23.410	2	11.7050	1
Zn	13632.090	2	6816.0500	73.3340**
Cu x Zn	93.690	2	23.4200	1
Error	1673.000	18	92.9444	

Appendix XXXX

Zinc content : straw (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	8968.00	26		
Treatment	8764.333	8	1095.5400	96.822**
Cu	155.620	2	77.8100	6.3550**
Zn	8154.670	2	4077.3400	360.3482**
Cu x Zn	454.040	2	113.510	10.0318**
Error	203.667	18	11.3150	

* significant at 0.05 level
** significant at 0.01 level

Appendix XXXXI

Zinc uptake by rice (Onattukara soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	31.2322	26		
Treatment	28.7731	8	3.5966	26.3255**
Cu	0.0229	2	0.0115	1
Zn	23.5874	2	14.2967	104.6611**
Cu x Zn	2.6219	4	0.2555	1.9981
Error	2.4591	18	0.1366	

Appendix XXXXII

Zinc content : grain (Kuttanad soil)
(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	14195.633	26		
Treatment	12431.633	8	1553.9500	15.8566**
Cu	3.630	2	1.8200	1
Zn	12302.370	2	6151.1900	62.7672**
Cu x Zn	1764.000	18	98.0000	

* significant at 0.05 level
** significant at 0.01 level

Appendix XXXXIII

Zinc content : straw (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	9425.851	26		
Treatment	9137.181	8	1142.1500	71.2188**
Cu	76.741	2	38.700	2.3925
Zn	8978.290	2	4489.1500	279.9210**
Cu x Zn	83.150	4	20.7900	1.2964
Error	288.670	18	16.0372	

Appendix XXXXIV

Zinc uptake by rice (Kuttanad soil)

(Analysis of variance)

Source	SS	DF	Variance	F-ratio
Total	28.3011	28		
Treatment	27.3634	8	3.4204	65.6670**
Cu	0.0221	2	0.0111	1
Zn	27.2547	2	13.6273	261.6106**
Cu x Zn	0.0866	4	0.0217	1
Error	0.9377	18	0.0521	

* significant at 0.05 level
** significant at 0.01 level