ZINC NUTRITION OF RICE (*Oryza sativa* L.) WITH SPECIAL REFERENCE TO VARIETIES, SOIL CONDITIONS, SOURCES AND METHODS OF APPLICATION OF ZINC

THESIS SUBMITTED IN PART FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (AGRICULTURE) IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY TO THE TAMIL NADU AGRICULTURAL UNIVERSITY COIMBATORE

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Certificate

This is to certify that the thesis entitled "ZINC NUTRITION OF RICE (*Oryza sativa* L.) WITH SPECIAL REFERENCE TO VARIETIES, SOIL CONDITIONS, SOURCES AND METHODS OF APPLICATION OF ZINC" submitted in part fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY (AGRICULTURE) IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY to the Tamil Nadu Agricultural University, Coimbatore is a record of **bona fide** research work carried out by Thiru. V. S. KRISHNAMURTHY under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABBREVIATIONS USED

N	=	Nitrogen	ha	=	hectare
P	=	Phosphorus	ppm	=	parts per million
K	=	Potassium	%	=	percentage
Ca	=	Calcium	me	=	milliequivalent
Mg	=	Magnesium	μM	=	micro molar
Fe	=	Iron	m mhos	=	milli mhos
Mn	=	Manganese	cm	=	centimetre
Cu	=	Copper	mm	=	millimetre
Zn	=	Zinc	EC	=	Electrical conductivity
Mo	=	Molybdenum	$>$	=	greater than
B	=	Boron	$<$	=	less than
g	=	Gram	Equival.	=	Equivalent
kg	=	Kilogram	Conc.	=	Concentration
t	=	Tonne	Till	=	Tillering stage
mg	=	milligram			

NS	=	Normal soil
CS	=	Calcareous soil
OS	=	Organic matter enriched soil
SS	=	Submerged soil
GM	=	Green manure
FYM	=	Farmyard manure

S.E.	=	Standard error	
C.D.	=	Critical difference	
N.S.	=	Non significant (in tables)	
G	=	Grain	(in tables)
S	=	Straw	(in tables)
R	=	Root	(in tables)
T	=	Total	(in tables)

Fig = Figure

INTRODUCTION

INTRODUCTION

CHAPTER I

INTRODUCTION

About fifty years ago Sommer and Lipman (1926) established the essentiality of zinc in the nutrition of crops. Since then the subject of zinc nutrition has attracted many workers and during the past one decade considerable volume of literature with respect to rice crop has accumulated. Due to the most favourable climatic conditions for the growth of rice crop India stands foremost in total rice area of the world. Inspite of the main emphasis given to the crop both by the scientists and farmers, the per hectare yield of rice is comparatively low in India. It is the constant endeavour of those concerned with rice research to increase the per unit yield of rice through various means such as varietal improvement, better management practices, optimal fertilisation and efficient plant protection measures.

With the fast spread of new and better high yielding varieties, use of more and more of high analysis fertilisers and reduced use of farmyard manure and compost, the micronutrient requirement of the crops as well as the depletion from the soil have been all the time on the increasing side. Hence the study of micronutrients, deserves special attention from the point of view of maximising rice yields.

A close analysis of the micronutrient requirements of rice reveals that with respect to iron and manganese the toxicity rather than deficiency is a problem in most cases. Copper, boron and molybdenum are not likely to become limiting in view of their comparatively meagre requirements. It is therefore reasonable to assume that in rice culture it is zinc which often becomes limiting and warrants special attention. It is perhaps for this reason that in the nutrition of rice zinc is considered next only to nitrogen.

A plethora of evidences have accumulated to show that rice is physiologically more adapted to flooded conditions (Jugsujinda, 1976). It is well recognised that the physico-chemical and biological system under conditions of submergence are different from what is observed under normal conditions. The investigations into the chemistry of submerged soil brought to light both advantages and disadvantages in relation to the nutrition of the rice plant. While on the one hand the availability of most of the nutrients viz., P, K, Ca, Mg, S, Fe and Mn increased the availability and uptake of zinc on the other hand decreased (Ponnamperuma, 1972).

Differences in the magnitude of susceptibility to the deficiency of a nutrient can be attributed to the differences in the ability to absorb the element in question from the soil and/or translocate it to the shoots or to the differences in the concentration of the element needed in the tissues for healthy growth (Vose, 1963). Varietal differences in the responses to the application of zinc with respect to rice have been investigated in several centres of India. In Tamil Nadu, certain amount of preliminary work had been done and detailed investigation for a clear understanding of genetic variability employing the popular varieties of the State have not so far been attempted. Most of the work carried out earlier confined to the study of grain and straw yield but the influence of zinc fertilisation on root growth, shoot growth, grain yield and uptake of nutrients have not been thoroughly studied yet. The first phase of the work was therefore aimed at to assess the relative responses of genetically variable popular rice varieties of the Tamil Nadu State for graded levels of zinc fertilisation.

The availability of zinc in the soil is controlled by several factors. Among the micronutrient elements, zinc is very unique in that it can behave both as cation and anion and the activity of zinc ion in the ambient soil solution nourishing plant roots is the net resultant of several simultaneous competitive chemical equilibria between its vario forms. The availability of zinc which shows pronounced interaction with the solid matrix of the soil is determined by the mutual interaction of quantity, intensity and kinetic parameters. Mineralogical composition, soil texture, soil pH, soil temperature and organic matter have been known to influence the quantity intensity relationships of zinc ions.

Responses to the application of micronutrient depends not only on its availability in the soil but also among other factors such as the availability of other nutrients. Since the requirements of micronutrients are modified by the presence of other macro and micro nutrients and as the composition and concentration of nutrient ions in the soil solution are governed by the soil conditions it is necessary to study the responses of a micronutrient in relation to varying soil conditions. Hence the soil plant relationship under varying soil conditions such as soil with and without calcium carbonate, soil with high organic matter content, high sodicity condition and submergence with particular reference to zinc nutrition was thought to be of interest and formed the second and third phases of investigation.

The recognition of widespread zinc deficiency created considerable interest in the materials that would be suitable as zinc fertilisers. Though zinc sulphate was found to be a satisfactory material for correcting the deficiency there are several reasons why other materials should not be investigated. Firstly zinc from a highly soluble material like zinc sulphate may be rapidly converted in the soil to forms not available to plants. There is need for development of a material which can release zinc slowly thus reducing the rapid conversion. Secondly zinc sulphate possess high solubility and poor physical form. Hence the farmers experience difficulty in applying it. Thirdly there is the possibility of cheaper material giving satisfactory control of deficiency.

A cheap and effective method of amending the zinc deficiency of soil is of paramount importance. Apart from solubility differences as a result of accompanying anions, the absorption and uptake of zinc has been found to be influenced by mode of application such as seed soaking, seedling dipping etc.

A myriad of chelating agents even at very low concentration are quite effective in overcoming the rate limiting steps of solution, desorption and diffusion which often limit the transport of zinc ions to plant roots. Natural and synthetic chelates, when applied also co-extract native forms of zinc and other micronutrients and it is the ultimate ionic balance of these ions within the confines of the laws of simultaneous chemical equilibria that govern its ultimate availability to plants. Finally how the plant uptake of zinc occurs by differences in physical and chemical form as well as different methods of application is worthy of scientific enquiry. Hence the fourth and final phase of the study involved an investigation of the efficacy of the different zinc carriers and different methods of application.

With the foregoing points in view investigations as detailed below were undertaken for a clearer understanding of the influence of zinc on the growth and nutrition of rice:

i. Influence of zinc fertilisation on the growth and nutrition of genetically variable popular rice varieties of Tamil Nadu.

ii. Growth and nutrition of rice as influenced by soil conditions and zinc fertilisation.

iii. Growth and nutrition of rice in sodic soil attendant upon reclamation and zinc fertilisation.

iv. Sources and methods of application of zinc on the growth and nutrition of rice.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

A brief review of literature pertaining to the various phases of investigation contemplated in the study is presented in this chapter.

A. Area and production of rice

The position of Tamil Nadu and India in rice area and production in relation to the global picture is presented in Appendix I.

The above table reveals that while India stands foremost in rice area the per hectare yield is not even fifty per cent of the world average yield. Compared to the per hectare yield of 6485 kg in Korea, 6185 kg in Japan and 5326 kg in Egypt we have to go a long way to match them if not to excel them.

Katyal (1975) reported that about 8 million hectares of rice growing area in India is deficient in Zn.

B. Zinc in the nutrition of rice

Tanka and Yoshida (1970) from their survey of rice crop in several Asian countries gave a generalised picture of critical levels for deficiency as well as toxicity for various nutrient elements (Appendix.II).

A consideration of the micronutrient requirements of rice would reveal that with respect to Fe and Mn in most cases the toxicity rather than deficiency is a problem. Cu, B and Mo are not likely to become limiting in view of the comparatively meagre requirement of crop. Therefore the micronutrient Zn alone often becomes limiting and warrants special attention. A shoot concentration of 10 ppm at tillering stage and straw concentration of 1500 ppm at maturity stage were fixed as critical respectively for deficiency and toxicity in rice.

According to Kanwar (1969) one hectare of rice crop yielding 6.5 tonnes of grain and 9 tonnes of straw removes 640 g of Fe, 645 g of Mn, 191 g of Zn, 76 g of Cu, 56 g of B and 3.6 g of Mo.

The analysis of rice plants from different rice growing areas of the world as reported by Tanaka and Yoshida (1970) is presented in Appendix III.

From the above table it can be seen that rice plants in India are poor in N, P, Mn and Zn but rich in K, Ca and Mg when compared to the rice plants grown in Korea and Japan, the two countries which stand foremost in per hectare yield of rice.

C. Role and functions of Zinc in rice

The indispensable nature of Zn in the nutrition of rice has been well brought out through solution culture and field experiments.

1. Zinc - related to the growth of rice

Tokuoka and Gyo (1939) in their water culture experiments observed the addition of 1 ppm of Zn to improve the growth, yield and quality of rice. Pillai (1962) in Tamil Nadu, Nene (1962) in Pantnagar, Murthy et al. (1969) in Andhra Pradesh, Randhawa and Takkar (1975) in Punjab have also reported beneficial effects of Zn application.

Tanaka and Yoshida (1970) reported the effect of application of 40 ppm of Zn on rice (Appendix IV). Increased concentration of zinc and higher dry matter yield were found to accompany Zn fertilisation.

Gangwar and Mann (1972) observed that Zn application increased the dry matter production of rice under flooded condition. Badrachalam (1971) observed poor growth of roots in Zn deficient plants. The retardation of root growth under deficiency of Zn was also reported by Sharma and Rathore (1970).

2. Zinc related to cell division

Brown et al. (1966) observed a sharp decrease in the level of RNA and ribosome contents of cells in the course of Zn deficiency. An essential involvement of Zn in cytoplasmic ribosomes has also been indicated by Prask and Plocke (1971). Polycorpochieuia and Khavekin (1972) considered Zn as essential for cell division. The retardation of cell differentiation and modification of plastid structure was observed by Butler and Bailey (1973). Perekhnevich (1973) observed Zn application to favour preferential accumulation of chlorophyll b and decrease chlorophyll a/chlorophyll b ratio. The necessity of Zn for grana formation was also indicated.

3. Zinc - related to the enzyme activity

Skoog (1940) observed Zn deficiency to be associated with deficiency of auxin. Nason et al. (1951) indicated a depression of tryptophan synthesis, under conditions of Zn deficiency. Wallace and Walker (1970) considered Zn to be an essential component of enzyme functioning in carbohydrate and protein metabolism viz., dehydrogenases, proteinases and peptidases. They listed out Zn metalloenzymes in plants viz., carbonic anhydrase, alcohol dehydrogenase, glutamic dehydrogenase, lactic and malic dehydrogenase and aldolase.

The effect on RNA activity in two varieties of rice (Jaya and NM 484) in a Zn deficient soil showed reduction in activity due to Zn fertilisation (Anonymous, 1973).

4. <u>Zinc related to the energy value of cereal grain</u>

Direct and indirect relationship of Zn to enzyme system in the plant is naturally reflected in changes of energy values of cereal grain. Reed (1939), Vesk <u>et al</u>. (1960) and Thompson <u>et al</u>. (1962) showed evidence for the role of Zn in starch metabolism. Singh and Jain (1964) observed an increase in crude protein of rice grain. Saigusa <u>et al</u>. (1972) registered an increase in amides and free amino acids in Zn deficient plants as compared to the control. They observed poor nitrate reductase and protease activities in the Zn deficient rice plants.

Dwivedi and Randhawa (1973) from their pot and field experiments observed that addition of 5 ppm of Zn caused a significant rise in carbohydrate, protein and fat content of rice.

D. Effect of zinc deficiency in rice

Due to the introduction of high yielding varieties in rice the most striking feature was Zn deficiency. As a result of higher yields obtained with increased fertiliser use, incidences of Zn deficiency in rice have become more frequent in many developing countries. One third of the acreage under rice in India is planted with high yielding varieties (Carney, 1977). Zn deficiency in rice in India was first reported by Nene (1966). About two million hectares in Japan and 8 million hectares in India (Katyal, 1975) have been reported to suffer from Zn deficiency. The Zn deficiency was reported to be widespread in Asian countries.

Zn deficiency symptoms in rice both under field and solution culture have been indicated by Karim and Vlamis (1962), Yoshida and Tanaka (1969) and Tanaka and Yoshida (1970).

1. Visual symptoms of deficiency

Deficiency of Zn in rice is supposed to cause Khaira disease (in India), Hadda disease (in Pakistan), Taya-taya disease (in Phillipines) and Akagare-type II disease (in Japan). The disease is characterised by midrib bleaching of third and younger leaves. Brown spots, blotch or streaks will be observed on the second or third leaves. The roots of affected plants are scanty and brown and the severely affected ones dies (Badrachalam, 1971).

Thorne (1957) described Zn deficiency as dramatic because of combination of chlorosis, resetting, dieback and depression of vegetative growth.

Karim and Vlamis (1962) conducted elaborate solution culture experiments to study the effect of micronutrient deficiencies in rice plant (Appendix V).

In Zn deficient plants the midribs of the youngest leaves especially at the base became yellowish white, the intensity of which decreased with length upward. The dark brown necrosis then appeared on the upper part near the tip of the third leaf of the Zn deficient plants during the second week after transplanting. The top growth was suppressed as a result of which the last emerging leaf grew very little. The whole leaf became necrotic and rolled from sides near the tip. Tillering was completely absent and no seeds were formed.

Murthy et al. (1969) and Krishnamurthy and Venketeswaralu (1971) observed Zn deficiency to cause bleaching of midribs at basal portions of young leaves and appearance of dark brown spots in affected leaves.

Forno et al. (1975) observed a faint interveinal chlorosis at the base of the young emerging leaf followed by the appearance of reddish brown spots on lower leaves. The chlorosis of young leaves at base became more severe and extended up to midveins.

2. Physiological effects of deficiency

Polyoorpoohkina and Khavekin (1972) observed inhibition of protein synthesis and accumulation of free amino acids accompanied by decrease in the activity of glutamate dehydrogenase due to Zn deficiency.

Epstein (1972) felt the marked effect on growth on account of Zn deficiency was due to the influence of Zn on the auxin level. He indicated that concentration of the auxin and indoleacetic acid in Zn deficient tissues drops well before visual symptoms. The requirement of Zn for maintenance of auxin in an active state was also observed by Skoog (1970) and Butler and Bailey (1973). Salami and Kenefic (1970) noted the essentiality of Zn for the synthesis of tryptophan. A severe effect on chloroplasts under conditions of Zn deficiency was reported by Thompson and Wier (1962). Nicholas (1961) suggested the need for enzymic assay (aldolase) to detect Zn deficiency. Saigusa et al. (1972) observed 4 to 8 fold increase in amides and free amino acids in Zn deficient plants as compared to control. Sharma and Rathore (1970) observed lower rates of necleotide synthesis and P^{32} incorporation into lipids and nucleic acids in Zn deficient plants.

3. Nutritional effects of deficiency

Nene (1962) has indicated the concentration of nutrient elements in the normal as well as Zn deficient rice plant (Appendix VI).

The above table reveals that a Zn starved plant tends to accumulate much less amounts of most nutrient elements and this accounts for the indirect effect of Zn deficiency in depressing growth of the rice plant.

E. Effect of zinc toxicity on rice

Beyond a certain level Zn produces undesirable effects both directly and indirectly.

Tokuoka et al. (1939) observed in their solution culture experiments the effect of increasing additions of Zn on growth of rice. Hindrance to flowering at 10 ppm level and poisonous effects at 20 ppm level were observed. But such a phenomenon seldom occurred in soil. Tanaka and Yoshida (1970) observed direct toxic effect only beyond 1500 ppm in the rice plant.

Indirect effects include the influence on the utilisation of other elements. Mills and Williams (1971) observed that excess Zn modified or increased the requirement of Cu and Fe. Maynard (1969) observed Zn to be toxic only beyond 900 ppm. Andriano et al. (1971) found that high levels of Zn in the growth medium lowered the concentration of P and Fe in plant tissue.

F. Factors influencing zinc nutrition of rice

The total Zn content of the soil in general varied from 2 to 1204 ppm and available Zn varied from nil to 22 ppm. (Randhawa and Takkar, 1975). In most cases the deficiency is one associated with soil and plant factors interacting with absorption and translocation of the element.

1. Plant factors

Differences in the susceptibility to the deficiency of a nutrient can be attributed to the differences in the ability to absorb the element from the soil and/or translocate it to the shoots or to the differences in concentration of the element needed in the tissues for healthy growth (Vose, 1963).

Seatz and Jurinac (1957) studied the relative ability of 26 different crops to utilise native soil Zn and classified them into three groups (i) Sensitive group - beans, soybeans, corn, grapes, limabean, castor and flax, (ii) moderately sensitive group - potato, tomato, onion, alfalfa, sorghum, sudangrass and sugarbeet and, (iii) insensitive group - cereals, peas, asparagas, mustard, carrot and sunflower.

From the experiments conducted under All India Co-ordinated Scheme on micronutrients and model agronomic experiments, the relative susceptibility of rice varieties for Zn deficiency were indicated as follows. (i) High - Pusa 2-21, Jamuna and Jaya, (ii) Medium - IR 8, Padma, Vijay, Cauvery, TN - 1, Karuna, T-9, Bala and IR 20, (iii) Low - Sabarmathi, Rathna, Kanchi and Annapoorna (Kanwar, 1972).

Poonamperuma and Castro Ruby (1973) tested thirty two varieties of rice on a Zn deficient soil. Twenty nine of these perished within 5 weeks after transplantation. IR 5, IR 20 and H_4 survived. IR 20 and H_4 were the best.

Rashid *et al*. (1976) attributed the differences in responses to Zn fertilisation in rice to the differences in their absorption mechanisms.

The studies on the performance of 10 varieties of rice at Ludhiana (India) revealed the following order of susceptibility for Zn deficiency viz., Jaya > Palmar 579 > Ratna > IR 8 > HM 95 > Padma > Basumathi 370 > HM 484 > Jhena 349. (Anonymous, 1973).

2. Soil factors

a. Mineralogical composition:

Elgabaly (1950) indicated the possibility of substitution of Mg by Zn. The possibility of fixation in the unfilled holes of octahedral layer of aluminium silicates was indicated. Zn once fixed could not be replaced by ammonium acetate. Demumbrum and Jackson (1956) gave increased absorption evidence for adsorption of Zn by montmorillonite beyond its CEC. Reddy (1973) observed fixation of significant amounts of Zn by bentonite and illite and very little fixation by kaolinite.

Chatterjee (1974) considered that the mineralogical composition of the soils was very important in determining available Zn in soils. Rao *et al*. (1974) conducted Zn sorption studies employing red, black and laterite soil clays. In the Ca saturated system, clays dominated by kaolinite and illite had higher sorption capacity than montmorillonite, while the order was reversed for H-clay system.

Nelson and Melsted (1955) studied the chemistry of Zn added to soils and clays. They observed a rapid conversion of added Zn to forms extractable only with ammonium acetate or dilute acid. They also showed that 0.1 N HCl Zn increased and ammonium acetate Zn decreased with time during twelve weeks of equilibration.

b. Soil texture:

Kalyanasundaram and Mehta (1970) observed decrease in the availability of added Zn with increase in clay content. Prasad and Pagel (1970) indicated the availability of Zn to be directly proportional to the amount of silt, clay and humus. Murthy and Mehta (1973) conducted fixation studies. Clayey soil fixed 71 per cent, sandy clay loam 38 per cent and loamy sand 38 per cent after 72 hours of Zn addition. Sen and Deb (1975) observed mobility of Zn irrespective of textural difference.

c. Soil pH

Among many factors which govern the availability of Zn in the soil pH assumes the foremost importance. This has been well brought out by several investigations.

Camp (1945) concluded that Zn was utilised most efficiently in soils having a pH between 6.0 to 6.5. Wear (1956) and Lagnin *et al*. (1962) indicated soil reaction as the most important factor influencing Zn availability in soils. The former reported that 92 per cent of variation in the Zn uptake from applied fertiliser was attributable to soil pH values. Steward and Berger (1965) observed in many cases negative correlation between pH and extractable Zn.

Scharrer and Hofner (1958) observed that as the pH changed, Zn transformed from one hydrolysed form to another, the various forms of Zn do not react equally with soil. Guinn and Joham (1962) found that decreasing pH strongly inhibited the absorption of Zn.

Okunev (1968) gave the scheme of hydrolysis of Zn ions in dilute solutions. In acid and weakly acid medium Zn occurs in the main ionic form (Zn^{++}). It hydrolyses as the pH increases so that several of its hydrolytic forms can exist concurrently in the solution. Doubly charged molecules of basic salts form in an alkaline medium. When the solution is stored these molecules gradually transform to $Zn(OH)_2$ colloids because of adsorption of OH^-, maximum amount of colloids at pH 9 to 10.

Lindsay and Norvell (1969) suggested a very useful and important relationship of Zn^{++} solubility in soil viz., $(Zn^{++}) = 10^6 (H^+)^2$. Sharpless et al. (1969) observed formation of poorly soluble Ca ZnO_2 at higher pH. Tanaka and Yoshida (1970) recorded a hundred fold decrease in the solubility of Zn for each unit increase in pH.

Jurinak and Inouye (1962) suggested the possibility of increase of Zn in solution as a result of peptidation of hydrous ZnO at relatively high pH values - however they did not observe it in case of acid soils low in organic matter and calcareous soil.

Saeed and Fox (1977) investigated the effect of suspension pH on Zn solubility. A linear relationship was observed up to pH 7.0 for acid soils. As the system passed to neutrality a general increase was noted in the amounts of Zn in solution for the soils high in organic matter due to dispersion of organic matter.

The usual pH - solubility relationship for Zn in soil in the presence of a chelating agent is modified by the simultaneous equilibria of competing cations at a given pH. The competition of Fe at low pH values and that of Ca at high pH values was observed.

The pH-negative log of Zn relationship for calcareous soil was non-linear. Zn solubility changed very little as the pH varied within the acidic range. High solubility under low pH conditions was ascribed to partial dissolution of soil mineral including adsorption sites. When the pH of the soil was increased above 6.0, Zn in soil solution disappeared rapidly. As the pH approached 7.0 almost all of the added Zn disappeared.

d. Other nutrient ions

Absorption both in concentration and total uptake increased with increasing concentration of N in culture solution. Zn requirement of rice increased with increasing N application (Anonymous, 1968). Forno et al. (1975) observed urea application to intensify the Zn deficiency.

Soils with a high content of available and water soluble P have low concentrations of water soluble Zn regardless of pH or the content of total or available Zn. Pathak et al. (1975) studied Zn-P interrelationship in rice. Zn and P applied in optimum combination increased dry matter yield. There was adverse effects of higher levels of P on the content of Zn in the plant and vice-versa. The studies on Zn-P interaction at radiotracer laboratory of Hyderabad employing 6 levels of P_2O_5 (initial to 1600 ppm) and 5 levels of Zn (initial to 8 ppm) revealed no adverse effects of high doses of P on Zn uptake in both red and black soils (Anonymous, 1973). Jamison (1943) studying the possibility of Cu and Zn forming insoluble phosphates, found that inorganic soil surfaces form stronger bonds than are found in the P precipitates.

Deb and Zeliang (1975) studied the effects of Zn and Fe , each applied at 0, 10, 20, 30 kg/ha on dry matter, Zn, Fe and P contents of rice. No significant effect of Fe/Zn ratio on dry matter was found. Venkatasubramanyam and Mehta (1975) in their incubation experiment observed application of Fe to decrease the availability of Zn and vice-versa. Brar and Sekhon (1976) from their solution culture studies reported that increasing concentration of Fe decreased the absorption and translocation of Zn. When Fe concentration increased from 0 to 60 μm, Zn uptake decreased to 85 per cent and this effect was more pronounced at lower concentration of Zn. The inhibition was noncompetitive. Translocation of Zn decreased with increasing levels of Fe from 0 to 20 μm. The ratio of Zn uptake by roots to Zn uptake by shoot showed that up to 20 μm Fe, translocation of Zn decreased with increasing concentration. Beyond 20 μm concentration, both absorption and translocation were affected indicating disturbed metabolism in the plant. The availability of Zn may be reduced as a consequence of either increased availability of Fe as a result of flooding or addition through a carrier to the rice nursery. Chaudhry and Wallace (1976) indicated a competitive inhibition of Fe on Zn absorption in solution culture. Fe also was indicated to have a competitive effect on translocation from roots to shoots. Chelated Fe alleviated the inhibitory effect to a large extent.

Ishizuka and Ando (1968) in their solution culture studies observed a considerable reduction in Zn absorption by rice plants with increasing Mn concentration in the solution. Venkatasubramanyam and Mehta (1975) observed Zn application to increase the availability of Mn.

Chaudhry *et al*. (1973) found an antagonistic effect of Zn on Cu and suggested that Zn application could reduce rice yields if available Cu is marginal in soil. Strong depression effect of Zn on Cu uptake was also observed by Kausar *et al*. (1976).

Rashid *et al*. (1976) studied the effect of different ions on the absorption of Zn from soil solution.

They observed a progressive depression in Zn absorption by rice with increasing Ca concentration. They also pointed out that in submerged calcareous soil increasing Ca concentration could accentuate Zn deficiency even in soils of optimum Zn. A similar effect for Mg was also observed.

Kausar *et al*. (1976) studied comparative Cu and Zn deficiency and their mutual interaction in rice. Applied Zn reduced Cu uptake but Cu had little effect on Zn uptake. Lowland rice responded to Zn and Cu fertilisers on soils containing much higher content than considered deficient for most crops.

Forno (1970) felt that the Zn deficiency in flooded rice was due to bicarbonate retardation of Zn uptake. Ponnamperuma (1972) pointed out that in calcareous soils bicarbonate concentration in excess of 10 mM was observed commonly following submergence. Forno *et al*. (1975) in solution culture studies observed that bicarbonate reduced the transport of Zn to shoot by more than 70 per cent.

G. Zinc nutrition relating to soil conditions

The supply parameters of Zn determined by various pools viz., water soluble, exchangeable, specifically adsorbed, chelated and complexed Zn and Zn in primary and secondary minerals is modified markedly depending upon the physico-chemical characteristics of the soils. Apart from inherent differences in the physico-chemical characteristics the calcareous soil, soils enriched with organic matter and sodic soil produce marked differences in the physico-chemical environment of plant roots upon intermittant or full submergence to which rice cultivation is subjected to. The activities of Zn ions in the ambient soil solution bathing the plant roots is controlled by the simultaneous equilibria of several competing reactions such as surface exchange, specific bonding lattice penetration, precipitation reactions and the processes leading to the desorption of surface and lattice bound ions. (Sidhu et al. 1977). The desorption of Zn from exchange complex to solution, release of Zn from organic matter, crystalline minerals and other precipitates to the solution phase are the processes that control the availability and mobility of Zn. The following review gives an idea of the Zn nutrition of rice as influenced by varying soil conditions.

1. Calcareous soil

Jurinak and Thorne (1955) indicated $CaZnO_2$ to be an important factor in decreasing the solubility of Zn in soils at higher pH values. Sikharulidge (1973) stated that in carbonate rich soils Zn was strongly bound and scarcely available. Peterson et al. (1974) observed the application of Zn to areas which had been limed and areas from where top soil had been removed to increase crop yields. Application of zinc (40 ppm) to calcareous soil was found to aggravate Fe deficiency (Chaudhry and Wallace, 1976). More adverse effect of carbonate ion as compared to sulphate ions was observed in a pot experiment with rice. (Anonymous. 1973). Mishra and Pandey (1977) indicated that high $CaCO_3$ content made Zn unavailable due to formation of insoluble $CaZnO_2$.

Navrot and Ravikovitch (1969) observed presence of increasing amounts of $CaCO_3$ ($< 2\mu$ particles) to inhibit available Zn in soils. Philips et al. (1972) suggested that Zn in a Ca-dominated soil diffused predominantly into the adsorbed phase. Prasad et al. (1976) reported low diffusion of Zn in calcareous soil due to intense competition between Ca and Zn. Udo et al. (1970) and Trehan and Sekhon (1977) indicated the adsorption of Zn by $CaCO_3$ in calcareous soils. They also opined that when Zn was added in excess of adsorption maxima it was precipitated as carbonate rather than as hydroxide.

Badrachalam (1969) observed Zn treated plots to give an yield of 5.4 to 5.6 t/ha as against only 1.8 t/ha for control on a Zn deficient calcareous alkali soil.

2. Organic matter

Makhonina and Malchanova (1961) observed Zn adsorption to be dependent on content and quality of organic matter. De Remer (1963) and Smith et al. (1965) studied the effect of ground sugarbeet tops on the fate of added Zn. There was decrease in water soluble, acid soluble and exchangeable Zn and increase in Zn associated with organic fraction, sand and silt fractions of the soil. A similar effect with ground alfalfa was recorded by latter workers. Mangaroo et al. (1965) observed increased Zn adsorption by soils when soluble organic matter was removed by NaOH extraction. Randhawa and Broadbent (1965) observed adsorption on organic matter to be more in basic than acidic conditions. Mis~~t~~ra and Pandey (1977) obtained a highly significant negative correlation between organic carbon and DTPA extractable Zn in central Utter Pradesh.

3. Submerged soil

Jackson (1967) observed high available Fe in low land rice to aggravate Zn deficiency. Badrachalam (1969) indicated that Zn deficiency might occur under flooded conditions in rice when available Zn in soil is < 1.5 ppm. Tanaka et al. (1969) observed that the soils which differed greatly in their initial soil solution concentrations (0.8 to 180 μm) on prolonged submergence, tended towards a common value within the range of 0.3 to 0.5 μm. Estepp and Keefer (1969) found that keeping the soil moist caused greater fixation of Zn on the inorganic soil fraction. Shafi and Majid (1971) reported that many areas of low land rice in Pakistan suffered from Cu and Zn deficiency. Gangwar and Mann (1972) considered khaira disease of rice as Fe and Mn induced Zn deficiency. Ponnamperuma (1972) indicated Zn and Cu deficiency in plants grown on flooded conditions and this was related to chemical and electrochemical changes associated with soil submergence which adversely affect Zn and Cu uptake. He further focussed in 1975 that the Fe toxicity and Zn deficiency in submerged anaerobic soils as the main limitation for the growth of rice.

Rahamatullah *et al*. (1976) stated that increased contents of various ions in the soil solution as a major cause for Zn and Cu deficiency in rice. Jugsujinda (1976) observed higher Zn uptake under aerobic conditions. The studies on the influence of three water regimes viz., saturation, 5 cm standing water and flooding and drying (Anonymous, 1973), indicated a large reduction in the concentration and uptake of Zn by Jaya and HR 19 varieties of rice in both red and black soils. This was attributed to lower availability of Zn under submerged conditions. The manifestation of Zn deficiency in rice under submerged and highly reduced environmental conditions even in soils well supplied with Zn was brought out.

Aymond (1972) observed that flooding decreased the concentration of Zn in plant but not uptake. He emphasised that the Zn effect on dry matter depended on water, lime treatment, rice variety and soil. Reddy and Patrick (1977) studied the effects of redox potential on the stability of Cu and Zn chelates. They observed a reduction in the percentage of added Zn that remained in the solution with decreasing redox potential apparently due to their physical adsorption and microbial decomposition of metal chelate complex. The greenhouse studies on the effect of submergence on the kinetics of Zn^{++} and pH in calcareous sodic and slightly calcareous alkaline soils revealed that $Zn(OH)_2$ and $ZnCO_3$ are the immediate reaction products of applied Zn. In calcareous sodic soil different systems regulated soil Zn during different periods, Zn system having higher solubility than the system $Zn(OH)_2$ - Zn^{++} and $ZnCO_3$ - Zn^{++} before 2/5 days, the $Zn(OH)_2$) - Zn^{++} and $ZnCO_3$ - Zn^{++} between 2/5 to 14/21 days and predominantly by $ZnCO_3$ - Zn^{++} system thereafter (Anonymous. 1977).

4. Sodic soil

Miller et al. (1964) reported Zn deficiency to be very common in plants grown under alkaline soil conditions. Bingham et al. (1964), Reddy and Perkins (1974) indicated increased adsorption of Zn in basic more than in acidic media.

Viets (1967), Wells et al. (1973) and Tiwari et al. (1976) gave evidence for Zn deficiency in sodic soils especially under waterlogged conditions. The application of Zn was found to correct chlorosis and increase rice yields. In moderately acid to slightly alkaline soils the availability of Zn and Cu would not be limited by the instability of ZnEDTA (Norwell and Lindsay, 1969).

Singh and Sekhon (1977) studied adsorption and desorption of Zn by Punjab alkaline soils. At a higher concentration of applied Zn, the possibility of precipitation of Zn as hydroxide was indicated. They reported although clay functioned independently, $CaCO_3$ and organic matter interacted with one another for adsorption of Zn.

H. Evaluation of soil and plant for zinc fertilisation

1. Soil analysis

Badrachalam (1969) suggested the critical limit of available Zn under flooded conditions as 1.5 ppm of EDTA plus $(NH_4)_2\ CO_3$ extractable Zn.

Cox and Kemprath (1972) examined soil test methods to evaluate critical levels of micronutrients. They suggested the following ranges for critical levels for the various extractants viz., 1.0 to 7.5 ppm for 0.1 N HCL, 0.3 to 2.3 ppm for Dithiozone + ammonium oxalate extract, 0.5 to 1.0 ppm for DTPA + $Ca\ Cl_2$.

Stewart et al. (1972) proposed grading of DTPA soil test values viz., 0.0 to 0.8 ppm-very low, 0.8 to 1.4 ppm-low, 1.4 to 2.0 ppm-borderline and 2 ppm as adequate. Later, these work (1974) they confirmed DTPA as the best extractant for assessing Zn availability for rice. The ratings also appeared quite satisfactory through soil test crop response studies. However in cases of high soil pH and organic matter, borderline rating also became deficient.

Katyal and Ponnamperuma (1975) suggested a critical limit of 1 ppm for soil available Zn extractable by 0.005 M DTPA extraction procedure.

Workers in the radiotracer laboratory, Rajendranagar, Hyderabad (Anonymous, 1973) suggested the following criteria for the plant and soil viz., <0.85 ppm DTPA Zn-low; >0.85 ppm-sufficient (for soil) and <10 ppm-deficient; 10 to 15 ppm-intermediate and >15 ppm-high (for plant).

2. Plant analysis

Yoshida and Tanaka (1969) considered 15 ppm in rice shoot as critical limit for Zn. This was later confirmed by Katyal and Ponnamperuma (1975). An average concentration of 27 ppm Zn in rice leaves was suggested as critical limit for Zn deficiency at the 15 to 20 days growth stage (Anonymous, 1973). Kausar et al. (1976) conducted exhaustive experiments and suggested 17.4 ppm in shoot as critical limit.

I. Zinc fertilisation studies for rice

Pillai (1967) observed beneficial effects of $ZnSO_4$ application to rice. Badrachalam (1969) observed that Zn treated plots gave an yield of 5.4 to 5.6 t/ha as against only 1.8 t/ha for control on a Zn deficient calcareous alkali soil. In the experiments in Tamil Nadu relating to the reclamation of alkali soils, a combination of 25 kg/ha of $ZnSO_4$ with gypsum was found to give better yields (Anonymous, 1973). Recent reports from Karnal, (Abrol *et al.*, 1973) also indicated the beneficial effect of $ZnSO_4$ in increasing rice yields in alkali soil. An application of 45 kg $ZnSO_4$/ha is recommended to improve rice yields. Bora *et al.* (1977) observed responses in both *kharif* and *rabi* seasons to the application of 50 kg/ha $ZnSO_4$ in Sibsagar area of Assam.

J. Sources and methods of application of zinc for rice

Giordano and Mortvedt (1973) studied sources and methods of Zn application to rice. Yield effect was similar with ZnO, $ZnSO_4$ and ZnEDTA. Uptake of Zn in the immature plant was in the order of ZnO > $ZnSO_4$ > ZnEDTA. They also observed no adverse effect of coating the rice seeds with low rates of $ZnSO_4$ and reported that it was equally effective as the mixing of $ZnSO_4$ with soil or applying it to the water at planting for flooded rice.

Beawn *et al.* (1957) considered $Zn_3(PO_4)_2$ to be both a good Zn and a good P fertiliser when finely ground and mixed with the soil.

Phillips *et al.* (1972) indicated that Zn in a Ca dominated soil diffuses predominantly in the adsorbed phase and that the presence of chelating agents could modify it.

Earlier in 1969, Norwell and Lindsay recorded very slow rate of equilibration between the solution and solid phases in the presence of chelating agents.

Sedberry *et al*. (1971) suggested application of one kg of Zn chelate per hectare to prevent Zn deficiency.

Mikkelson and Brandon (1975) observed sulphates, chlorides and nitrate forms to be equally effective in Zn deficient calcareous soils. Oxide was less effective but cheap. Effective rate was indicated as 9 kg/ha. Murphy and Walsh (1972) from their review of literature concluded that the seed treatment with Zn solution or Zn powders can not prevent Zn deficiency in various upland crops. Yoshida *et al*. (1970) observed $ZnSO_4$ application either as soil or foliar to be as effective as dipping of seedlings in ZnO suspension for calcareous soils of West Pakistan. Sedberry *et al*. (1976) obtained higher yields of rice with ZnO than with $ZnCl_2$, $ZnSO_4$ or ZnEDTA.

Segars (1973) indicated ZnEDTA to be more effective in supplying Zn than $ZnSO_4$ when the pH exceeded 6.0. The materials were similar in Zn supplying power when the soil pH was 6.0. Elgawhary *et al*. (1970) also reported enhanced diffusion of Zn in soil on addition of EDTA and attributed this to the transformation of solid phase Zn in the soil into soluble Zn complexes.

Prasad *et al*. (1976) studied the effect of DTPA, EDTA and FA on the self diffusion of Zn in an alkaline and calcareous soil. They observed increased co-efficient of diffusion of Zn due to the addition of DTPA, EDTA and FA and the increase was attributed to the conversion of solid phase soil Zn into soluble Zn complexes. Their studies revealed that both natural and synthetic chelating agents play an important role in overcoming rate limiting steps of solution and adsorbed phase diffusion which are mainly responsible for the movement of Zn ion in alkaline and calcareous soils. They concluded that organic amendments and chelated Zn fertilisers could be expected to be more effective than soluble Zn salts in alleviating its deficiency in such soil. Kang and Okoro (1976) in their studies on Zn mobility observed a greater movement of Zn from ZnEDTA than fritted Zn. While all of applied Zn as fritted Zn remained within 0.1 cm depth, movement up to 10 cm was observed with ZnEDTA. Under flooded condition Giordano and Mortvedt (1972) also observed greater mobility of Zn from EDTA as compared to ZnO and $ZnSo_4$.

Kang and Okoro (1976) compared $ZnSO_4$, ZnEDTA, metallic Zn powder and fritted Zn at 2, 4, 6 and 8 ppm Zn, levels with IR 20 as test crop. While the dry matter yield showed no significant differences, Zn from water soluble sources was more available to the plant than the two non-soluble sources. Soaking of the seeds with ZnEDTA resulted in enrichment of seeds with Zn through diffusion, while a substantial amount of Zn was found to be attached to the seeds on soaking in suspension of Zn fruits. Soaking of seeds with ZnEDTA at a concentration of > 0.1 per cent Zn delayed germination and depressed early growth.

In the field experiments on alkali soils in Punjab (Anonymous, 1977), broadcast application of 7.5/10 ppm Zn gave the highest response. Dipping of seedling roots in 4 per cent ZnO suspension was equally efficient and was on par with 5 ppm of Zn as $ZnSO_4$ though both treatments were inferior to broadcast application of 10 ppm of Zn. Foliar application of $ZnSO_4$ proved inferior. Singh and Jain (1964) observed soil application of 2.53 kg/ha of Zn to increase dry weight and tillering. At lower levels foliar spray was superior to soil application.

MATERIALS AND METHODS

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The details of experiments carried out and the analytical techniques employed for the analysis of soil and plant samples are presented in this Chapter.

A. Experimental details

1. Experiment 1. Studies on the influence of Zn fertilisation on the growth and nutrition of popular rice varieties of Tamil Nadu

This pot experiment was conducted with the main objective of studying the nutrition and relative tolerance of popular and genetically variable rice varieties of Tamil Nadu for Zn deficiency. The particulars of varieties investigated are presented in Table I.

An alluvial soil containing 0.8 ppm of DTPA extractable Zn having a pH of 7.3 was used for the experiment. Twenty five to thirty days old seedlings were transplanted (at 12 seedlings per pot in four hills) into polythene lined earthen pots containing 8 kg of soil. Four levels of Zn viz., 0, 5, 10 and 15 ppm Zn as $ZnSO_4 \cdot 7H_2O$ and three replications were adopted. A common dressing of 120:60:60 kg/ha N, P_2O_5 and K_2O was applied to all the pots. N as urea was applied in two splits (planting and tillering) while P, K and Zn were applied in one

TABLE I. PARTICULARS OF RICE VARIETIES INVESTIGATED

S.No.	Variety	Common name	Duration (days)	Parentage
1.	Co 39	Amaravathy	95	Culture 340 x Kannaki
2.	Co 37	Vaigai	115	T.N.1 x Co 29
3.	TNAU 658	..	115	ASD 1 x Padma
4.	IR 20	..	130	IR 262 x Thadukkan
5.	RP 4-14	Prakash	130	IR 8 xT-90
6.	Ponni	Masuri	135	Taichung 65 x Mayang ESP 80
7.	Bhavani	Bhavani	135	Peta x BPI - 176
8.	IR 8	..	140	Peta x Dee Gee Woogen
9.	Co 38	Bagavathy	140	IR 8 x Co 25
10.	TNAU 13493	Rajarajan	165	IR 8 x Co 25

single dose as ammonium phosphate, muriate of potash and $ZnSO_4$ at planting. Analar reagents were used for each of the above nutrients. The experiment consisted of a total of 120 pots representing ten varieties and four Zn levels under three replications.

The plants were grown up to harvest. Grain, straw and root dry matter yield at harvest stage were recorded. The grain, straw and root samples collected for each of the treatments were analysed for the concentration of nutrients and uptake values computed based on dry matter yield.

2. <u>Experiment 2. Growth and nutrition of rice as influenced by soil conditions and Zn fertilisation</u>

This experiment was conducted with the main objective of studying the availability of nutrients under the influence of varying soil conditions and Zn fertilisation and consequent effect on dry matter yield and nutrition of rice.

The experiment involved 12 treatments as detailed below.

Normal soil		No Zn addition
Calcareous soil		Zn at 10 ppm (As $ZnSO_4.7H_2O$)
Soil enriched with organic matter	x	ZnEDTA (0.5 kg/ha)
Submerged soil		

A noncalcareous soil having a pH of 6.8 collected from wetlands of Tamil Nadu Agricultural University Farm was placed into polythene lined earthen pots at 8 kg per pot. Calculated quantities of analar grade $CaCO_3$ were added so as to represent a 6 per cent calcareous soil. Glyricidia leaves at 200 g per pot was added to represent the treatment of soil enriched with organic matter. Water allowed to stand to a height of 5 cm throughout the crop growth after puddling to represent submergence treatment of soil. The above treatments were given a week prior to planting. Soil samples were collected from each of the treatments and twenty two days old seedlings of RP 4-14, one among the high Zn responsive varieties were transplanted at the rate of six seedlings in three hills per pot. Prior to planting all pots were manured uniformly at 120:60:60 kg/ha. N was applied as urea in two splits (Planting and tillering). P and K were applied in the form of ammonium phosphate and muriate as basal dressing. Zn fertilisers were also applied as per treatments just before planting. Analar reagents were used for all the above sources. There were 48 pots representing four replications x four soil conditions x three Zn levels.

One among the four replications was utilised for collecting soil and plant samples at tillering phase and the rest continued up to harvest. Biometric observations at tillering and harvest stages and individual dry matter yield of shoot and root at tillering and grain, straw and root at harvest were recorded for the different treatments. The soil samples were also collected for the above stages.

The soil samples representing tillering and harvest stages were analysed for an appraisal of nutrient availability. The grain, straw and root samples were individually examined for their nutrient content and uptake values computed.

3. <u>Experiment 3. Yield and nutrition of rice in sodic soil attendant upon application of amendments and Zn fertilisation</u>

This pot experiment was conducted with the main aim of studying the influence of organic and inorganic amendments and Zn fertilisation in sodic soil on the yield and nutrition of the rice plant. ~~The experiment consisted of 12 treatments of the rice plant.~~ The experiment consisted of 12 treatments as per the following details.

Gypsum (as per Gypsum requirement) i.e. 12 t/ha	x	0	ppm of Zn
FYM (30 t/ha)		2.5	
Green leaves (30 t/ha)		5.0	
		7.5	

A total of 48 polythene lined earthen pots were filled up with a typical air dried sodic soil (pH 8.95 and ESP 24) at 8 kg soil per pot. These pots represented four replications. Calculated quantities of amendments were thoroughly mixed in respective pots, puddled and allowed to remain for a week. The pots were manured at 120:60:60 kg per hectare of N, P_2O_5 and K_2O as was done for the other experiments. Calculated quantity of $ZnSO_4.7H_2O$ was added as per the treatments scheduled. Six seedlings of IR 8 at the age of twenty eight days were transplanted in each pot in three hills.

One among the four replications was utilised for collecting soil and plant samples at tillering phase. Biometric data on plant height, tillering and dry matter yield of shoot and root were collected. The other three replications were continued up to harvest and soil and plant samples to represent this stage were also collected. Individual dry matter yield of grain straw and root for each pot was also recorded.

The soil and plant samples collected as above were analysed in detail for the availability of nutrients in soil and related concentration and uptake of the above by plants.

4. Experiment 4. Sources and methods of Zn fertilisation for rice

This experiment was conducted with the objective of comparing the efficacy of different sources and methods of application of Zn for rice and to fix cheap and efficient method of Zn application for rice. The details of treatments are presented in Table II.

TABLE II. DETAILS OF TREATMENTS

Treatment number	Particulars
1	Control (No addition of zinc)
2	Zinc sulphate (5 ppm of Zn)
3	Zinc chloride (5 ppm of Zn)
4	Zinc phosphate (5 ppm of Zn)
5	Zinc acetate (5 ppm Zn)
6	Seed soaking in 1 per cent $ZnSO_4$ (24 hours)
7	Dipping of seedling roots in 2 per cent ZnO
8	Nursery fed seedlings (5 ppm Zn)
9	Zinc EDTA (0.5 kg/ha applied to soil)
10	Zinc dust (5 ppm Zn)
11	Seed soaking in 0.1 per cent ZnEDTA (24 hours)

The experiment was conducted on alluvial soil (pH 7.3 and available Zn 0.8 ppm) with variety Bhavani as test crop. Eight kg of soil was placed in polythene lined earthen pots and twenty two days old seedlings were transplanted at 6 seedlings/pot in three hills. The soil in the pots was well puddled and common dose of N, P_2O_5 and K_2O at 120:60:60 kg/ha (as in earlier experiments) and Zn application was made at planting. For treatments 6 and 11, seedlings raised from soaked seeds were utilised. For treatment 8, seedlings from nursery to which 5 ppm of Zn was added was used. Analar reagents were used as sources for the above nutrients.

Out of the four replications one was utilised for collecting soil and plant samples at tillering stage and the rest continued up to harvest. Apart from recording the biometric data on plant height, tillering and dry matter yield the soil and plant samples collected were analysed for evaluating availabilities of nutrients in soil and concentration and uptake of nutrients by plant.

B. Analytical techniques for soil samples

1. Details of soil samples

Surface (0-9") soil samples representing Noyyal series (collected at Perur, Coimbatore) was employed for the first and fourth phases of the experiment.

The noncalcareous surface soil (0-9") collected from Paddy Breeding Station of Tamil Nadu Agricultural University Farm was utilised for the second phase of study.

The typical alkali soil (0-9") collected from Sommanthuaichitoor (Pollachi, Coimbatore District) was employed for conducting the third experiment.

2. Preparation of soil samples

The soil samples were air dried in the shade, gently pounded with a wooden mallet and used for potting.

3. Characteristics of the soil samples

a. Physical and chemical properties:

The physical and chemical properties of the soil samples were determined as per the methods of analysis outlined by Piper (1966) and Jackson (1973).

b. Micronutrient evaluation:

The air dried soil samples passing through 2 mm plastic sieve were utilised for the appraisal of micronutrient availability. The method described by Lindsay and Norwell (1969) was employed for extraction of micronutrients. This method (DTPA extraction procedure) consists of equilibration of soil with DTPA extract (0.005 M Diethyl triamine penta acetic acid + 0.01 M $CaCl_2$ + 0.1 M Triethanolamine, the pH of the mixture adjusted to 7.3) in the ratio of 1:2 by shaking for two hours over a horizontal type mechanical shaker. The concentrations of different micronutrients in the extract was determined by using Varian Tectron 120 Atomic Absorption Spectrophotometer.

C. Analytical techniques for plant samples

1. Preparation of the sample

The plant samples collected were washed with deionised water, dried in the air oven at 60°C for 48 hours and after recording dry matter weight powdered in Wiley Mill with stainless steel blades.

2. Estimation of nitrogen

The micro Kjeldahl method described by Jackson (1973) was adopted.

3. Preparation of di-acid extract

One gram of powdered plant material was digested with 15 ml of di-acid mixture of HNO_3 and $HClO_4$ (Analar grade) in the ratio of 4:1. The extract was allowed to cool and made up to a known volume and used for estimating the following elements.

a. Phosphorus:

In a known aliquot of the diacid extract the P was estimated colorimetrically using Vanadomolybdate method described by Jackson (1973).

b. Potassium:

A known aliquot of the di-acid extract was neutralised with 1:4 ammonia and potassium determined by using EEL flame photometer.

c. Calcium and magnesium:

A known aliquot of the Di-acid extract from which iron and aluminium were eliminated was used and calcium and magnesium determined by Versenate method described by Jackson (1973).

d. Micronutrients:

The micronutrients Fe, Mn, Cu and Zn were determined by using Varian Tectron 120 Atomic Absorption Spectrophotometer employing the respective cathode tubes at the wave lengths mentioned below:

Element	Wave length
a. Zn	2138.6 Å
b. Cu	3247.5 Å
c. Fe	2483.3 Å
d. Mn	2794.8 Å

D. Statistical analysis

The experimental data collected for each of the four phases of investigation were individually analysed statistically by the method of analysis of variance.

RESULTS

CHAPTER IV

RESULTS

The biometric observations relating to growth characteristics in respect of different phases of investigation and the chemical analytical data of the soil and plant samples are presented in this Chapter.

A. Experiment 1. Studies on the influence of Zn fertilisation on the growth and mineral nutrition of popular rice varieties of Tamil Nadu

Ten genetically variable popular rice varieties of Tamil Nadu were grown up to harvest under four levels of added Zn employing a sandy loam soil containing 0.8 ppm of DTPA extractable Zn. The macro and micro element nutrition as well as grain, straw, root and total dry matter yield as influenced by varieties and different levels of Zn are enumerated and the inferences arising therefrom are briefly summarised below.

1. Soil analysis

The physico-chemical characteristics of the soil sample (surface soil 0"-9") collected from Noyyal series (Perur, Coimbatore) employed for the study are presented in Table XXII.

The soil has a sandyloam texture containing 34.66 per cent finer fractions. The pH and EC of the soil was observed to be 7.7 and 0.62 m mhos/cm respectively. The soil ~~possess~~ had CEC of 18.6 me/100 g and 75 per cent of the exchange complex is occupied by Ca and Mg. The soil also contained 1.82 per cent free $CaCO_3$. The status of available P and K was medium while that of N poor. The soil recorded low status of available Zn (0.8 ppm). The status of available Cu was marginal while that of available Fe and Mn were above the critical level.

2. Dry matter yield

Total dry matter yield as well as individual dry matter yield of grain, straw and root recorded for each of the varieties under different levels of Zn employed are presented in Table III along with the results of statistical analysis.

a. Total yield of dry matter:

The total dry matter yield differed significantly due to varieties and Zn levels. Variety Co 38 recorded the highest yield of 98.9 g/pot, while Co 39 the least amount of 31.9 g/pot. The long duration varieties tended to record much higher dry matter yield than short duration varieties. Application of Zn increased the dry matter yield to the extent of 10 to 15 per cent over control.

b. Grain yield:

The grain yield differences due to varieties and Zn fertilisation as well as the interaction "varieties x Zn

No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
19.5	11.7	1.5	29.1	16.5	13.0	1.9	31.4	16.4	11.4	1.7	29.5	16.2	12.5	1.9	30.6	16.3	12.2	1.8	30.2
22.7	19.0	1.0	42.7	23.3	22.5	1.5	47.3	23.5	22.8	1.5	47.8	23.0	21.1	1.7	45.8	23.1	21.3	1.4	45.9
20.0	16.7	3.3	40.0	21.6	20.3	3.6	45.5	24.0	21.7	2.9	48.6	21.7	20.4	3.0	45.1	21.9	19.9	3.2	44.9
20.1	24.3	3.7	48.1	20.7	29.4	4.7	54.8	18.4	24.9	4.1	47.4	11.7	23.4	4.3	39.4	17.7	25.5	4.2	47.4
15.5	29.0	4.8	49.3	22.3	35.8	7.2	65.3	17.2	34.7	6.7	58.6	18.3	33.8	7.5	59.6	18.3	33.3	6.5	58.1
20.7	54.0	6.8	81.5	19.7	52.8	7.5	80.0	21.2	57.7	5.8	84.7	19.3	57.7	7.4	84.4	20.2	55.5	6.9	82.6
19.2	41.7	8.5	69.4	18.5	40.3	7.1	65.9	23.1	49.4	8.9	81.4	22.1	53.2	11.3	86.6	20.7	46.2	8.9	75.8
13.8	33.6	4.7	52.1	20.1	51.7	8.4	80.2	22.0	49.5	8.3	79.8	20.2	54.8	10.3	85.3	19.0	47.4	7.9	74.3
20.0	61.8	11.2	93.0	20.6	60.2	11.0	91.8	22.8	64.6	9.9	97.3	25.4	68.6	11.5	105.5	22.4	63.8	10.9	97.1
12.7	36.8	3.9	53.4	14.6	42.8	4.0	61.4	17.1	48.6	4.2	69.9	13.1	29.8	4.4	47.3	14.4	39.5	4.1	58.0
18.2	32.9	4.9	57.7	19.8	36.9	5.7	64.0	20.6	38.5	5.4	66.2	19.1	37.5	6.4	64.3	-	-	-	-

(G=Grain S=Straw R=Root T=Total)

C.D.
- Grain yield : Var=2.2; Zn=1.4; VxZn=4.2
- Straw yield : Var=5.6; Zn=3.6; VxZn=N.S.
- Root yield : Var=1.4; Zn=0.3; VxZn=N.S.
- Total dry matter : Var=7.0; Zn=4.5; VxZn=14.1

levels" showed statistical significance. The variety Co 37 recorded the highest grain yield of 23.1 g/pot. Co 38 and TNAU 658 were on par with it. The lowest yield of 14.4 g/pot was associated with TNAU 13493. It was notable that variety Co 37 which showed much less total dry matter yield ranked foremost in grain yield. Zn fertilisation registered grain yield increase of 5 to 13 per cent over control, the increase being more pronounced at 10 ppm. However, the effect of Zn in enhancing the grain yield was found to be confined only to certain varieties as revealed by the interaction effect. While all levels of Zn including control were on par in respect of varieties Co 39, Co 37, IR 20 and Ponni, addition of Zn caused significant improvement in others. The increase in grain yield ranged from 20 to 39 per cent among the varieties which showed responses to added Zn. In most of the cases 10 ppm level of Zn appeared the best. In variety RP 4-14, 5 ppm level and in Co 38 15 ppm level produced maximum grain yield. Even in the non responsive varieties the yield tended to increase though not appreciably.

e. <u>Straw yield</u>:

The mean straw yield differences due to varieties and Zn levels were statistically significant. Variety Co 38 recorded the highest straw yield of 63.8 g/pot, while Co 39 the least mean straw yield of 12.2 g/pot. The varieties IR 20, Co 37, TNAU 658 and Co 39 recorded significantly lower straw yield than others. As a general rule long duration varieties recorded higher straw yield obviously due to long period of growth. The straw producing ability of different varieties may be graded as Co 38 = Ponni > IR 8 = Bhavani > TNAU 13493 > RP 4-14 > IR 20 = Co 37 = TNAU 658 > Co 39. Application of 5 ppm of Zn brought about 12 per cent increase in straw yield over control and further increase of Zn levels showed no significant improvement. The interaction effect as observed in grain was not observed for straw yield. The application of Zn enhanced straw yield in all the ten varieties examined and the effect was more pronounced in Zn responsive variety IR 8. In others the increase was only marginal. It is significant to note that varieties Co 37, IR 20, Co 39 and Ponni which recorded no appreciable increase in grain yield due to Zn fertilisation, showed marginal increase in straw yield.

d. Root dry matter yield:

Root weight also differed considerably due to varieties. Variety Co 38 recorded the highest root weight 10.9 g/pot and Co 37 the least. A point of interest was that variety Co 37 which recorded the highest grain yield recorded the lowest root dry matter yield. This explains the more important nature of the physiological functioning rather than the quantum of roots produced. The variety Co 37, however, appears to be an exception to the general rule. A significant positive correlation (r=0.80) was observed between root dry matter yield and yield of grain in the present study. Zn fertilisation also brought about enhanced root growth. The mean root dry matter yield from 4.93 g/pot in control increased to 5.41, 5.69 and 6.36 g/pot due to application of 10, 5 and 15 ppm Zn respectively. Thus Zn fertilisation favoured better root growth in all varieties including non-responsive varieties. The effect on root growth in varieties RP 4-14 and IR 8 was more pronounced than all other varieties.

3. Concentration and uptake of nutrients

The concentration and nutrient uptake individually by grain, straw and root and the computed total uptake as influenced by Zn fertilisation in different varieties are presented in Tables IV to XXI. The statistical parameters for comparison of means are also indicated.

a. Nitrogen: (Tables IV and V)

The concentration of N in grain varied from 0.93 to 1.48 per cent. Neither the varieties nor the Zn fertilisation caused any significant variation in grain N concentration. The uptake, however, varied markedly. It ranged from 139 mg/pot to 279 mg/pot. IR 20 recorded the highest and TNAU 13493 the least uptake. Zn fertilisation brought about no significant change in the N accumulation in grain. However,

TABLE IV. N CONTENT (%) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	1.40	0.50	1.31	0.99	0.45	1.20	1.14	0.41	0.80	1.11	0.38	0.72	1.16	0.44	1.01
2.	0.97	0.38	0.70	1.16	0.31	1.15	1.22	0.32	0.78	1.00	0.21	0.65	1.05	0.30	0.82
3.	1.05	0.42	1.05	1.08	0.43	0.66	0.95	0.39	0.70	1.06	0.44	0.53	1.03	0.42	0.73
4.	1.56	0.48	0.74	1.87	0.45	0.74	1.35	0.46	1.20	1.13	0.48	0.84	1.48	0.47	0.88
5.	1.36	0.48	0.92	0.99	0.48	0.77	1.46	0.54	0.88	1.20	0.61	0.97	1.25	0.53	0.88
6.	1.41	0.48	0.62	1.57	0.45	0.56	1.18	0.59	0.57	1.13	0.49	0.77	1.32	0.48	0.63
7.	1.58	0.47	0.72	0.89	0.47	0.67	1.21	0.59	0.55	1.13	0.58	0.63	1.20	0.52	0.64
8.	1.05	0.57	0.80	1.12	0.54	0.75	1.06	0.65	0.74	1.18	0.74	0.56	1.10	0.62	0.71
9.	0.87	0.45	0.62	1.18	0.58	0.41	0.82	0.50	0.61	1.04	0.48	0.45	0.98	0.50	0.52
10.	0.95	0.38	0.37	1.05	0.45	0.42	0.91	0.43	0.32	0.79	0.45	0.42	0.93	0.43	0.38
Mean	1.26	0.46	0.78	1.22	0.46	0.73	1.13	0.48	0.72	1.11	0.48	0.65	-	-	-

(G = Grain S = Straw R = Root)

C.D.
- Grain : Var = N.S.; Zn = N.S.; V x Zn = N.S.
- Straw : Var = 0.07; Zn = N.S.; V x Zn = N.S.
- Root : Var = 0.0 ; Zn = N.S.; V x Zn = N.S.

TABLE V. UPTAKE OF N (Mgm/pot) BY DIFFERENT RICE VARIETIES UNDER DIFFERENT ZINC LEVELS

Var.	No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
1.	225	59	20	304	162	58	23	243	188	48	13	249	179	47	13	239	189	53	17	259
2.	256	73	7	336	269	70	18	357	282	68	11	361	229	44	11	284	259	64	12	335
3.	210	70	34	314	236	90	24	350	227	83	20	330	231	90	16	337	226	85	26	335
4.	316	118	27	461	389	132	34	555	249	118	48	415	162	113	37	312	279	120	17	436
5.	211	138	44	393	224	169	56	449	253	186	59	498	220	205	73	498	227	174	59	460
6.	292	262	42	596	312	251	41	604	253	281	33	567	215	279	58	552	268	268	44	580
7.	301	194	62	557	163	191	48	402	280	291	50	621	254	294	71	619	250	241	59	550
8.	144	194	37	375	225	278	64	567	234	323	61	618	233	409	58	700	209	301	55	565
9.	183	283	70	536	243	344	46	633	186	325	61	572	265	330	52	647	220	321	56	597
10.	120	145	14	279	156	202	19	377	157	207	13	377	117	134	12	263	139	172	16	327
Mean	226	154	36	412	238	178	37	453	231	193	37	461	211	194	41	446	-	-	-	-

C.D.
- Grain : Var = 50; Zn = N.S.; V x Zn = 99
- Straw : Var = 51; Zn = 32 ; V x Zn = N.S.
- Root : Var = 10; Zn = N.S.; V x Zn = 19
- Total : Var = 63; Zn = 40 ; V x Zn = 127

the interaction effect "V x Zn" showed significance. Zn application tended to increase the grain N uptake in varieties IR 8, Co 38 and RP 4-14, while high levels of Zn significantly depressed the same in IR 20.

The straw N concentration ranged from 0.30 to 0.62 per cent. IR 8 recorded the highest N content. Application of Zn tended to increase the N content though not appreciably. The mean straw N concentration for increasing levels of Zn was 0.46, 0.46, 0.48 and 0.48 per cent respectively. The straw N uptake varied from 53 to 321 mg/pot. Apart from varietal influence, Zn fertilisation also brought about significant changes in straw N uptake. Highest N uptake was associated with Co 38. Long duration varieties tended to accumulate more N in straw than short duration varieties. Zn application beyond 10 ppm caused marked and significant enhanced straw N uptake. The increase ranged from 16 per cent at 5 ppm level to 26 per cent at 10 and 15 ppm levels. Increase in dry matter yield with no corresponding dilution effect on N concentration has accounted for such increased N uptake.

The concentration of N in root varied from 0.36 per cent to 0.99 per cent. Varieties Co 39, TNAU 658, IR 20 and RP 4-14 recorded higher root N concentration. Long duration varieties contained comparatively less root N concentration than short duration varieties. Zn fertilisation caused no appreciable difference in root N concentration. The root uptake of N differed significantly among varieties. Varieties RP 4-14, Bhavani, IR 8 and Co 38 recorded higher uptake than others. The interaction means indicated the effect of Zn in significantly increasing root N uptake in varieties IR 8 and RP 4-14, while depressing the same particularly at high levels in variety Co 38. Roots of Co 37 registered the lowest uptake owing to reduced root growth. The uptake, however, increased with gradual increase in the level of Zn.

The total N uptake varied significantly due to individual as well as interaction effect. Co 38 recorded the highest uptake of 597 mg/pot as against the lowest of 259 mg/pot in Co 39. Zn fertilisation enhanced total N uptake and the effect was more pronounced at 10 ppm level. The mean uptake values registered were 412, 453, 463 and 446 mg/pot for increasing Zn levels. The interaction means, however, indicated this effect to be confined to IR 8. In other varieties all levels were on par suggesting that Zn application had no differential influence in total N uptake.

(ii) <u>Phosphorus</u>: (Tables VI and VII)

The mean concentration of P in grain ranged from 0.18 per cent in Co 37 to 0.26 per cent in Ponni. Neither the varieties nor the differences in Zn levels caused any appreciable variation in grain P concentration. The uptake of the element by grain, however, differed significantly due to both the main effects. Co 38 and TNAU 658 recorded higher uptake of 52 and 47 mg/pot as compared to 37 to 45 mg/pot in others. A slight yet significant increase of grain P uptake was observed due to added Zn fertilisers. The interaction means revealed a definite positive influence of Zn application on grain P uptake in varieties RP 4-14, Bhavani, IR 8, Co 38 and TNAU 13493. A depression in P uptake at 15 ppm Zn level was observed in IR 20.

The mean straw P concentration ranged from 0.06 to 0.13 per cent. While Zn fertilisation caused no significant variation, straw P concentration varied due to varieties. The varieties TNAU 658, Co 39, Ponni and IR 20 recorded higher P concentration than others. The uptake of the element as is observed for grain differed significantly due to varieties, Zn levels as well as its interaction. The uptake varied from 14 mg/pot in Co 39 to 68 mg/pot in Ponni. The varieties Co 39 and Co 37 were associated with significantly less straw P uptake than others. The application of Zn at 15 ppm significantly depressed the straw P uptake over other levels which remained on par. The interaction indicated that with the exception of Co 38 and Co 37 a definite depression on P uptake resulted at the highest level of Zn employed.

TABLE VI. P CONTENT (%) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	0.23	0.13	0.12	0.23	0.09	0.17	0.21	0.11	0.14	0.24	0.13	0.13	0.23	0.11	0.14
2.	0.17	0.07	0.12	0.19	0.05	0.12	0.15	0.06	0.15	0.17	0.08	0.13	0.18	0.06	0.13
3.	0.21	0.13	0.14	0.21	0.14	0.14	0.21	0.10	0.16	0.23	0.13	0.13	0.22	0.13	0.14
4.	0.21	0.11	0.13	0.21	0.11	0.12	0.26	0.10	0.13	0.26	0.11	0.13	0.23	0.11	0.13
5.	0.21	0.11	0.11	0.21	0.10	0.12	0.23	0.11	0.11	0.23	0.08	0.12	0.22	0.10	0.12
6.	0.28	0.13	0.11	0.27	0.14	0.11	0.24	0.12	0.11	0.25	0.11	0.13	0.26	0.12	0.12
7.	0.21	0.10	0.11	0.22	0.10	0.12	0.23	0.09	0.12	0.21	0.07	0.12	0.22	0.09	0.12
8.	0.21	0.13	0.15	0.22	0.10	0.13	0.22	0.09	0.14	0.22	0.08	0.15	0.22	0.10	0.14
9.	0.21	0.11	0.13	0.22	0.09	0.14	0.21	0.08	0.15	0.21	0.07	0.12	0.21	0.09	0.14
10.	0.16	0.10	0.16	0.21	0.10	0.16	0.21	0.07	0.15	0.25	0.07	0.15	0.21	0.08	0.15
Mean	0.21	0.11	0.13	0.22	0.10	0.13	0.22	0.09	0.13	0.22	0.09	0.13	-	-	-

×0.0286

C.D. { Grain : Var = 2.86; Zn = N.S.; V x Zn = N.S.
Straw : Var = 0.03; Zn = N.S.; V x Zn = N.S.
Root : Var = N.S.; Zn = N.S.; V x Zn = N.S.

TABLE VII. UPTAKE OF P (mgm/pot) BY DIFFERENT RICE VARIETIES UNDER DIFFERENT ZINC LEVELS

Var.	No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
1.	36	15	2	53	38	12	2	52	35	12	2	49	39	16	3	58	37	14	2	53
2.	37	16	1	54	43	11	2	56	41	15	3	59	39	17	2	58	41	14	2	57
3.	42	22	5	69	47	28	5	80	51	23	5	79	50	27	4	81	47	25	5	77
4.	43	28	5	76	43	32	6	81	47	27	5	79	30	26	6	62	41	28	5	74
5.	33	31	6	70	47	35	8	90	40	39	7	86	42	27	10	79	40	33	8	81
6.	59	70	8	137	52	74	9	135	52	67	8	127	47	63	10	120	52	68	9	129
7.	40	41	10	91	41	41	9	91	52	47	11	110	47	35	13	95	45	41	11	97
8.	30	43	7	80	44	54	11	109	47	45	11	103	44	45	15	104	41	47	11	99
9.	43	69	15	127	46	55	16	117	47	52	15	114	53	47	14	114	47	56	15	118
0.	31	35	6	72	34	40	7	81	42	33	6	81	41	20	6	67	37	32	6	75
Mean	39	36	6	81	43	38	8	89	46	36	7	89	43	32	8	83	-	-	-	-

C.D.
- Grain : Var = 5.0; Zn = 3.0; V x Zn = 9.0
- Straw : Var = 2.0; Zn = 2.0; V x Zn = 3.0
- Root : Var = 0.7; Zn = 0.8; V x Zn = N.S.
- Total : Var = 3.7; Zn = 2.4; V x Zn = N.S.

The mean root P concentration varied within very narrow limits between 0.12 to 0.15 per cent and neither the varieties nor Zn fertilisation caused any significant difference. The root dry matter yield differences accounted for conspicuous variation in root P uptake which ranged from 2 mg/pot in Co 37 to 14.9 mg/pot in Co 38. The varieties Co 38, IR 8 and Bhavani recorded two to three fold enhanced P accumulation in roots as compared to other varieties. There was increase in the root P accumulation due to application of Zn, the mean P uptake being 6.2, 7.5, 7.2 and 8.2 mg/pot for increasing Zn levels.

The total P uptake ranged from 53 mg/pot in Co 39 to 129 mg/pot in Ponni. The mean total P uptake for increasing Zn levels worked out to 81, 89, 89 and 83 mg/pot and thus there was no appreciable influence of Zn on total P uptake. The interaction effect also was non-significant.

(iii) Potassium: (Tables VIII and IX)

The K concentration ranged from 0.39 to 0.60 per cent in grain, 0.86 to 1.36 per cent in straw and 0.21 to 0.43 per cent in root. Neither the varieties nor the Zn fertilisation produced any significant change in the concentration of K. The uptake of the element, however, differed significantly due to varieties as well as Zn fertilisation. Varieties Co 38, Ponni and RP 4-14 registered significantly higher uptake of K

TABLE VIII. K CONTENT (%) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	0.46	1.28	0.32	0.53	1.43	0.44	0.49	1.37	0.45	0.40	1.35	0.49	0.47	1.36	0.43
2.	0.40	1.32	0.21	0.39	1.25	0.24	0.39	1.30	0.36	0.40	1.21	0.29	0.39	1.27	0.28
3.	0.31	1.08	0.47	0.39	1.24	0.45	0.38	1.04	0.39	0.41	1.16	0.39	0.39	1.13	0.42
4.	0.38	1.05	0.21	0.44	1.06	0.27	0.52	0.91	0.26	0.53	1.09	0.26	0.47	1.05	0.26
5.	0.58	0.86	0.22	0.60	0.98	0.18	0.60	0.94	0.22	0.61	0.94	0.22	0.60	0.94	0.21
6.	0.56	0.78	0.27	0.54	0.84	0.22	0.59	0.81	0.33	0.59	1.02	0.33	0.56	0.86	0.28
7.	0.41	0.97	0.19	0.48	0.96	0.16	0.48	1.14	0.27	0.44	0.96	0.27	0.45	1.01	0.21
8.	0.61	1.13	0.23	0.56	0.89	0.21	0.58	0.85	0.27	0.50	1.00	0.27	0.56	0.97	0.24
9.	0.61	0.80	0.28	0.56	0.90	0.24	0.55	0.76	0.29	0.59	1.04	0.29	0.58	0.88	0.27
10.	0.53	0.91	0.24	0.60	1.17	0.37	0.57	1.10	0.38	0.48	1.02	0.38	0.55	1.05	0.33
Mean	0.49	1.02	0.26	0.51	1.08	0.28	0.51	1.02	0.31	0.49	1.08	0.32	-	-	-

C.D. { Grain : Var = N.S.; Zn = N.S.; V x Zn = N.S.
Straw : Var = 0.08; Zn = 0.05; V x Zn = N.S.
Root : Var = 0.05; Zn = 0.05; V x Zn = 0.10

TABLE IX. UPTAKE OF K (mgm/pot) BY DIFFERENT RICE VARIETIES UNDER VARYING ZINC LEVELS

Var.	No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
1.	72	164	5	241	87	188	9	284	79	156	8	243	65	169	10	244	76	169	8	253
2.	92	253	2	347	91	281	4	376	92	296	7	395	91	255	5	351	92	271	5	367
3.	76	180	15	271	85	261	17	363	92	226	11	329	89	237	11	337	85	226	14	325
4.	77	256	8	341	91	314	13	418	96	225	12	333	62	257	11	330	82	263	11	356
5.	89	252	11	352	135	351	12	498	103	328	15	446	114	321	18	453	110	313	14	437
6.	125	436	19	580	107	443	18	568	133	469	17	619	106	592	23	721	118	485	19	622
7.	79	401	16	496	89	378	11	478	111	565	20	696	99	513	31	643	95	464	20	578
8.	84	376	11	471	113	461	17	591	128	422	20	570	93	547	28	668	105	452	19	575
9.	127	503	31	661	116	545	26	687	126	491	29	646	151	709	35	895	130	562	30	722
10.	68	385	9	462	87	504	15	606	99	521	14	634	63	306	17	386	80	429	14	522
Mean	89	321	13	422	100	373	14	465	106	370	15	468	93	391	19	503	-	-	-	-

C.D.
- Grain : Var = 20; Zn = N.S.; V x Zn = N.S.
- Straw : Var = 60; Zn = 38 ; V x Zn = 104
- Root : Var = 5; Zn = 3 ; V x Zn = N.S.
- Total : Var = 71; Zn = 38 ; V x Zn = 121

by grain. Grain K uptake was not influenced by Zn application. Varieties Co 38 Ponni, Bhavani and IR 8 recorded greater straw and root K uptake in conjunction with higher dry matter yield. Zn fertilisation favoured more straw and root K uptake, the uptake being significant even at low levels of added Zn in respect of straw.

A consideration of total K uptake revealed the significantly increased uptake in Co 38 and Ponni as compared to others. Long duration varieties showed greater uptake than medium and short duration varieties. However, the total K uptake had no relation to grain yield but reflected more or less the trend of total dry matter yield.

(iv) Calcium (Tables X and XI)

The concentration of Ca in the grain showed considerable variation. There were varietal differences. The content varied from 0.43 to 0.55 per cent, the highest being associated with TNAU 658 and the lowest with IR.8. Addition of Zn enhanced the Ca concentration of grain, the increase being more pronounced with higher levels. The concentration differences obviously reflected in uptake differences. The varietal influence was much more pronounced than Zn fertilisation. Variety TNAU 658 registered the highest grain uptake. The uptake of Ca increased up to 10 ppm level of Zn and decreased subsequently.

The straw Ca concentration differed significantly due to varieties. The content ranged from 0.34 per cent in Co 37 to 0.58 per cent in IR 20. Zn application produced no marked change in straw Ca concentration. The uptake of Ca significantly differed both due to varieties and Zn levels. The uptake varied from 48 to 297 mg/pot. It is interesting to note that Zn responding varieties tended to accumulate more Ca in straw than non responsive types.

Genetic variability of the varieties and added Zn fertilisers were observed to cause significant difference in the Ca concentration of the root. The concentration varied from 1.52 to 1.80 per cent. Varieties TNAU 658 and Co 38 registered the highest root Ca content, while IR 20 the least. Increasing levels of Zn caused a progressively increased concentration of Ca in the root. The concentration differences combined with dry matter yield differences accounted for marked differential uptake of Ca by root as well. The uptake ranged from 24.5 mg to 194.8 mg/pot. Varieties Co 38, Bhavani and IR 8 recorded greater uptake. Application of Zn even at 5 ppm caused a significant increase of root Ca uptake, the increase being more pronounced at higher levels of Zn.

Genetic variability and Zn fertilisation brought about wide differences in total Ca uptake. Co 38 recorded a three fold increased uptake as compared to Co 39. Long duration

TABLE X. Ca CONTENT (%) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	0.59	0.39	1.60	0.51	0.31	1.73	0.50	0.38	1.83	0.49	0.47	1.80	0.52	0.39	1.74
2.	0.49	0.52	1.47	0.46	0.52	1.63	0.55	0.52	1.70	0.46	0.31	1.70	0.49	0.47	1.63
3.	0.57	0.37	1.67	0.53	0.54	1.77	0.55	0.39	1.87	0.56	0.45	1.90	0.55	0.44	1.80
4.	0.49	0.64	1.50	0.47	0.63	1.43	0.55	0.43	1.47	0.61	0.60	1.70	0.53	0.58	1.52
5.	0.40	0.30	1.60	0.49	0.26	1.77	0.51	0.42	1.73	0.46	0.31	1.73	0.47	0.34	1.71
6.	0.38	0.40	1.63	0.48	0.50	1.73	0.57	0.41	1.80	0.52	0.40	1.77	0.49	0.43	1.73
7.	0.51	0.36	1.60	0.58	0.51	1.67	0.56	0.50	1.70	0.50	0.54	1.66	0.54	0.48	1.66
8.	0.37	0.53	1.60	0.39	0.51	1.73	0.49	0.51	1.63	0.49	0.54	1.67	0.43	0.52	1.66
9.	0.40	0.53	1.73	0.46	0.43	1.80	0.51	0.47	1.80	0.52	0.44	1.83	0.48	0.47	1.80
10.	0.40	0.53	1.70	0.49	0.57	1.63	0.51	0.55	1.77	0.53	0.51	1.87	0.48	0.53	1.74
Mean	0.46	0.46	1.61	0.49	0.48	1.69	0.53	0.45	1.73	0.51	0.46	1.76	-	-	-

C.D. { Grain : Var = 0.05; Zn = 0.05; V x Zn = N.S.
Straw : Var = 0.07; Zn = N.S.; V x Zn = N.S.
Root : Var = 0.10; Zn = 0.06; V x Zn = N.S.

TABLE XI. UPTAKE OF Ca (mgm/pot) BY DIFFERENT RICE VARIETIES UNDER VARYING ZINC LEVELS

No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
94	50	23	167	83	40	33	156	81	43	26	150	79	59	35	173	84	48	29	161
110	98	14	222	108	116	24	248	127	119	31	277	104	65	28	197	112	100	25	237
114	62	54	230	115	113	64	292	133	75	54	262	121	86	58	265	120	84	58	262
99	155	55	309	96	188	67	351	101	108	60	269	71	148	71	290	91	150	64	305
62	105	76	243	107	94	128	329	86	145	117	348	85	106	133	324	85	112	114	311
77	212	110	399	93	264	130	487	122	234	103	459	98	231	131	460	97	235	119	451
97	152	133	382	107	204	117	428	129	245	149	523	110	282	187	579	111	221	148	480
51	179	75	305	78	261	145	484	107	253	135	495	96	297	171	564	85	248	132	465
85	330	160	575	95	261	198	554	116	302	176	594	132	296	211	639	106	297	195	598
51	200	66	317	71	251	66	388	87	249	74	410	70	151	82	303	69	213	72	354
84	154	81	319	95	179	97	371	108	177	92	377	96	172	111	379	-	-	-	-

C.D.
- Grain : Var = 14; Zn = 9; V x Zn = N.S.
- Straw : Var = 30; Zn = 19; V x Zn = 60
- Root : Var = 20; Zn = 13; V x Zn = N.S.
- Total : Var = 46; Zn = 29; V x Zn = 92

varieties showed higher uptake than others. Zn addition, although did not produce such appreciable variation as varieties, yet even 5 ppm level could favour significantly more uptake as compared to the control.

(v) Magnesium (Tables XII and XIII)

The concentration of Mg in grain ranged from 0.17 to 0.26 per cent. The concentration differed significantly within varieties as well as due to Zn fertilisation. Ponni recorded the highest Mg concentration. Addition of Zn fertiliser caused an enhanced Mg concentration of grain over control. The Mg content of 0.19 per cent in control increased to 0.24 per cent at 15 ppm. The differences in concentration between 5, 10 and 15 ppm Zn levels were not appreciable. The concentration differences combined with dry matter yield variations reflected in significant differences of uptake as well. The uptake of Mg varied from 32 to 52 mg/pot. As a general rule, Zn responsive types showed greater Mg uptake than others. All levels of added Zn remained on par and registered significantly higher uptake than control.

The concentration of Mg in straw varied from 0.30 to 0.48 per cent. Varieties TNAU 658, IR 20 and RP 4-14 recorded higher concentration than others. The concentration differences due to Zn levels was not appreciable. Mg uptake by straw ranged from 36 to 242 mg/pot. The highest uptake was observed

TABLE XII. Mg CONTENT (%) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	0.19	0.30	1.00	0.22	0.25	0.77	0.21	0.31	0.95	0.22	0.32	0.85	0.21	0.30	0.88
2.	0.14	0.40	0.90	0.19	0.40	0.90	0.15	0.42	0.80	0.22	0.33	0.75	0.18	0.39	0.85
3.	0.19	0.50	0.90	0.18	0.45	0.80	0.16	0.53	0.77	0.15	0.42	0.77	0.17	0.48	0.81
4.	0.19	0.46	0.90	0.18	0.35	0.67	0.23	0.54	0.60	0.23	0.39	0.67	0.21	0.44	0.71
5.	0.20	0.44	0.95	0.19	0.49	0.85	0.23	0.48	0.70	0.25	0.47	0.75	0.22	0.47	0.80
6.	0.21	0.41	0.87	0.25	0.38	0.90	0.30	0.44	1.00	0.28	0.29	0.87	0.26	0.38	0.91
7.	0.15	0.32	0.80	0.24	0.32	0.85	0.18	0.34	0.80	0.24	0.31	0.77	0.21	0.33	0.80
8.	0.19	0.40	0.87	0.23	0.45	0.87	0.23	0.42	0.75	0.26	0.40	0.80	0.23	0.42	0.82
9.	0.19	0.38	0.87	0.24	0.39	0.87	0.26	0.35	0.85	0.25	0.40	0.85	0.23	0.38	0.85
10.	0.20	0.34	0.80	0.23	0.40	0.73	0.25	0.33	0.85	0.25	0.38	0.80	0.23	0.36	0.80
Mean	0.19	0.40	0.88	0.21	0.39	0.82	0.22	0.42	0.80	0.24	0.37	0.78	-	-	-

C.D. { Grain : Var = 0.02; Zn = 0.02; V x Zn = N.S.
Straw : Var = 0.04; Zn = 0.02; V x Zn = 0.08
Root : Var = 0.06; Zn = 0.04; V x Zn = 0.13

TABLE XIII. UPTAKE OF Mg (mgm/pot) BY DIFFERENT RICE VARIETIES UNDER VARYING ZINC LEVELS

No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
31	35	15	81	36	33	15	84	35	36	15	86	35	39	16	90	34	36	15	85
35	77	9	121	45	90	13	148	35	93	14	142	51	71	13	135	41	83	12	136
39	84	30	153	38	94	29	161	38	117	22	177	33	87	23	143	37	95	26	158
38	112	33	183	36	103	32	171	39	132	34	205	27	92	29	148	35	110	30	175
31	127	44	202	42	181	60	283	39	169	47	255	46	159	58	263	39	159	52	250
44	229	59	332	47	204	69	320	67	257	57	381	53	169	63	235	52	215	62	329
36	134	68	238	49	135	59	243	42	169	73	284	52	164	87	303	44	151	72	267
26	135	42	203	47	237	72	356	51	208	60	319	53	207	83	343	44	197	64	305
40	235	97	372	49	232	94	375	59	228	81	368	61	271	95	427	52	242	92	386
25	126	31	182	32	170	30	232	42	159	35	236	32	114	36	182	32	143	33	208
34	128	43	205	42	148	47	237	45	157	43	245	45	137	50	232	-	-	-	-

C.D.
- Grain : Var = 7.0; Zn = 4.0; V x Zn = N.S.
- Straw : Var =25.0; Zn =15.8; V x Zn = N.S.
- Root : Var =11.7; Zn = N.S; V x Zn = N.S.
- Total : Var =31.7; Zn =20.2; V x Zn = N.S.

in Co 38 and the least in Co 39. Long duration varieties tended to show much higher uptake than short duration varieties. Zn fertilisation favoured greater accumulation of Mg as compared to the control. The increase was, however, limited to lower levels of Zn viz., 5 and 10 ppm. 15 ppm showed a depressing effect.

The concentration of Mg in the root ranged within narrow limits of 0.80 to 0.91 per cent and was found to be not influenced to any appreciable extent either by varieties or Zn application. The root uptake of Mg ranged from 12 to 92 mg/plot and was observed to be mainly a varietal factor. The uptake was more or less related to root dry matter yield. Co 38, Bhavani and IR 8 registered greater uptake than others.

The total Mg uptake varied from 85 mg/pot in Co 39 to 387 mg/pot in Co 38. The long duration varieties tended to accumulate more Mg than short duration varieties. The total Mg uptake was also increased significantly due to addition of Zn fertiliser.

(vi) Iron: (Table XIV and XV)

The concentration of iron in grain varied from 104 ppm in Co 39 to 147 ppm in TNAU 13493. Long duration varieties recorded significantly higher grain Fe concentration than others. Zn fertilisation also brought about significant variation in grain Fe concentration. Each successive increased

Zn level caused a significant decrease of grain Fe concentration. The concentration differences reflected in the variation of uptake as well. Co 38 and Bhavani recorded higher uptake than others. TNAU 13493 registered low uptake in spite of having high concentration owing to low grain yield. Among Zn levels 15 ppm was found to bring about a significant reduction of grain Fe uptake.

The concentration of Fe in straw which was roughtly three to fourfold higher as compared to grain ranged from 396 ppm in IR 20 to 576 ppm in Bhavani. As observed in grain the increasing dose of Zn brought about significant reduction of straw Fe concentration, the decrease being more pronounced even with the addition of 5 ppm. It may also be observed that the effect of Zn in affecting the Fe concentration was more pronounced in straw than grain. The uptake of Fe appears to vary markedly due to genetic variability. It ranged from 6 to 32 mg/per pot. Co 38, Bhavani, Ponni and IR 8 registered greater uptake than others. The uptake of Fe decreased in conjunction with concentration due to Zn fertilisation.

Roots contained very high concentration of Fe as compared to grain and straw. The content ranged from 1062 ppm in IR 20 to 1500 ppm in Bhavani. The genetic variability among varieties and the Zn fertilisation accounted for significant differences in the concentration of Fe in the root. Bhavani, Ponni and Co 37 contained higher root Fe concentration than

TABLE XIV. Fe CONTENT (ppm) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	127	666	1561	119	621	1331	95	437	1205	77	385	1249	104	527	1328
2.	134	605	1676	119	465	1212	108	429	1425	100	405	1552	115	476	1466
3.	133	589	1547	115	476	1336	113	395	1286	115	347	1186	119	451	1339
4.	158	526	1123	124	407	989	127	305	1126	103	345	1011	128	396	1062
5.	163	683	1600	121	506	1208	115	415	1141	99	404	993	124	502	1235
6.	151	539	1651	135	415	1477	121	521	1407	111	367	1382	129	460	1480
7.	155	689	1690	143	565	1602	141	545	1513	137	504	1197	144	576	1500
8.	154	761	1627	129	439	1263	135	545	1047	131	459	917	137	551	1213
9.	161	715	1599	141	450	1178	125	467	1130	114	365	1099	135	500	1251
10.	171	615	1385	155	468	936	143	366	961	119	301	995	147	437	1069
Mean	151	639	1542	130	481	1253	122	442	1224	111	388	1158	-	-	-

C.D. { Grain Fe Conc. : Var = 11; Zn = 7; V x Zn = N.S.
Straw Fe Conc. : Var = 48; Zn = 30; V x Zn = 96
Root Fe Conc. : Var = 131; Zn = 85; V x Zn = N.S.

:.	No	
	G	S
	1.05	7.79
,	3.04	11.50
	2.66	9.79
	3.17	12.81
	2.53	19.80
	3.13	29.48
	2.97	28.99
	2.11	25.61
	3.38	43.79
	2.17	22.87
n	2.75	21.24

Mean			
G	S	R	T
1.69	6.42	2.33	10.44
2.66	10.04	2.14	14.84
2.59	8.82	4.28	15.69
2.30	10.11	4.42	16.83
2.27	16.40	8.34	27.01
2.64	25.64	10.12	38.40
2.97	26.76	13.22	42.95
2.58	25.13	10.18	37.89
3.01	31.80	13.65	48.46
2.11	17.24	4.40	23.75
-	-	-	-

ls

others. The antagonistic effect of Zn on the nutrition was observed in roots also. A progressive decrease of Fe concentration was observed with increasing levels of Zn. The decrease was more pronounced with the addition of 5 ppm Zn. There was a wide difference in the root Fe uptake which ranged from 2.14 to 13.64 mg/pot. Co 38, Bhavani, IR 8 and RP 4-14 registered higher uptake than others. The uptake of Fe was also found to reflect the same trend of dry matter yield. Among Zn levels control recorded the highest Zn uptake. However, the differences between added Zn levels were not appreciable.

The total Fe uptake ranged from 10.4 to 48.5 mg/pot. Co 38 and Bhavani recorded higher uptake than others. The differences are attributable mainly to varietal variations and partly to concentration differences. The total Fe uptake showed a significant decline due to the addition of even 5 ppm of Zn. The decrease was not appreciable with further increased Zn levels. The mean total Fe uptake for the increasing Zn levels worked out to 32.3, 27.0, 26.8 and 24.3 mg/pot respectively.

(vii) Manganese: (Tables XVI and XVII)

The concentration of Mn in grain ranged from 90 ppm in Co 37 to 109 ppm in IR 8. Except the varieties Co 39 and Co 37, all other varieties tended to remain on par and thus genetic variability appear to be not related to concentration

TABLE XVI. Mn CONTENT (ppm) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	83	362	509	91	371	765	87	430	663	105	414	659	92	394	649
2.	73	368	617	95	330	423	95	321	501	99	373	658	90	348	549
3.	79	396	521	108	349	440	115	371	543	100	330	551	101	361	514
4.	77	333	470	105	335	468	113	396	577	117	375	528	103	359	511
5.	91	484	572	101	346	444	99	300	476	125	323	465	104	363	489
6.	85	276	289	91	306	240	119	271	282	104	257	256	100	277	267
7.	92	229	223	118	309	227	100	243	338	117	243	352	107	247	285
8.	97	341	376	105	244	300	112	250	298	119	221	294	109	264	317
9.	84	265	303	96	237	302	108	177	280	113	170	262	101	212	286
10.	82	356	354	93	315	408	102	254	333	102	327	403	95	313	374
Mean	84	341	423	100	311	402	104	302	429	111	303	443	-	-	-

C.D. { Grain : Var = 9; Zn = 6; V x Zn = N.S.
Straw : Var = 40; Zn = 25; V x Zn = 80
Root : Var = 56; Zn = N.S.; V x Zn = 111

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Var.			Mean			
	G	S	G	S	R	T
1.	1.32	4.2	1.48	4.81	1.16	7.45
2.	1.61	7.0	2.07	7.45	0.81	10.33
3.	1.58	6.5	2.23	7.18	1.64	11.05
4.	1.55	8.0	1.80	9.15	2.21	13.16
5.	1.41	14.0	1.92	11.92	3.17	17.01
6.	1.75	15.1	2.01	15.44	1.80	19.25
7.	1.78	7.5	2.21	11.60	2.63	16.44
8.	1.39	11.4	2.10	12.07	2.45	16.62
9.	1.76	16.1	2.29	13.35	3.13	18.77
10.	1.05	12.8	1.38	12.12	1.53	15.03
Mean	1.52	10.5	-	-	-	-

of Mn in grain contrary to what was observed in the case of Fe. The effect due to Zn levels revealed a synergistic 'Zn-Mn' interaction. A progressive increase of concentration of Mn due to increasing Zn levels was observed. The uptake of the element varied from 1.37 to 2.28 mg/pot. Co 38, TNAU 658, Bhavani and IR 8 recorded significantly higher uptake than others. Application of Zn even at 5 ppm could bring about a significant increase in grain Mn uptake. Further increase in Zn levels were on par.

The straw Mn concentration ranged from 212 to 394 ppm. Co 39, RP 4-14, TNAU 658 and IR 20 recorded higher concentration than others. While grain Mn concentration increased due to Zn addition the same decreased significantly in straw and the decrease was more pronounced at higher levels of Zn employed. The uptake of Mn by straw ranged from 4.8 to 15.4 mg/pot. Co 38 and Ponni recorded greater straw Mn uptake than others. There was no marked effect on straw Mn uptake on account of Zn fertilisation.

The Mn concentration of root varied from 267 to 649 ppm. Thus the roots of all varieties contained greater concentration of Mn as compared to grain and straw. Among the varieties Co 39 registered the highest root Mn concentration while Ponni the least. The added Zn fertilisers at all levels had no impact on root Mn concentration. The uptake of Mn by root varied from 0.81 to 3.17 mg/pot. RP 4-14 and Co 38 recorded higher root Mn uptake as compared to others. The application of Zn tended to increase the accumulation of Mn and the effect was significant at higher levels of Zn.

The total Mn uptake ranged from 7.46 to 19.26 mg/pot and was observed to be mainly a varietal factor. Long duration varieties showed higher uptake. Zn fertilisation had no appreciable influence on total Mn uptake.

(viii) Copper: (Tables XVIII and XIX)

The concentration of Cu in the grain varied from 6.6 ppm in Bhavani to 14.8 ppm in IR 20. Added Zn fertiliser did not influence the grain Cu content. The mean values observed for increasing Zn levels were 10.1, 11.5, 11.4 and 11.9 ppm. The interaction effect 'V x Zn' showed significance. IR 20, Ponni, RP 4-14, TNAU 658 and Co 38 remained on par and had significantly high Cu content. In TNAU 658 and Ponni, an increase in Cu concentration was observed, while in IR 8 there was an inhibitory effect. The uptake of Cu differed significantly. The mean Cu uptake varied from 0.126 to 0.281 mg/pot. TNAU 13493 and Bhavani showed much less uptake than others. Application of Zn enhanced Cu uptake by grain which however did not vary appreciably within added levels. The interaction effect indicated this effect of Zn in enhancing Cu uptake by grain to be confined to TNAU 658, IR 20, RP 4-14 and Ponni.

TABLE XVIII. Cu CONTENT (ppm) IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

Var.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	10	17	72	9	18	55	7	13	70	5	13	69	8	15	63
2.	9	22	28	9	18	45	13	24	60	9	30	48	10	24	45
3.	11	27	71	8	15	60	11	13	62	21	13	42	13	16	60
4.	11	29	57	19	23	51	16	25	69	14	28	64	15	26	60
5.	11	35	96	14	27	86	12	15	83	14	21	101	13	24	91
6.	10	39	48	13	33	59	12	35	78	16	40	79	13	38	65
7.	4	29	50	7	29	61	7	17	69	9	39	52	7	28	58
8.	13	47	59	14	37	59	12	38	47	8	27	69	11	37	58
9.	11	19	49	12	31	56	15	21	68	12	20	81	13	22	63
10.	11	36	55	12	37	65	11	25	53	12	40	54	11	35	57
Mean	10	29	58	12	27	60	11	23	66	12	28	65	-	-	-

C.D. { Grain : Var = 2.3; Zn = N.S.; V x Zn = 4.7
Straw : Var = 4.5; Zn = 2.8 ; V x Zn = 8.7
Root : Var = 4.5; Zn = 2.9 ; V x Zn = 9.0

TABLE XIX. UPTAKE (mgm/pot) OF Cu BY DIFFERENT RICE VARIETIES UNDER DIFFERENT Zn LEVELS

	No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
	0.17	0.20	0.10	0.47	0.14	0.23	0.11	0.48	0.12	0.15	0.13	0.40	0.08	0.17	0.13	0.38	0.13	0.20	0.12	0.47
	0.23	0.41	0.03	0.67	0.20	0.40	0.24	0.84	0.29	0.54	0.11	0.94	0.20	0.64	0.09	0.93	0.23	0.50	0.13	0.8[illegible]
	0.22	0.39	0.24	0.84	0.17	0.30	0.22	0.69	0.26	0.30	0.19	0.75	0.45	0.27	0.13	0.85	0.27	0.32	0.20	0.7[illegible]
	0.22	0.70	0.21	1.13	0.38	0.67	0.24	1.29	0.29	0.64	0.09	1.02	0.16	0.66	0.28	1.10	0.26	0.67	0.25	1.1[illegible]
	0.17	1.00	0.45	1.62	0.31	0.97	0.59	1.87	0.21	0.55	0.56	1.32	0.26	0.79	0.79	1.84	0.24	0.80	0.59	1.6[illegible]
	0.21	2.09	0.31	2.61	0.24	1.94	0.42	2.60	0.27	2.00	0.45	2.72	0.32	2.30	0.59	3.21	0.27	2.08	0.44	2.7[illegible]
	0.08	1.25	0.42	1.75	0.13	1.12	0.43	1.68	0.16	0.81	0.60	2.07	0.18	1.21	0.61	2.00	0.14	1.10	0.53	1.7[illegible]
	0.18	1.57	0.27	2.02	0.26	1.95	0.49	1.70	0.26	1.92	0.40	2.58	0.20	1.47	0.69	2.36	0.22	1.73	0.46	2.4[illegible]
	0.24	1.22	0.55	2.01	0.26	1.83	0.63	2.72	0.33	1.35	0.67	2.35	0.30	1.32	0.93	2.55	0.28	1.43	0.68	2.5[illegible]
	0.14	1.33	0.21	1.68	0.18	1.55	0.26	1.99	0.18	1.22	0.23	1.63	0.15	1.19	0.25	1.59	0.16	1.32	0.24	1.7[illegible]
m	0.18	1.02	0.28	1.48	0.23	1.10	0.37	1.70	0.24	0.95	0.36	1.55	0.23	0.99	0.45	1.67	-	-	-	-

C.D. { Grain : Var = 0.06; Zn = 0.03; V x Zn = 0.10
Straw : Var = 0.24; Zn = 0.15; V x Zn = N.S.
Root : Var = 0.13; Zn = 0.08; V x Zn = N.S.
Total : Var = 0.25; Zn = 0.15; V x Zn = N.S.

The straw Cu concentration ranged from 15 to 38 ppm. Ponni and IR 8 registered higher straw Cu, while TNAU 658 and Co 39 the least. The application of Zn tended to decrease Cu concentration in straw and this effect was more at 10 ppm Zn level. The straw uptake of Cu varied from 0.2 to 2.08 mg/pot and it was found to be higher in Ponni and IR 8 than others. Zn fertilisation brought about no appreciable variation in straw Cu uptake.

The root Cu concentration ranged from 45 to 91 ppm. As in the case of Fe and Mn, roots contained higher Cu concentration than straw and grain. Zn application did not affect the root Cu concentration. Root uptake of Cu ranged from 0.12 in Co 39 to 0.70 mg/pot in Co 38. The addition of Zn favoured greater accumulation of Cu in root.

Total uptake of Cu varied considerably due to varieties. It ranged from 0.44 to 2.78 mg/pot. Most of the Zn responsive varieties showed higher uptake. Zn application favoured greater uptake with added Zn levels remaining on par. The mean total Cu uptake values for the increasing levels of Zn were observed to be 1.48, 1.69 and 1.67 mg/pot.

(ix) <u>Zinc</u>: (Tables XX and XXI)

The concentration of Zn in the grain differed significantly not only due to varieties but also due to Zn fertilisation. The concentration of Zn in grain ranged from 7.2 to

18.9 ppm. IR 20, IR 8 and TNAU 13493 recorded significantly higher Zn content than others. A significantly increased Zn concentration in grain was observed due to added Zn fertiliser. The mean concentration values observed were 9.7, 14.3, 15.0 and 17.5 ppm for increasing Zn levels. The interaction effect "variety x Zn levels" was also significant. With the exception of Co 39 and Co 37 varieties, all others showed increased Zn content in grain as a result of Zn fertiliser application. The genetic variability of varieties and added Zn fertiliser also brought about variations in the uptake of Zn by grain. The uptake varied from 0.12 to 0.36 mg/pot. IR 8, Co 38, RP 4-14 and Ponni recorded greater uptake than others. The uptake of Zn increased significantly from 0.167 mg/pot in control to 0.288 to 0.325 mg/pot due to application of Zn fertilisers.

The content of Zn in straw also varied significantly due to varieties as well as Zn application. The mean Zn concentration due to varieties ranged from 18.4 ppm in IR 20 to 33 ppm in TNAU 13493. TNAU 13493, Ponni, IR 8, Co 38 and RP 4-14 recorded significantly higher straw Zn concentration than other varieties. Increasing Zn levels progressively enhanced Zn concentration, the increase ranging from 32 to 60 per cent. The mean concentration values observed were 16.7 ppm in control and 22.1, 23.9 and 26.8 ppm for increasing levels of Zn. The straw Zn uptake also differed significantly

TABLE XX. CONCENTRATION (ppm) OF Zn IN DIFFERENT RICE VARIETIES UNDER VARYING Zn LEVELS

VAR.	No Zn			5 ppm Zn			10 ppm Zn			15 ppm Zn			Mean		
	G	S	R	G	S	R	G	S	R	G	S	R	G	S	R
1.	7.6	17.1	60.0	8.9	17.7	61.7	7.3	20.1	63.7	7.0	20.9	71.3	7.5	19.0	64.2
2.	6.6	15.2	42.0	7.2	18.7	50.0	7.1	20.1	40.7	8.0	20.3	32.7	7.2	18.6	41.3
3.	7.2	17.6	54.7	10.3	17.9	46.0	11.2	18.1	54.7	14.1	23.3	47.3	10.9	19.2	50.6
4.	11.1	14.3	64.3	17.1	14.7	57.3	22.5	19.4	56.7	24.4	25.3	85.0	18.9	18.4	65.3
5.	8.2	16.0	63.7	12.6	16.7	62.0	20.1	29.2	64.0	22.6	29.9	70.0	15.5	23.0	64.9
6.	10.3	20.1	47.3	15.0	24.2	47.7	16.1	25.1	50.7	22.8	31.2	45.7	16.1	25.1	47.8
7.	9.8	14.2	35.3	13.7	20.6	35.7	12.9	20.5	36.7	16.1	22.3	44.0	13.1	19.4	37.9
8.	13.2	15.5	31.0	21.4	24.4	47.0	17.5	27.7	44.7	22.9	30.6	70.0	18.7	24.5	48.2
9.	7.6	16.3	36.3	14.8	28.9	41.3	18.9	24.7	48.3	14.7	27.2	43.7	15.0	24.3	42.4
10.	15.1	22.7	39.0	18.2	37.7	73.0	16.4	34.4	69.0	22.1	37.3	77.5	18.0	33.0	64.7
Mean	9.7	16.9	47.4	14.3	22.7	52.1	15.0	23.9	52.9	17.5	26.8	58.5	-	-	-

C.D. { Grain : Var = 2.4; Zn = 1.5; V x Zn = 4.7
Straw : Var = 3.7; Zn = 2.3; V x Zn = N.S.
Root : Var = 8.2; Zn = 5.2; V x Zn = N.S.

TABLE XXI. UPTAKE (mgm/pot) OF Zn BY DIFFERENT RICE VARIETIES UNDER DIFFERENT Zn LEVELS

No Zn				5 ppm Zn				10 ppm Zn				15 ppm Zn				Mean			
G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T	G	S	R	T
0.12	0.20	0.09	0.41	0.15	0.23	0.12	0.50	0.12	0.23	0.11	0.46	0.11	0.26	0.14	0.51	0.13	0.23	0.12	0.48
0.15	0.28	0.04	0.47	0.17	0.42	0.08	0.67	0.17	0.46	0.08	0.71	0.18	0.43	0.05	0.66	0.17	0.40	0.06	0.63
0.13	0.33	0.18	0.64	0.26	0.39	0.16	0.71	0.23	0.35	0.16	0.74	0.34	0.46	0.14	0.94	0.24	0.38	0.16	0.78
0.22	0.35	0.23	0.80	0.35	0.43	0.24	1.02	0.37	0.42	0.23	1.02	0.32	0.59	0.36	1.27	0.31	0.45	0.26	1.02
0.11	0.46	0.31	0.88	0.39	0.60	0.44	1.43	0.35	1.01	0.43	1.79	0.42	0.89	0.55	1.86	0.32	0.74	0.43	1.49
0.22	1.09	0.30	1.61	0.30	1.29	0.35	1.94	0.35	1.47	0.29	1.11	0.43	1.80	0.36	2.59	0.32	1.41	0.33	2.06
0.19	0.58	0.30	1.07	0.21	0.81	0.25	1.27	0.35	1.03	0.34	1.72	0.36	1.21	0.51	2.08	0.28	0.91	0.35	1.54
0.18	0.52	0.15	0.85	0.40	1.54	0.39	2.33	0.38	1.22	0.37	1.97	0.45	1.61	0.72	2.78	0.36	1.22	0.41	1.99
0.16	1.03	0.40	1.59	0.38	1.73	0.46	2.57	0.43	1.61	0.48	2.52	0.38	1.83	0.51	2.72	0.34	1.55	0.46	2.35
0.18	1.21	0.15	1.54	0.27	1.53	0.30	2.10	0.28	1.59	0.29	2.16	0.28	1.11	0.34	1.73	0.25	1.36	0.25	1.86
0.17	0.60	0.22	0.99	0.29	0.89	0.28	1.46	0.30	0.94	0.27	1.51	0.33	1.02	0.37	1.72	-	-	-	-

C.D.
- Grain : Var = 0.06; Zn = 0.04; V x Zn = N.S.
- Straw : Var = 0.24; Zn = 0.15; V x Zn = N.S.
- Root : Var = 0.09; Zn = 0.05; V x Zn = N.S.
- Total : Var = 0.30; Zn = 0.19; V x Zn = N.S.

due to varieties and Zn levels. Among the varieties Co 38 was associated with highest straw Zn uptake while Co 39 the least. In general Zn responsive varieties showed greater straw accumulation of Zn. The mean straw Zn uptake ranged from 0.23 to 1.55 mg/pot. The uptake value of 0.6 mg/pot in control increased to 0.89 to 1.02 mg/pot as a result of Zn application representing an increase of 40 to 70 per cent. Increased straw yield values combined with enhanced Zn concentration accounted for such enhanced uptake.

The root Zn concentration and uptake were also influenced by varieties and Zn fertilisation. The concentration varied from 37 ppm in Bhavani to 65 ppm in IR 20. RP 4-14, Co 39 and TNAU 13493 remained on par with IR 20. The concentration of Zn ranged from 47 to 58 ppm for the different Zn levels and the differences were significant. Co 38, RP 4-14 and IR 8 registered higher root Zn uptake than others. Application of Zn caused a 30 to 40 per cent increased root Zn uptake as compared to the control.

The total uptake of Zn varied from 0.47 to 2.35 mg/pot. Both varieties and Zn fertilisation accounted for significant variation in the total Zn uptake. Among the varieties Co 38, IR 8, Ponni and TNAU 13493 recorded higher total uptake comparatively. Zn uptake increased significantly with addition of Zn fertilisers, the increase being more pronounced at higher level of Zn. The total uptake of 0.99 mg/pot in control increased to 1.43 to 1.71 mg/pot on account of Zn fertilisation.

B. Growth and mineral nutrition of rice as influenced by soil conditions and zinc fertilisation

The Zn responsive rice variety RP 4-14 was grown under four soil conditions viz., normal soil, calcareous soil, soil enriched with organic matter and submerged soil. Zn applied as $ZnSO_4$ (10 ppm Zn) and ZnEDTA (0.5 kg/ha) was compared with no Zn (control) in each of the above soil conditions. The macro and micro elements nutrition as well as grain, straw and root dry matter yield as influenced by the treatments were studied. The biometric data and the analytical data of the soil and plant samples at tillering and harvest stages are presented and inferences drawn are briefly indicated below.

1. Soil analysis

The physico-chemical characteristics of the soil samples initially and at planting are given in Tables XXII and XXIII respectively.

The initial soil representing the Paddy Breeding Station (TNAU, Coimbatore district) possessed sandy loam texture with a CEC value of 18.6 me/100 g. The pH and EC

TABLE XXII. PHYSICO-CHEMICAL CHARACTERISTICS OF INITIAL SOIL SAMPLES

Particulars of analysis	First and fourth experiments	Second experiment	Third experiment
MECHANICAL COMPOSITION			
Clay	20.26	19.46	34.26
Silt	14.40	15.02	10.20
Fine sand	46.50	44.64	36.70
Coarse sand	15.18	16.12	13.64
Textural class	Sandy loam	Sandy loam	Clay loam
PHYSICAL AND MOISTURE CONSTANTS			
Apparent density	1.26	1.24	1.32
Absolute density	2.32	2.26	2.42
Pore space	56.84	58.24	52.40
Water holding capacity	52.00	53.12	50.25
CHEMICAL ANALYSIS			
Loss on ignition (%)	4.86	4.06	3.62
Free calcium carbonate (%)	1.82	0.14	2.04
Organic carbon (%)	0.68	0.50	0.32
Iron oxide (Fe_2O_3)(%)	5.84	5.22	6.46
Alumina (Al_2O_3) (%)	8.02	7.88	9.20
Silica (SiO_2) (%)	12.10	11.84	16.46
Lime (CaO) (%)	1.86	0.42	2.10
Mangnesia (MgO) (%)	0.72	0.12	0.32
Total potash (K_2O) (%)	0.52	0.49	0.18
Total phosphoric acid (P_2O_5)(%)	0.06	0.06	0.05
Total Manganese (ppm)	400.00	362.00	264.00
Total copper (ppm)	29.00	42.00	42.00
Total nitrogen (%)	0.12	0.10	0.08
Total Zinc (ppm)	125.00	85.00	175.00

(Continued)

TABLE XXII. (CONTINUED)

Particulars of analysis	First and fourth experiments	Second experiment	Third experiment
AVAILABLE PLANT NUTRIENTS			
Available nitrogen (N) (ppm)	64	58	42
Available phosphorus (P) (ppm)	8.1	6.2	3.2
Available potassium (K) (ppm)	258	214	146
Available calcium (exch+water soluble) (ppm)	1828	712	2440
Available magnesium (exch+water soluble) (ppm)	616	740	1110
Available iron (ppm)	5.4	9.2	4.6
Available manganese (ppm)	4.6	3.4	3.8
Available copper (ppm)	1.2	3.2	1.8
Available zinc (ppm)	0.8	1.2	0.6
CATION EXCHANGE PROPERTIES			
Cation exchange capacity (me/100g)	18.60	17.42	28.62
Exchangeable calcium (me/100g)	9.06	9.24	12.40
Exchangeable magnesium (me/100g)	6.76	5.82	8.76
Exchangeable potassium (me/100g)	0.52	0.54	0.12
Exchangeable sodium (me/100g)	1.29	1.00	6.72
OTHER PROPERTIES			
pH (1:2)	7.70	7.20	8.95
EC (1:2) (m mhos/cm)	0.62	0.42	0.42

of the soil are 7.7 and 0.62 m mhos/cm respectively and were thus within normal limits for plant growth. The soils contained 64, 8 and 258 ppm of available N, P and K and hence may be considered as low in N medium in P and high in K as per the conventional soil testing ratings adopted in Tamil Nadu. With respect to micronutrient elements, while available Fe, Mn and Cu were sufficiently above the critical levels, the available Zn was 1.2 ppm which may be considered as borderline.

The soil samples collected at planting after allowing the soil to equilibrate with treatments imposed (Table XXIII) revealed the ideal experimental conditions. The pH of the soil increased from 8.3 to 8.5 in treatments which received $CaCO_3$. The added organic matter and submergence tended to decrease the pH. The EC varied from 0.46 to 0.70 m mhos/cm and submerged soil showed a slight increase in EC value. The enrichment of soil with organic matter obviously caused a substantial increase in organic carbon content. The different treatments also brought about differences in the status of available nutrients. While calcareous soil tended to depress the availability of P, Mg, Fe, Mn and Zn, there was enhanced Ca concentration. While there was no appreciable difference between normal and submerged soil in respect of N P K, the submerged soil tended to increase Fe and Mn concentration and decrease Zn concentration. The mere enrichment of the soil with organic matter caused an enhanced Zn availability while the submergence tended to depress it.

The soil samples collected at tillering phase (Table XXIV) revealed no appreciable change in pH as compared to those collected at planting. The calcareous soil condition recorded a mean pH value of 8.3 as compared to other soil conditions, where the pH ranged from 7.1 to 7.7. All treatments tended to register slightly increased values of EC over initial soil, the effect was more pronounced under organic matter enriched and submerged soil conditions. However, the value remained well within the normal range for plant growth. The initial EC value of 0.62 mmhos/cm and 0.46 to 0.70 mmhos/cm at tillering increased to 0.60 to 0.92 at harvest. The status of available N, P and K was more during tillering for all soil conditions. The increase in available P in calcareous soil was not pronounced as observed in others. The soil enriched with organic matter continued to maintain comparatively higher amounts of nutrients. This treatment along with submerged soil registered better N, P and K status than normal and calcareous soil. The calcareous soil tended to cause further increase in Ca concentration. Soil enriched with organic matter showed comparatively more available Mg than others. Apart from calcareous soil other soil conditions viz., organic matter enriched and submerged soil also caused greater Ca concentration as compared to normal soil. In respect of micronutrients

TABLE XXIV. AVAILABILITY OF PLANT NUTRIENTS IN DIFFERENT TREATMENTS AT TILLERING

Soil condition	Zinc source	pH	EC	Available nutrients (ppm)								
				N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
Normal soil	No zinc	7.3	0.60	84	10.2	320	700	647	43.2	15.4	5.5	1.6
	$ZnSO_4$	7.2	0.60	84	8.8	390	864	620	43.4	25.2	6.7	5.0
	ZnEDTA	7.4	0.60	80	11.4	370	742	648	31.3	18.6	5.3	2.4
Calcareous soil	No zinc	8.3	0.68	70	6.4	355	5200	609	34.1	17.3	5.5	0.7
	$ZnSO_4$	8.3	0.72	67	5.8	345	5810	682	48.3	16.4	5.5	2.6
	ZnEDTA	8.2	0.62	90	7.2	355	5070	648	45.2	19.2	5.5	3.0
Soil + organic matter	No zinc	7.4	0.80	105	14.8	550	1600	805	60.1	24.1	4.8	2.8
	$ZnSO_4$	7.7	0.84	120	10.8	540	2000	860	54.2	31.4	6.0	3.6
	ZnEDTA	7.0	0.82	95	10.6	495	1400	792	36.2	27.3	4.2	3.0
Submerged soil	No Zinc	7.4	0.70	90	18.1	390	1080	695	54.2	31.2	6.2	0.8
	Zn SO_4	7.1	0.92	85	16.2	410	1040	712	41.4	38.4	6.0	2.1
	ZnEDTA	7.4	0.84	95	14.0	400	920	698	55.2	42.3	6.7	3.7

there was a pronounced and marked increase in available Fe, Mn and Cu irrespective of the soil conditions, the effect being least in calcareous soil and high in submerged soil. In normal soil available Zn increased even in control, the increase being more pronounced in $ZnSO_4$. In calcareous soil the available Zn was found to be less than 1 ppm in the absence of added Zn while Zn application in either form could cause three to four fold enhanced Zn availability. In the soil enriched with organic matter there was no appreciable change in the status of available Zn and this was true even for control. Under submerged soil condition the poor availability of Zn as observed at planting continued to be so in the absence of added Zn. The concentration continued to be less than the critical levels. Zn fertilisation in either form particularly ZnEDTA resulted in enhanced Zn concentration and the increase was three to fivefold.

The analysis of the post harvest soil samples (Table XXV) indicated that the pH of the soil remained more or less the same as observed at tillering stage while EC values decreased slightly under all soil conditions. The status of available N, P and K decreased in all treatments. There was no marked change in the concentration of Ca and Mg. The availability of Fe, Mn and Cu decreased markedly and the changes produced in available Zn was not appreciable. The addition of Zn fertilisers to calcareous and submerged soil

TABLE XXV. AVAILABILITY OF PLANT NUTRIENTS IN DIFFERENT TREATMENTS AT HARVEST

Soil condition	Zinc source	pH	EC	Available nutrients (ppm)								
				N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
Normal soil	No Zn	7.2	0.52	58	4.2	262	586	506	6.4	6.2	2.4	1.6
	$ZnSO_4$	7.0	0.62	42	4.6	284	612	512	5.0	4.4	3.2	2.4
	ZnEDTA	7.4	0.50	48	5.6	302	608	610	5.0	6.8	3.0	1.8
Calcareous soil	No Zn	8.2	0.66	48	3.0	286	4810	500	6.2	6.0	2.5	0.5
	$ZnSO_4$	8.0	0.60	56	4.0	242	4386	412	5.0	4.0	1.8	1.8
	ZnEDTA	8.2	0.64	52	3.8	265	5010	510	4.4	4.2	2.0	1.4
Soil enriched with organic matter	No Zn	7.0	0.68	62	5.6	318	1180	752	10.2	8.0	3.2	2.2
	$ZnSO_4$	6.9	0.70	58	8.8	402	1684	710	10.2	7.4	2.8	3.4
	ZnEDTA	7.2	0.72	66	7.2	415	1284	740	9.2	7.4	2.2	3.6
Submerged soil	No Zn	7.1	0.66	60	6.8	296	910	562	8.8	5.8	2.8	1.4
	$ZnSO_4$	7.2	0.64	52	5.8	255	800	602	7.4	6.2	3.4	2.4
	ZnEDTA	7.0	0.70	46	6.4	310	840	600	8.8	5.8	3.4	2.4

maintained a higher Zn availability than control even at the harvest stage.

2. Dry matter yield and nutrition at tillering stage

The biometric data on dry matter yield, concentration and uptake of nutrients individually by shoot and root at tillering stage of the crop are furnished in Table XXVI.

The mean shoot dry matter yield was 3.40, 2.60, 3.60 and 2.90 g/pot respectively for normal calcareous, organic matter enriched and submerged soil respectively. The mean root dry matter yield recorded were 1.50, 0.95, 1.50 and 1.20 g/pot respectively for the above soil conditions. Thus, calcareous soil and submerged soil showed comparatively reduced growth as compared to the other two soil conditions. Zn application in either form showed 14 per cent increased shoot and 20 per cent increased root dry matter yield.

The N content of shoot was the highest in normal soil while that relating to submerged soil contained the least N concentration. The N concentration of the root was comparatively high in organic matter enriched soil. Zn fertilisation showed no appreciable influence on N concentration of both shoot and root. The uptake of N reflected the trend of dry matter yield. Calcareous soil and submerged soil showed comparatively less N uptake. Zn fertilisation tended to increase the N uptake. There was no appreciable difference in P content of shoot and

TABLE XXVI. BIOMETRIC DATA, CONCENTRATION AND UPTAKE OF NUTRIENTS AT TILLERING

.ition	Zinc source	Biometric data					Nitrogen					Phosphorus				
		Height (cm)	Tillering No/Hill	Shoot dm g/pot	Root dm g/pot	Total dm g/pot	Shoot conc. %	Root Conc. %	Shoot up-take mg/pot	Root uptake mg/pot	Total up-take mg/pot.	Shoot conc. %	Root conc. %	Shoot up-take mg/pot	Root uptake mg/pot	Total up-take mg/pot
al L	No Zn	60	7	3.90	1.50	5.40	1.92	2.04	75	30	105	0.26	0.30	9	6	15
	$ZnSO_4$	56	7	3.60	1.50	5.10	2.00	2.24	72	33	105	0.22	0.28	9	3	12
	ZnEDTA	52	8	2.70	1.50	4.20	1.86	2.80	51	42	93	0.24	0.24	6	3	9
areous L	No Zn	57	6	2.10	0.90	3.00	1.74	1.98	37	18	55	0.18	0.20	5	2	7
	$ZnSO_4$	61	7	3.15	0.90	4.05	1.88	2.42	56	23	79	0.20	0.21	6	2	8
	ZnEDTA	63	7	2.55	1.05	3.60	1.80	2.62	46	27	73	0.26	0.22	6	2	8
L + anic ter	No Zn	62	8	3.60	1.20	4.80	1.90	2.60	69	30	99	0.28	0.20	12	3	15
	$ZnSO_4$	56	9	3.30	1.80	5.10	1.84	2.74	60	48	108	0.32	0.30	12	6	18
	ZnEDTA	53	9	3.90	1.50	5.40	1.88	2.80	72	42	114	0.32	0.26	12	3	15
erged L	NoZn	58	6	1.80	0.90	2.70	1.70	1.94	30	18	48	0.26	0.21	6	3	9
	$ZnSO_4$	60	8	3.00	1.20	4.20	1.80	2.42	54	30	84	0.24	0.26	6	3	9
	ZnEDTA	56	8	3.90	1.50	5.40	1.78	2.20	72	33	102	0.28	0.30	12	6	18

(Continued)

TABLE XXVI (CONTINUED)

...ition	Zinc source	Potassium: Shoot conc. (%)	Potassium: Root conc. (%)	Potassium: Shoot uptake (mg/pot)	Potassium: Root uptake (mg/pot)	Potassium: Total uptake (mg/pot)	Calcium: Shoot conc. (%)	Calcium: Root conc. (%)	Calcium: Shoot uptake (mg/pot)	Calcium: Root uptake (mg/pot)	Calcium: Total uptake (mg/pot)	Magnesium: Shoot conc. (%)	Magnesium: Root conc. (%)	Magnesium: Shoot uptake (mg/pot)	Magnesium: Root uptake (mg/pot)	Magnesium: Total uptake (mg/pot)
...al	No Zn	1.24	0.68	48	9	57	0.56	1.60	21	24	45	0.20	1.00	9	15	24
	$ZnSO_4$	1.24	0.68	45	9	54	0.63	1.80	24	27	51	0.28	0.84	9	12	21
	ZnEDTA	1.18	0.50	33	9	42	0.63	1.80	18	27	45	0.26	1.26	6	18	24
...areous ...	No Zn	0.82	0.72	17	6	23	0.62	1.83	13	17	30	0.14	0.88	3	7	10
	$ZnSO_4$	1.00	0.68	32	6	38	1.04	2.00	32	18	50	0.15	0.68	5	6	11
	ZnEDTA	1.22	0.80	31	8	39	1.12	1.40	28	15	43	0.24	0.60	6	6	12
...l + ...nic ...er	No Zn	1.40	0.42	51	6	57	0.96	2.00	36	24	60	0.25	0.58	9	6	15
	$ZnSO_4$	1.32	0.80	45	15	60	0.80	1.80	27	33	60	0.35	0.56	12	9	21
	ZnEDTA	1.48	0.86	57	12	69	1.10	1.86	42	27	69	0.37	0.70	15	12	27
...merged ...	No Zn	0.82	0.68	15	6	21	0.88	1.66	15	15	30	0.27	0.86	6	9	15
	$ZnSO_4$	1.32	0.72	39	9	48	1.00	1.80	30	21	51	0.31	0.84	9	9	18
	ZnEDTA	1.24	0.76	48	12	60	1.06	1.58	42	24	66	0.30	0.92	12	15	27

(Continued)

l lition	Zinc source	Iron: Shoot conc. (ppm)	Iron: Root conc. (ppm)	Iron: Shoot uptake (mg/pot)	Iron: Root uptake (mg/pot)	Iron: Total uptake (mg/pot)	Manganese: Shoot conc. (ppm)	Manganese: Root conc. (ppm)	Manganese: Shoot uptake (mg/pot)	Manganese: Root uptake (mg/pot)	Manganese: Total uptake (mg/pot)	Copper: Shoot conc. (ppm)	Copper: Root conc. (ppm)	Copper: Shoot uptake (mg/pot)	Copper: Root uptake (mg/pot)	Copper: Total uptake (mg/pot)
mal l	No Zn	224	1720	0.87	2.58	3.45	208	112	0.81	0.18	0.99	24	48	0.09	0.06	0.15
	$ZnSO_4$	192	1384	0.69	2.07	2.76	194	90	0.69	0.15	0.84	24	64	0.09	0.09	0.18
	ZnEDTA	158	1218	0.42	1.83	2.25	210	88	0.57	0.12	0.69	32	56	0.09	0.09	0.18
careous l	No Zn	298	1910	0.63	1.72	2.35	140	138	0.28	0.12	0.40	26	20	0.05	0.02	0.07
	$ZnSO_4$	260	1530	0.82	1.38	2.20	131	70	0.42	0.06	0.48	20	48	0.06	0.05	0.11
	ZnEDTA	244	1120	0.62	1.17	1.79	130	75	0.33	0.08	0.41	26	36	0.06	0.04	0.10
l + anic ter	No Zn	208	1020	0.75	1.23	1.98	141	90	0.51	0.12	0.63	28	60	0.09	0.06	0.15
	$ZnSO_4$	118	1000	0.39	1.80	2.19	174	72	0.57	0.12	0.69	28	72	0.09	0.12	0.21
	ZnEDTA	186	1120	0.72	1.68	2.40	150	78	0.60	0.12	0.72	30	40	0.12	0.06	0.18
merged l	No Zn	386	1864	0.69	1.68	2.37	265	330	0.48	0.33	0.81	19	40	0.03	0.03	0.06
	$ZnSO_4$	268	1386	0.78	1.65	2.43	254	130	0.75	0.15	0.90	24	32	0.06	0.03	0.09
	ZnEDTA	318	1180	1.23	1.77	3.00	180	108	0.69	0.15	0.84	28	40	0.12	0.06	0.18

root due to treatment effects. The soil enriched with organic matter recorded the highest and calcareous soil showed the least uptake values. The K nutrition was found to be influenced by treatments. Concentration and uptake of the element by shoot was the least in calcareous soil. However root showed higher concentration of K but not uptake in calcareous soil. Organic matter enriched soil and added Zn fertilisers recorded comparatively higher uptake, persumably due to increased dry matter yield.

Regarding Ca nutrition normal soil showed comparatively less shoot Ca concentration but not root concentration of the element. Zn fertiliser tended to enhance the Ca content of shoot but not the root. The organic matter enriched soil and application of Zn in either form recorded higher uptake than others. Both concentration and uptake of Mg in shoot was comparatively less in calcareous soil. The roots of normal soil contained a relatively high concentration than others. Zn fertilisation tended to slightly increase the shoot Mg concentration but not root concentration of the element. The net result was calcareous soil and absence of Zn addition showed high uptake as compared to other treatments.

Roots contained six to eightfold enhanced Fe concentration as compared to shoot under all soil conditions. The shoot and root relating to organic matter enriched soil recorded relatively lower Fe concentration than others. Zn fertilisation in either form tended to decrease the concentration of Fe both in root and shoot. Submerged soil showed the highest shoot Fe concentration. Calcareous soil and organic matter enriched soil recorded relatively lower uptake than the other soil conditions. Zn fertilisation tended to slightly decrease the total Fe uptake. The Mn nutrition showed the shoot to contain higher Mn concentration contrary to what was observed for Fe. Shoot and root relating to submerged soil contained comparatively higher concentration of the element. Zn fertilisation particularly ZnEDTA tended to reduce the concentration of the element and this was particularly pronounced in the root. Calcareous soil recorded the least total as well as individual uptake of the element. The mean Cu concentration of shoot varied from 24 to 27 and that in root ranged from 35 to 57. Calcareous soil and submerged soil recorded less root Cu concentration than others. Application of Zn as $ZnSO_4$ recorded high root Cu concentration while there was no appreciable difference in shoot Cu concentration. The uptake of the element was comparatively less in calcareous and submerged soil than other two soil conditions. Total uptake tended to slightly increase due to added Zn fertilisers.

The concentration of Zn in shoot and root relating to calcareous soil was comparatively the least. Zn concentration of shoot in submerged soil was also low, but root in this soil condition contained phenomenally high concentration of the element. The total and individual uptake of the element by shoot and root was relatively less in calcareous soil, while there was not much difference among other soil conditions. Zn fertilisation accounted for appreciable improvement in total as well as individual uptake by shoot and root.

3. Dry matter yield at harvest

Total dry matter yield as well as individual dry matter yield of grain, straw and root recorded for each of the treatments are presented in Table XXVII along with the results of statistical analysis.

a. Total dry matter yield

The total dry matter yield differed significantly due to differences in soil conditions as well as Zn fertilisation. Soil enriched with organic matter produced a significantly higher mean dry matter yield of 18.3 g/pot as against 13.9 g for submerged soil, 13.5 g for normal soil and 12.3 g for calcareous soil. The latter three remained on par. Zn fertilisation in both forms were on par and registered mean dry matter yield of 13.5 and 13.9 g/pot and were superior to control. This represented 5 to 11 per cent increase of total dry matter over control. The interaction effect was also observed to be significant. While the increase in dry matter yield due to Zn fertilisation in normal and organic

TABLE XXVII. DRY MATTER YIELD (g/pot) AND BIOMETRIC DATA AT HARVEST AS INFLUENCED BY SOIL CONDITIONS AND Zn FERTILISATION

Soil condition	Zn Source	Grain yield	Straw yield	Root yield	Total dry matter yield	Chaff yield	Chaff per cent
Normal soil	No Zn	4.87	6.43	2.77	14.07	0.70	14.5
	$ZnSO_4$	4.50	6.00	2.60	13.10	0.57	12.8
	ZnEDTA	4.13	6.77	2.47	13.37	0.46	11.3
Calcareous soil	No Zn	3.33	5.10	2.24	10.67	0.47	13.9
	$ZnSO_4$	4.70	5.80	2.23	12.73	0.54	11.7
	ZnEDTA	4.53	6.80	2.44	13.77	0.73	16.2
Soil enriched with organic matter	No Zn	5.93	8.57	3.37	17.87	0.70	11.9
	$ZnSO_4$	6.43	7.94	3.80	18.17	0.74	11.6
	ZNEDTA	6.97	8.30	3.60	18.87	0.96	14.1
Submerged soil	No Zn	3.60	6.23	2.00	11.83	0.87	24.6
	$ZnSO_4$	5.20	6.27	2.33	13.80	0.73	14.2
	ZnEDTA	5.10	8.40	2.80	16.30	0.63	12.4
C.D.(Soil)	-	0.67	1.34	0.11	1.84	0.16	-
C.D.(Zinc)	-	0.59	1.10	N.S.	1.62	N.S.	-
C.D.(S x Zn)	-	1.26	N.S.	N.S.	N.S.	0.27	-

matter enriched soil was not appreciable, there was pronounced improvement to the extent of 11 to 13 per cent in calcareous soil and 12 to 28 per cent in submerged soils. While Zn application in either form produced similar effect in calcareous soil, the chelated form in submerged soil proved to be better as it recorded further improvement in total dry matter yield over $ZnSO_4$.

b. Grain yield

Soil enriched with organic matter showed significant and substantial improvement in grain yield over all other soil conditions. The above treatment recorded increased grain yield ranging from 40 to 50 per cent as compared to other treatments. The mere application of green leaves to raise the initial organic matter content of the soil to about 2 per cent resulted in phenomenal enhanced grain yield. The presence of 6 per cent $CaCO_3$ and also growing rice under continuous submergence produced no appreciable variation in the grain yield values as compared to normal soil. The mean grain yield recorded were 4.3, 4.2, 6.4 and 4.6 g/pot respectively for normal, calcareous, organic matter enriched and submerged soil respectively. Zn application irrespective of the dose and form employed brought about a significant increase (18 per cent) in grain yield over control. However, this effect of Zn was found to depend on soil conditions. Application of Zn in both forms were not advantageous in normal and organic matter enriched soil. A significant improvement in yield to the extent of 42 to 44 per cent was observed in calcareous and submerged soil - in both cases, both forms were on par. It may be added that the chelated form of Zn which brought about substantial improvement in total dry matter yield in submerged soil had not contributed appreciably in grain yield.

c. Straw yield

The mean straw yield values differed significantly due to both the main effects. Organic matter enriched soil and growing of the crop under continuous submergence registered higher straw yield than the other two soil conditions. The increase ranged from 18 per cent in submerged soil to 29 per cent for the other case as compared to normal soil. Calcareous soil tended to depress slightly but not significantly the straw yield over normal soil. While $ZnSO_4$ brought about no improvement in straw yield, the definite advantage of ZnEDTA was revealed. The above treatment recorded 15 per cent increased straw yield over the other two.

d. Root dry matter yield

The mean root dry matter yield varied due to soil conditions. The soil enriched with organic matter recorded significantly higher root dry matter yield of 3.6 g/pot as compared to 2.4 to 2.6 g/pot in others. Thus it was observed that the beneficial effect of added organic matter extended to root growth as well. The mean dry matter yield of root varied within very small limits due to Zn addition.

e. Chaff dry matter yield

In tune with the enhanced total and grain dry matter yield the chaff weight was higher in organic matter enriched soil and submerged soil as compared to normal and calcareous soil. A consideration of the interaction effect revealed the negative influence of Zn in the presence of added organic matter, while under submerged conditions they proved extremely useful in reducing the chaff weight.

f. Chaff percentage

The percentage of chaff calculated on grain weight basis differed significantly due to main as well as interaction effects. Among the soil conditions submerged soil registered the highest while soil plus organic matter the least chaff percentage. The application of Zn in both forms reduced the chaff percentage. The interaction means, however, revealed this beneficial effect to be more pronounced under submerged soil conditions where 10 to 14 per cent reduction in chaff weight was observed.

4. Concentration and uptake of nutrients at harvest

The concentration and uptake of nutrients individually by grain, straw and root and the computed total uptake as influenced by soil conditions and Zn fertilisation are presented in Tables XXVIII to XXXII. The statistical parameters for comparison of means are also indicated.

a. Nitrogen (Table XXVIII)

The mean N concentration of grain ranged from 1.51 to 1.79 per cent. While soil conditions produced very little difference in concentration, Zn application both in organic and inorganic form increased N content significantly, but only marginally (6.1 per cent). The increase was more pronounced in normal and submerged soil conditions. Soil enriched with organic matter even without any added Zn recorded N concentration on par with added levels. The uptake of N by grain differed significantly for both the main and interaction effects. Among the soil conditions the absolute superiority of organic matter enriched soil was well revealed. All other soil conditions were on par. Zn addition in either form contributed to greater uptake. The interaction effect revealed the beneficial effect of Zn addition only in respect of calcareous and submerged soil. In the absence of any added Zn, it is calcareous and submerged soil which suffered most in respect of N nutrition. The mean grain N uptake for normal, calcareous, soil enriched with organic matter and submerged soils were 76, 69, 113 and 78 mg/pot respectively. The mean N uptake for Zn levels were 72, 91 and 89 mg/pot for control, $ZnSO_4$ and chelated Zn respectively.

[TA]BLE XXVIII. CONTENT (%) AND UPTAKE (mg/pot) OF N AND P UNDER DIFFERENT SOIL CONDITIONS AND ZINC SOURCES

Soil [Co]ndition	Zinc Source	NITROGEN							PHOSPHORUS						
		Content			Uptake				Content			Uptake			
		G	S	R	G	S	R	T	G	S	R	G	S	R	T
[No]rmal [so]il	No Zn	1.60	0.61	1.05	77	41	32	150	0.32	0.13	0.10	15	8	3	26
	$ZnSO_4$	1.79	0.67	1.00	80	40	27	147	0.34	0.12	0.12	15	6	3	24
	ZnEDTA	1.71	0.54	0.91	71	49	22	142	0.26	0.15	0.09	11	9	2	22
[Ca]lcareous [so]il	No Zn	1.63	0.63	1.04	54	39	23	116	0.34	0.10	0.12	11	5	3	19
	$ZnSO_4$	1.69	0.69	1.15	80	41	26	147	0.37	0.09	0.14	17	5	3	25
	ZnEDTA	1.61	0.89	1.10	73	49	27	149	0.24	0.14	0.10	11	9	3	23
[So]il + [or]ganic [ma]tter	No Zn	1.75	1.05	1.45	104	97	49	250	0.38	0.14	0.15	23	11	5	39
	$ZnSO_4$	1.79	1.22	1.25	116	91	49	256	0.37	0.16	0.14	27	13	6	46
	ZnEDTA	1.73	1.07	1.29	120	87	46	253	0.33	0.20	0.14	25	16	5	46
[Su]bmerged [so]il	No Zn	1.51	1.07	1.01	54	78	20	152	0.39	0.21	0.13	14	13	3	30
	$ZnSO_4$	1.69	1.12	0.99	84	69	23	180	0.39	0.17	0.14	20	11	3	34
	ZnEDTA	1.79	1.24	0.91	91	91	26	208	0.44	0.18	0.12	23	15	3	41
[C.]D.(Soil)	-	N.S.	0.28	0.21	13	49	8	23	N.S.	0.05	N.S.	2	3	2	5
[C.]D.(Zinc)	-	0.14	N.S.	N.S.	12	N.S.	N.S.	20	N.S.	N.S.	N.S.	N.S.	2	N.S.	N.S.
[C.]D.(SxZn)	-	N.S.	N.S.	N.S.	23	N.S.	N.S.	41	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Soil conditions significantly influenced straw N concentration. Submerged soil and organic matter enriched soil registered much greater N concentration than the other two soil conditions. The mean N concentration values for the former two soil conditions were 1.14 and 1.11 per cent as against 0.67 and 0.74 per cent for the other two. Zn application tended to increase straw N concentration marginally if not significantly and the effect was more marked in calcareous and submerged soils. The mean N content observed were 0.84 per cent for control, 0.99 per cent for $ZnSO_4$ and 0.93 per cent for ZnEDTA. The above concentration differences combined with straw yield variations accounted for significantly higher straw N uptake by the soil which received organic matter. An uptake value of 92 mg/pot was observed as against 44 to 79 for others. The mean straw N uptake for Zn levels were 63 mg/pot in control, 61 for $ZnSO_4$ and 69 for ZnEDTA and thus straw N uptake was not altered to any marked extent by Zn application.

The content of N in root varied from 0.97 to 1.33 per cent. The added organic matter favoured a greater root N concentration. The effect of Zn levels on root N concentration and uptake was non significant. The increased root N concentration coupled with enhanced dry matter yield of roots obviously resulted in roughly doubling of the uptake the other in straw P concentration. The trend observed was submerged soil > organic matter added soil > normal soil > calcareous soil. Zn fertilisation produced no differential concentration of P in straw. The mean values were 0.35 and 0.31 per cent for Zn added treatments as against 0.35 per cent in control. The uptake of the element differed due to both the main factors. Soil enriched with organic matter and submerged soil with mean uptake values 13.4 and 12.8 mg/pot registered higher uptake than normal and calcareous soil which stood on par among themselves with mean uptake values of 7.7 and 6.4 mg/pot. Application of ZnEDTA showed greater uptake value of 12.4 mg/pot over $ZnSO_4$ and control which remained on par with uptake values of 8.8 and 9.0 mg/pot.

The concentration of P in the root ranged from 0.09 to 0.15 per cent and was found to be not influenced by the treatments studied. The differential dry matter yield contributed to significant differences in uptake. Enrichment of the soil with organic matter showed an uptake of 5.4 mg/pot as against 2.7 to 3.0 mg/pot in respect of other soil conditions. The P uptake by root was not significantly enhanced by Zn treatment.

The mean total P uptake varied from 22.4 mg to 42.6 mg/pot. The normal and calcareous soil recorded significantly lower uptake as compared to submerged soil and organic matter enriched soil. Zn application in either form had no significant effect on total P uptake.

c. Potassium (Table XXIX)

While the concentration of K in the grain was not influenced by treatment effects, the dry matter yield variations accounted for the significant differences in uptake. Among soil conditions, soil enriched with organic matter showed an uptake of 49 mg/pot as against 27 to 31 mg/pot observed in others. Application of Zn in either form increased the uptake and this was more pronounced in ZnEDTA. The mean uptake values were 37, 46 and 52 mg/pot respectively for no Zn, $ZnSO_4$ and ZnEDTA treatment.

The concentration of K in straw differed significantly due to both soil factor and Zn application. Enrichment of the soil with organic matter caused a pronounced increase in straw K concentration, while calcareous soil significantly decreased it as compared to other two soil conditions. The mean straw K concentration was 0.82, 0.69, 1.24 and 0.86 for normal, calcareous, soil enriched with organic matter and submerged soil respectively. Application of ZnEDTA favoured a higher K content than $ZnSO_4$ and control. The mean K concentration values were 0.96, 0.88 and 0.86 per cent respectively in the order mentioned. The K uptake by straw differed significantly and the trend of concentration was repeated in uptake as well. The mean P uptake worked out to 101.8 mg/pot for soil treated with organic matter, 52.7 mg for normal soil, 41.o mg for calcareous soil and 60.1 mg for submerged soil.

TABLE XXIX. CONTENT (%) AND UPTAKE (mg/pot) OF K AND Ca UNDER DIFFERENT SOIL CONDITIONS AND Zn FERTILISERS

Soil condition	Zinc source	POTASSIUM							CALCIUM						
		Concentration			Uptake				Concentration			Uptake			
		G	S	R	G	S	R	T	G	S	R	G	S	R	T
Normal soil	No Zn	0.68	0.74	0.65	33	48	18	99	0.50	0.51	1.32	25	35	37	97
	$ZnSO_4$	0.58	0.79	0.57	23	48	15	86	0.54	0.56	1.45	24	33	38	95
	ZnEDTA	0.68	0.93	0.71	28	63	18	109	0.39	0.57	1.35	16	38	33	87
Calcareous soil	No Zn	0.68	0.66	0.46	23	34	10	67	0.59	0.49	1.63	18	25	36	79
	$ZnSO_4$	0.63	0.66	0.49	29	38	11	78	0.54	0.81	1.70	25	47	38	110
	ZnEDTA	0.63	0.76	0.52	29	51	13	93	0.45	0.68	1.56	21	45	38	104
Soil + organic matter	No Zn	0.57	1.20	0.75	34	101	26	161	0.44	0.54	1.48	26	46	50	122
	$ZnSO_4$	0.82	1.24	0.62	52	98	24	174	0.41	0.72	1.55	26	57	59	142
	ZnEDTA	0.88	1.27	0.66	62	106	24	192	0.45	0.72	1.44	31	59	52	142
Submerged soil	No Zn	0.60	0.85	0.73	21	53	15	89	0.48	0.59	1.37	17	36	27	80
	$ZnSO_4$	0.65	0.81	0.67	34	50	16	100	0.55	0.67	1.44	27	42	34	103
	ZnEDTA	0.73	0.91	0.70	37	76	19	132	0.49	0.61	1.36	27	52	38	117
C.D.(Soil)	-	N.S.	0.09	0.08	5	10	5	44	N.S.	0.08	N.S.	4	8	5	15
C.D.(Zinc)	-	N.S.	0.08	N.S.	5	9	N.S.	N.S.	N.S.	0.07	N.S.	4	7	4	13
C.D.(SxZn)	-	N.S.	N.S.	N.S.	9	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

While ZnEDTA treatment showed an uptake of 74.2 mg/pot the other two Zn levels recorded an uptake of 58.5 and 59.0 mg/pot.

The significantly less root K concentration observed may be attributed to the calcareous nature of the soil. The root K uptake was highest again in organic matter enriched soil. The addition or otherwise of Zn made no appreciable difference in root K concentration which ranged from 0.59 to 0.63 per cent.

The mean total K uptake varied from 79 in calcareous soil to 176 mg/pot in soil enriched with organic matter. The normal and submerged soils recorded uptake of 108 and 97 mg/pot and were on par. The differences in uptake due to the presence and absence of Zn was non significant. ZnEDTA showed an uptake of 132 mg/pot as compared to 109 mg/pot in $ZnSO_4$ and 104 mg/pot in control.

d. Calcium: (Table XXIX)

The grain Ca content varied from 0.54 to 0.75 per cent and treatment differences were non-significant. The uptake, however, differed significantly on account of soil conditions as well as Zn fertilisation. Soil treated with organic matter recorded an uptake of 28 mg/pot as against normal calcareous and submerged soils recording 22, 21 and 23 mg/pot. Zn application did not influence grain Ca uptake.

Straw Ca content ranged from 0.55 to 0.66 per cent. Calcareous soil and soil enriched with organic matter tended to cause greater straw Ca concentration. Zn addition did not influence the straw Ca content. The mean Ca uptake was observed to be 56 mg/pot in soil enriched with organic matter as against 36 to 43 mg/pot observed in others. While control registered an uptake of 36 mg/pot Zn added treatments showed uptake values of 45 and 48 mg/pot.

Roots showed Ca concentration values ranging from 1.32 to 1.70 per cent and different treatments imposed produced no variation. The dry matter yield variation caused an enhanced Ca uptake in organic matter enriched soil and Zn applied treatments.

The mean total Ca uptake for the normal, calcareous, organic matter enriched and submerged soil conditions worked to 135, 100, 98 and 93 mg/pot respectively. In the absence of Zn addition the mean uptake was observed to be 93 mg/pot as compared to both forms of Zn registering an uptake of 113 mg/pot.

e. <u>Magnesium</u> (Table XXX)

The mean grain Mg concentration ranged from 0.17 to 0.25 per cent. Neither the soil conditions nor Zn levels had any significant effect upon Mg concentration of grain. Differential dry matter yield due to treatments, however,

XXI. CONTENT AND UPTAKE (mg/pot) OF Mg AND Fe UNDER DIFFERENT SOIL CONDITIONS AND ZINC SOURCES

l tion	Zinc sources	MAGNESIUM							IRON						
		Content(%)			Uptake				Content (ppm)			Uptake			
		G	S	R	G	S	R	T	G	S	R	G	S	R	T
l	No Zn	0.19	0.42	0.78	9.67	26.33	21.67	57.67	142	673	1225	0.69	4.41	3.39	8.49
	$ZnSO_4$	0.21	0.39	0.95	9.33	32.00	25.33	66.66	108	566	999	0.49	3.42	2.63	6.54
	ZnEDTA	0.25	0.51	1.00	10.33	36.33	24.67	71.33	128	631	1112	0.53	4.27	2.75	7.55
reous	No Zn	0.17	0.40	0.73	5.67	20.67	16.33	42.67	103	757	1060	0.35	3.92	2.38	6.65
	$ZnSO_4$	0.17	0.40	0.67	8.00	33.33	14.67	56.00	125	569	905	0.59	3.37	2.01	5.97
	ZnEDTA	0.21	0.41	0.85	7.67	28.00	20.67	56.34	100	593	971	0.46	4.04	2.37	6.87
+	No Zn	0.18	0.42	1.09	10.67	47.33	36.33	94.33	170	746	1826	1.02	6.30	6.13	13.45
lic	$ZnSO_4$	0.23	0.58	1.33	14.67	45.67	50.33	110.67	122	713	1404	0.77	5.63	5.31	11.71
r	ZnEDTA	0.22	0.53	1.01	14.67	42.33	36.67	93.67	180	523	1289	1.24	4.20	4.71	10.15
rged	No Zn	0.19	0.41	0.90	7.00	25.33	18.33	50.66	172	783	1899	0.62	4.87	3.83	9.32
	$ZnSO_4$	0.25	0.38	0.99	12.67	31.67	23.00	67.34	145	637	1477	0.74	3.99	3.42	8.15
	ZnEDTA	0.23	0.52	1.06	11.33	43.33	29.67	84.33	197	499	1163	1.00	4.18	3.26	8.44
(Soil)	-	N.S.	0.11	0.31	2.30	7.80	4.70	9.60	42	N.S.	138	0.24	0.96	0.82	1.37
(Zinc)	-	0.04	N.S.	N.S.	1.90	6.70	4.00	8.40	N.S.	93	120	N.S.	N.S.	0.70	1.24
(SxZn)	-	N.S.	N.S.	N.S.	N.S.	N.S.	8.20	16.80	N.S.	N.S.	240	N.S.	N.S.	N.S.	N.S.

brought about differences in uptake values. Soil enriched with organic matter showed an uptake of 13.3 mg/pot which was significantly higher than others. Normal and submerged soil conditions were on par and recorded uptake values of 9.7 and 10.3 mg/pot. Calcareous soil recorded the least grain uptake of 7.1 mg/pot. The mean grain Mg uptake of 8.3 mg/pot in control increased to 11.0 mg/per pot in Zn treatments.

Straw Mg content was found to be significantly high (0.55 per cent) in the case of soil treated with organic matter. Calcareous soil recorded the lowest value of 0.40 per cent. Normal and submerged soil conditions showed Mg concentration of 0.49 and 0.48 per cent. The effect of Zn levels was non significant. The mean values were 0.40 per cent for control and 0.50 per cent for Zn applied treatments.

The mean root Mg concentration ranged from 0.67 to 1.33 per cent. Soil enriched with organic matter caused a higher root Mg concentration. Added Zn fertilisers had not appreciably altered the root Mg content. The uptake of the element was obviously more in the soil enriched with organic matter and least in calcareous soil. The uptake of the element also increased due to added Zn fertilisers. However, this effect of Zn was found to be confined to submerged soil only.

The main as well as interaction effect indicated significance for the total Mg uptake. The soil enriched with organic matter with mean uptake value of 99.8 mg/pot among soil factors and ZnEDTA and $ZnSO_4$ with mean uptake values of 76.6 and 74.3 mg/pot among Zn levels were observed to show significantly greater Mg uptake than the others. The effect of Zn, however, was confined to submerged soil only.

f. <u>Iron</u>: (Table XXX)

The concentration of Fe in grain differed significantly due to differences in soil conditions. Submerged soil with a mean value of 171 ppm was on par with organic matter enriched having a mean value of 157 ppm. Both these treatments showed substantial enhanced grain Fe concentration over normal soil and calcareous soil which registered mean values of 126 and 109 ppm respectively. $ZnSO_4$ application tended to decrease the Fe content of grain slightly. The submerged soil and organic matter enriched soil registered almost double the uptake of Fe by grain. The mean uptake observed were 7.1 and 9.1 mg/pot for the former two and 5.1 and 4.1 mg/pot for the latter. Grain Fe uptake was not influenced by Zn levels.

While soil conditions produced no significant variation, Zn fertilisation in both forms caused a significant decrease in straw Fe content. The mean concentration for the normal, calcareous, organic matter enriched and submerged soils were 624, 639, 661 and 640 ppm. The mean concentration for $ZnSO_4$

and ZnEDTA treatments worked out to 621 and 562 ppm as compared to 740 ppm in control. Regarding straw Fe uptake, soil enriched with organic matter was found to cause an increased straw Fe uptake of 5.4 mg/pot as compared to 3.8 to 4.3 mg/pot in others. Zn application which showed concentration differences failed to reflect in uptake differences. The mean uptake values ranged within 4.10 to 4.87 mg/pot.

The soil enriched with organic matter caused mean root Fe uptake value of 5.4 mg/pot which was significantly higher than normal and submerged soil with mean uptake values of 2.92 and 3.50 mg/pot. Calcareous soil was associated with least root Fe uptake value of 2.25 mg/pot. Added Zn fertilisers depressed the root Fe uptake.

The total Fe uptake was highest in soil enriched with organic matter (11.56 mg/pot). Calcareous soil recorded the least total Fe uptake (6.61 mg/pot). Normal and submerged soil recorded uptake of 8.64 and 7.56 mg/pot. Zn fertilisation in both forms depressed Fe uptake over control. The mean uptake for control was 9.68 as against 8.0 mg/pot in Zn added treatments. Although the interaction was non-significant it is worthwhile to mention that under all soil conditions the depressing effect of Zn fertilisers on Fe uptake was evident.

g. <u>Manganese</u>: (Table XXXI)

The grain Mn concentration was the highest in submerged soil with a mean value of 114 ppm. This was, however, not

'ABLE XXXI. CONTENT (ppm) AND UPTAKE (mg/pot) OF Mn AND Cu UNDER DIFFERENT SOIL CONDITIONS AND ZINC LEVELS

Soil ndition	Zinc source	MANGANESE							COPPER						
		Content			Uptake				Content			Uptake			
		G	S	R	G	S	R	T	G	S	R	G	S	R	T
rmal il	No Zn	95	140	275	0.47	0.89	0.75	2.11	10	11	41	0.06	0.07	0.11	0.24
	$ZnSO_4$	80	129	196	0.37	0.74	0.50	1.61	19	14	23	0.08	0.08	0.06	0.22
	ZnEDTA	117	203	372	0.49	1.37	0.92	2.78	16	11	29	0.07	0.07	0.07	0.21
lcareous il	No Zn	68	104	381	0.22	0.52	0.82	1.56	8	11	35	0.03	0.05	0.08	0.16
	$ZnSO_4$	82	155	172	0.38	0.93	0.38	1.69	11	12	43	0.05	0.07	0.10	0.22
	ZnEDTA	98	159	120	0.45	1.12	0.33	1.90	16	15	34	0.07	0.10	0.08	0.25
il + ganic tter	No Zn	110	162	602	0.66	1.37	2.02	4.05	15	15	85	0.09	0.13	0.29	0.51
	$ZnSO_4$	85	133	656	0.53	1.07	2.49	4.09	14	10	73	0.09	0.08	0.28	0.45
	ZnEDTA	103	172	670	0.71	1.45	2.05	4.21	7	15	80	0.05	0.13	0.27	0.45
bmerged il	No Zn	117	156	452	0.42	0.97	0.90	2.29	19	11	78	0.07	0.07	0.16	0.30
	$ZnSO_4$	102	179	198	0.53	1.02	0.46	2.01	11	9	73	0.06	0.06	0.17	0.29
	ZnEDTA	125	191	297	0.64	1.60	0.82	3.06	17	12	77	0.08	0.10	0.21	0.39
.D.(Soil)	-	19	24	74	0.09	0.27	0.18	0.51	N.S.	N.S.	6.60	N.S.	0.02	0.51	0.11
.D.(Zinc)	-	16	21	64	0.08	0.23	0.16	0.44	N.S.	N.S.	5.80	N.S.	0.02	N.S.	N.S.
.D.(SxZn)	-	N.S.	N.S.	N.S.	N.S.	N.S.	0.33	N.S.	8	N.S.	12.00	N.S.	0.03	N.S.	0.19

far different from those recorded in normal and organic matter enriched where mean values observed were 97 and 99 ppm. Calcareous soil registered the lowest content of 83 ppm. Application of Zn favoured greater grain Mn concentration and the effect was more pronounced in ZnEDTA. These concentration differences combined with dry matter yield variations resulted in each of the soil condition differing significantly from the other in the matter of uptake. The uptake trend observed was organic matter enriched soil > submerged soil > normal soil > calcareous soil. Chelated Zn caused a greater Mn uptake.

The submerged soil condition registered the highest straw Mn concentration of 176 ppm as against the lowest value or 139 ppm in calcareous soil. A trend similar to that observed for grain was reflected in straw as well. Among Zn levels while chelated form could cause a significant and marked increase in Mn content, the addition of $ZnSO_4$ could not bring about such increase and was on par with control. The latter two treatments showed values of 149 and 140 ppm as against 186 ppm observed for ZnEDTA. The effect of ZnEDTA in positively influencing straw Mn concentration was observed under all soil conditions. In line with concentration, submerged soil and organic matter enriched soil as well as ZnEDTA treated soils were associated with greater uptake values. The mean straw Mn uptake observed were 1.39 and 1.19 mg/pot for the organic matter enriched soil and submerged soil respectively as against 1.01 and 0.86 mg/pot recorded in normal and calcareous soils. ZnEDTA recorded an uptake of 1.38 mg/pot as compared to 0.95 and 0.94 mg/pot for $ZnSO_4$ and control.

Under all soil conditions roots registered comparatively higher Mn concentration than grain and straw. The content of the element in root varied from 120 to 670 ppm. Differences in soil conditions accounted for such wide variation. Soil enriched with organic matter produced root Mn concentration of 642 ppm which was two to threefold higher as compared to other soil conditions. Calcareous soil recorded the lowest concentration of 235 ppm. The root Mn concentration which was found to be 642 ppm in control decreased to 372 ppm in ZnEDTA and 305 ppm in $ZnSO_4$ treatments. The uptake of Mn by root varied considerably and appears to be determined not only by the soil conditions but also by Zn fertilisation. The organic matter enriched soil registered the highest root Mn uptake of 2.30 mg/pot as compared to 0.52 to 0.73 mg/pot in others. The interaction means indicated the depressing effect of $ZnSO_4$ on root Mn uptake in normal, calcareous and submerged soil.

Submerged soil and normal soil recorded mean total uptake of 2.45 and 2.18 mg/pot. Organic matter enriched soil recorded significantly higher uptake of 4.22 mg/pot and calcareous soil significantly lower uptake of 1.73 mg/pot. Among Zn levels

ZnEDTA treatment showed total uptake of 3.07 mg/pot as against 2.50 mg/pot in control and 2.35 mg/pot in $ZnSO_4$.

h. Copper: (Table XXXI)

The grain Cu concentration varied from 7 ppm to 19 ppm. While both main effects showed no statistical significance the interaction was observed to be significant. The absence of Zn did not make much difference in calcareous soil and organic matter enriched soil. In normal soil Cu content increased while in submerged soil it decreased as a result of Zn fertilisation. The uptake of the element was not affected either by soil conditions or Zn application.

The mean straw Cu concentration varied from 9 to 15 ppm and the treatments imposed had no differential influence. The uptake, however, varied markedly. There was no effect on Cu uptake due to Zn fertilisation in normal soil. The use of chelated Zn enhanced Cu uptake in calcareous and submerged soil. Combined application of organic matter and Zn fertiliser tended to decrease the Cu uptake and this was particularly so in $ZnSO_4$ treatment.

The root Cu concentration ranged from 31 to 80 ppm. The content was nearly double in organic matter enriched and submerged soil as compared to normal and calcareous soil. Zn application in either form tended to decrease slightly but not significantly the Cu content of roots. Root Mn uptake was found to be more in organic matter enriched soil and submerged soil. The mean uptake values were 0.28 and 0.18 mg/pot respectively for the above cases and 0.08 and 0.09 mg/pot for the other two soil conditions.

The main as well as interaction effects were found to cause differences in total Cu uptake. Organic matter enriched soil recorded a total uptake of 0.46 mg/pot followed by submerged soil with 0.32 mg/pot. These two soil conditions were significantly superior in the matter of total Cu uptake. The normal soil and calcareous soil recorded uptake of 0.21 mg/pot. While application of $ZnSO_4$ decreased, the chelated form enhanced the total Cu uptake. The interaction revealed the chelated form to enhance the Cu uptake in calcareous and submerged soil, the effect being more pronounced in submerged soil.

i. Zinc:(Table XXXII)

The grain Zn concentration ranged from 7 to 19 ppm. The main as well as interaction effects showed statistical significance. Among the different soil conditions the calcareous soil recorded the least Zn concentration of 11 ppm. Application of Zn in either form registered a significantly higher Zn concentration in grain. The mean Zn content was 10.5 ppm for control as against 15.5 and 15.3 ppm for added Zn fertilisers. In the absence of any added Zn normal and organic matter enriched soil registered higher Zn content than submerged soil and calcareous soil. Addition of $ZnSO_4$

enhanced Zn concentration of grain whatever be the soil condition, the increase being more pronounced in normal and submerged soil. Addition of Zn as ZnEDTA also showed increased Zn concentration, the increase however being more pronounced in calcareous soil. In other words application of either form of Zn could cause a substantive enhanced Zn concentration in grain in submerged soil, while ZnEDTA only brought about such a marked increase in the calcareous soil. The concentration differences were reflected in uptake differences as well. The organic matter enriched soil recorded significantly higher uptake of 0.175 mg/pot as against 0.096 mg/pot in calcareous soil. Normal and submerged soil recorded similar uptake. The Zn addition in either form could enhance the Zn uptake by grain considerably. A study of the interaction revealed that in the absence of added Zn the submerged and calcareous soil conditions registered much less uptake in tune with lower concentration of the element. Higher grain yield and enhanced Zn concentration both accounted for a phenomenal 2 to 4 fold increased Zn uptake in normal and in soil enriched with organic matter. The addition of $ZnSO_4$ proved helpful in increasing the grain Zn uptake in all including calcareous soil condition. Submerged soil even surpassed the normal and organic matter enriched soil. The addition of ZnEDTA brought about increased uptake and uptake increased by twice in calcareous and submerged soil.

TABLE XXXII. CONCENTRATION AND UPTAKE OF ZINC IN DIFFERENT TREATMENTS AT TILLERING AND MATURITY

Soil condition	Zinc source	TILLERING					MATURITY						
		Conc.(ppm)		Uptake (mg/ pot)			Conc. (ppm)			Uptake (mg / pot)			
		Shoot	Root	Shoot	Root	Total	Grain	Straw	Root	Grain	Straw	Root	Total
Normal soil	No Zn	28	75	0.12	0.12	0.24	13	19	52	0.07	0.13	0.14	0.34
	$ZnSO_4$	38	112	0.15	0.18	0.33	19	20	66	0.08	0.12	0.17	0.37
	ZnEDTA	34	75	0.09	0.12	0.21	14	18	41	0.06	0.12	0.10	0.28
Calcareous soil	No Zn	18	53	0.05	0.04	0.09	7	9	68	0.03	0.05	0.15	0.23
	$ZnSO_4$	26	48	0.08	0.04	0.12	12	14	80	0.05	0.08	0.18	0.31
	ZnEDTA	32	27	0.08	0.03	0.11	14	16	54	0.06	0.10	0.13	0.29
Soil + organic matter	No Zn	26	85	0.09	0.09	0.18	12	18	58	0.07	0.14	0.19	0.40
	$ZnSO_4$	34	95	0.12	0.15	0.27	14	16	64	0.09	0.12	0.24	0.45
	ZnEDTA	32	75	0.12	0.12	0.24	15	19	40	0.10	0.16	0.14	0.40
Submerged soil	No Zn	18	110	0.06	0.09	0.15	10	10	63	0.04	0.06	0.13	0.23
	$ZnSO_4$	28	125	0.09	0.15	0.24	17	18	75	0.09	0.11	0.18	0.38
	ZnEDTA	36	100	0.15	0.15	0.30	18	18	47	0.09	0.14	0.13	0.36
C.D.(Soil)	-						2.6	2.0	12.2	0.02	0.05	0.05	0.05
C.D.(Zinc)	-						2.2	1.8	10.5	0.02	N.S.	0.02	0.04
C.D.(SxZn)	-						4.5	3.4	N.S.	N.S.	N.S.	N.S.	0.10

The concentration of Zn in straw averaged to 13 to 19 ppm for soil conditions and 14 to 23 for different Zn levels. Normal and soil enriched with organic matter recorded straw Zn concentration of 19 and 18 ppm respectively. Calcareous soil and submerged soil recorded significantly less straw Zn concentration of 13 and 15 ppm. The straw Zn concentration of 14 ppm in control increased to 23 ppm due to Zn application. The interaction revealed the absence of any appreciable effect in normal and organic matter enriched soil. In calcareous and submerged soil Zn application in either form could enhance straw Zn concentration. In tune with concentration the uptake of the element by straw was more in normal soil and organic matter enriched soil as compared to calcareous and submerged soil. Zn application enhanced the uptake in both forms.

Roots recorded much greater concentration of the element as compared to straw and grain. Within the different soil conditions normal and submerged soils recorded much greater root Zn concentration. The mean Zn concentration observed was 67 ppm for calcareous soil, 62 ppm for submerged soil, 53 ppm for normal soil and 54 ppm for organic matter enriched soil. The mean root Zn concentration was 60 ppm in control as against 71 ppm for $ZnSO_4$ and 45 ppm for ZnEDTA. The uptake of the element was the highest in organic matter enriched soil where an uptake of 0.19 mg/pot was observed as against 0.14

to 0.15 mg/pot in other soil conditions. The root Zn uptake increased from 0.15 mg/pot in control to 0.19 mg/pot in $ZnSO_4$ and to 0.17 mg/pot in ZnEDTA treatment.

There was considerable variation in total Zn uptake. Differential soil condition, Zn application as well as the interaction effect brought about differences in total Zn uptake. The order of uptake showed the trend organic matter enriched soil (0.42 mg/pot) > normal soil (0.33 mg/pot) > submerged soil (0.32 mg/pot) > calcareous soil (0.28 mg/pot). For Zn levels the order of uptake was $ZnSO_4$ (0.38 mg/pot) = ZnEDTA (0.34 mg/pot) > control (0.30 mg/pot). The interaction showed the pronounced effect of added Zn fertilisers in increasing the total Zn uptake in calcareous and submerged soils.

5. <u>Equivalent concentration of nutrients in relation to Zn</u>

The ratio of different nutrients in relation to Zn calculated on equivalent concentration basis (concentration of the nutrient divided by the equivalent weight) in shoot and root at tillering stage as influenced by the soil conditions and Zn fertilisation are presented in Fig. 11 and 12.

In the absence of addition of Zn fertiliser, all soil conditions showed wider N/Zn ratio in shoot and this was more pronounced in calcareous soil and submerged soil. Zn application in either form tended to narrow down this ratio and ZnEDTA in both calcareous soil and submerged soil showed pronounced decrease. In the absence of addition of Zn, P/Zn and K/Zn ratios were comparatively wider for all the soil conditions. The addition of Zn fertiliser narrowed the ratio and the decrease was more pronounced in submerged soil particularly with the use of ZnEDTA. Ca/Zn ratio varied considerably due to differences in soil conditions and Zn fertilisation had no influence in normal soil. However, use of $ZnSO_4$ in organic matter enriched soil and ZnEDTA in submerged soil tended to narrow down the ratio. Mg/Zn ratio was more or less the same in the absence as well as addition of Zn fertiliser in normal soil. The submerged soil showed very wide ratios among the soil conditions and addition of Zn fertiliser favoured the reduction of ratio while in others the effect was not much pronounced. Calcareous soil and submerged soil recorded comparatively higher Fe/Zn ratios as compared to normal soil and organic matter enriched soil. The addition of Zn fertiliser irrespective of the soil conditions tended to narrow down the ratio which was more pronounced in organic matter enriched soil and submerged soil. Highest Mn/Zn ratio was associated with submerged soil and Zn fertilisation could cause narrowing of the ratio and in submerged soil the ratio was reduced to parallel values to other soil conditions. A relatively higher Cu/Zn ratio existed in shoot in the absence of addition of Zn under all soil conditions and in normal soil and calcareous soil the addition of Zn fertiliser caused substantial decrease.

Calcareous soil showed a comparatively high N/Zn, Ca/Zn ratios in root in the absence of addition of any Zn fertiliser. Addition of Zn fertiliser accounted for the widening of the ratios. In spite of this the roots relating to calcareous soil continued to have wider ratios as compared to others and use of ZnEDTA accounted for wider ratio than $ZnSO_4$. The nutrient ratios Mg/Zn, Fe/Zn and Mn/Zn showed identical trends. In all the above cases and in respect of all soil conditions $ZnSO_4$ recorded low ratios and use of ZnEDTA widened the ratios. The effect of Zn fertiliser on Mn/Zn ratio in respect of submerged soil deserves a special mention. The ratio showed a phenominal decrease on application of Zn in either form to the soil. Root Cu/Zn ratio widened in all soil conditions due to the addition of Zn fertiliser.

C. Growth and nutrition of rice in sodic soil as influenced by amendments and Zn fertilisation

The growth and nutrition of rice in a calcareous, non saline sodic soil as influenced by the application of amendments (gypsum at 12 t/ha, farmyard manure at 30 t/ha and green manure at 30 t/ha) each under four levels of Zn (0, 2.5, 5.0 and 7.5 ppm) were studied with rice variety IR 8 as the test crop. The results of soil and plant analysis and the biometric observations recorded during the course of investigation are presented and inferences arising from data are indicated.

1. <u>Soil analysis</u>

The physico chemical characteristics for the initial soil sample employed for the study are given in Table XXII. The salient points are briefly indicated below.

The soil has pH and EC values of 8.95 and 0.42 m mhos/cm respectively. It has clay loam texture containing 44.46 per cent finer fractions. The organic carbon and exchangeable sodium percentage values observed were 0.32 per cent and 24 per cent respectively. The soil also contained 2.04 per cent $CaCO_3$. The status of available N, P and K was 4.2, 3.2 and 14.6 ppm representing respectively low, low and medium grouping as per the conventional grading system adopted by soil testing service in Tamil Nadu. While the soil is were supplied with total micronutrient, the status of available micronutrients was less than critical.

The analysis of the soil samples at planting, tillering and harvest stages are presented in Tables XXXIII to XXXV.

The pH of the soil got reduced to 8.0 in gypsum treatment. There was increase in EC values as compared to the initial soil and the increase was more pronounced in green manure treatment. The organic carbon was several fold

TABLE XXXIII. AVAILABILITY OF PLANT NUTRIENTS IN DIFFERENT TREATMENTS AT PLANTING

Amend-ments	Zinc levels (ppm)	pH	EC	Organic carbon %	Available nutrients (ppm)								
					N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
GYPSUM	0	8.0	0.62	0.3	32	1.86	185	2420	1320	18.2	3.4	2.84	0.92
	2.5	8.3	0.72	0.3	30	2.04	165	2810	1200	19.4	4.2	2.62	1.20
	5.0	8.0	0.80	0.3	40	3.22	180	2840	1324	17.2	7.8	2.84	1.26
	7.5	8.1	0.80	0.3	35	2.42	175	2760	1420	18.8	12.4	1.82	1.40
FYM	0	8.5	0.54	3.2	68	4.96	212	1924	1454	21.4	24.2	4.22	1.98
	2.5	8.3	0.58	3.6	76	5.22	208	1844	1526	22.8	25.0	5.40	2.42
	5.0	8.5	0.66	3.2	70	5.44	215	2120	1642	19.4	24.4	3.82	2.42
	7.5	8.6	0.82	3.0	74	5.42	210	2200	1484	22.6	24.4	4.00	2.86
GM	0	8.8	0.76	3.6	52	4.82	284	1860	1742	25.4	18.6	3.44	1.84
	2.5	8.8	0.90	4.0	68	5.00	302	1710	1640	22.8	19.0	2.82	2.00
	5.0	8.8	0.80	3.2	72	5.12	302	1684	1824	34.0	22.6	3.22	2.62
	7.5	8.4	0.94	3.2	70	4.18	280	1840	1800	25.8	28.6	2.46	2.62

TABLE XXXIV. AVAILABILITY OF PLANT NUTRIENT IN DIFFERENT TREATMENTS AT TILLERING

Amend-ments	Zinc levels (ppm)	pH	EC	Organic carbon %	Available nutrients (ppm)								
					N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
GYPSUM	0	8.3	0.80	0.3	45	3.68	335	2800	1690	24.1	16.2	3.80	1.34
	2.5	8.1	1.00	0.3	37	4.48	355	2700	1440	32.2	25.1	4.00	2.26
	5.0	8.3	1.00	0.2	45	5.32	350	3400	1420	26.3	26.4	4.00	3.34
	7.5	8.0	0.80	0.3	50	3.92	350	3300	1680	38.4	20.2	2.66	2.80
FYM	0	8.3	0.58	1.8	96	3.36	350	2000	1960	42.1	27.3	3.54	1.98
	2.5	8.6	0.74	2.2	102	5.80	395	3200	1860	48.2	31.1	3.80	2.06
	5.0	8.6	0.80	1.4	120	5.80	400	3600	1260	48.3	20.3	3.32	2.44
	7.5	8.7	1.00	1.4	100	4.80	350	3200	1880	46.4	26.4	2.88	2.62
GM	0	8.9	0.94	2.5	110	6.16	310	3600	2860	40.2	51.2	4.44	2.42
	2.5	8.8	0.96	2.8	124	6.16	375	3400	2280	54.1	42.1	3.80	2.16
	5.0	8.7	0.80	2.6	108	5.04	375	2600	2980	46.2	51.2	4.44	4.24
	7.5	8.5	1.20	2.2	120	5.82	335	3400	2420	52.1	38.4	3.80	4.16

TABLE XXXV. AVAILABILITY OF PLANT NUTRIENTS IN DIFFERENT TREATMENTS AT HARVEST

Amend-ments	Zinc levels (ppm)	pH	EC m mhos/cm	Organic carbon %	Available nutrients (ppm)								
					N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
GYPSUM	0	8.1	0.62	0.3	34	1.68	212	2542	1210	10.2	5.4	1.82	0.74
	2.5	8.2	0.84	0.3	28	1.82	210	2520	1040	11.4	6.2	1.82	0.92
	5.0	8.0	1.02	0.3	36	2.32	200	2540	1260	9.6	5.4	2.02	1.02
	7.5	8.0	0.82	0.3	38	2.12	196	2660	1360	10.2	6.8	1.94	1.68
FYM	0	8.4	0.64	0.5	50	1.92	244	1840	1240	11.4	10.2	2.12	1.02
	2.5	8.5	0.74	0.7	64	2.56	264	1620	1180	10.8	9.6	2.74	1.42
	5.0	8.2	0.74	0.5	52	3.00	302	2020	1364	12.4	10.2	2.00	1.30
	7.5	8.2	0.82	0.8	48	2.82	300	1864	1264	9.2	10.4	2.12	1.46
GM	0	8.6	0.84	1.0	44	2.42	242	1980	1412	9.6	7.6	1.92	1.10
	2.5	8.5	1.04	0.9	44	3.02	250	2100	1510	8.8	9.4	1.02	1.24
	5.0	8.5	1.22	0.8	52	2.86	275	2210	1550	10.4	10.2	1.24	2.42
	7.5	8.6	1.36	1.1	62	2.84	290	2100	1580	11.2	10.6	1.86	2.86

higher in organic amendment applied treatments. Available N, P and K also showed considerable improvement as a result of organic amendments. The gypsum treatment recorded enhanced Ca concentration of soil solution. Among the micronutrients there was build up of available Fe in all treatments. The increase of Mn was confined to organic amendment treatments. There was no marked change in Zn availability. Zn application tended to increase Zn availability irrespective of nature of amendments and the increase was more pronounced in the presence of organic amendments.

The change in pH observed at planting was maintained at tillering and harvest and there was further slight increase in EC. The organic carbon progressively decreased with further stages of sampling and at harvest the values showed marked decrease. Yet the application of organic amendments recorded two to threefold higher values as compared to gypsum. The available N, P and K also showed considerable decrease in the post-harvest soil samples. The availability of Fe, Mn, Cu and Zn also decreased. However the available Zn whose availability increased during tillering was more or less maintained and this was especially so with organic amendments particularly green manure. The availability of Zn tended to decrease in gypsum treatment with progress in the stage. In control (no Zn) the available Zn was reduced to the point of deficiency.

2. Dry matter yield, concentration and uptake of nutrients at tillering

The total and individual dry matter yield of shoot and root at tillering phase as well as the concentration and uptake data are presented in Table XXXVI.

Green manure treatment recorded the highest total mean dry matter yield of 13.1 g/pot as compared to 8.9 and 11.9 g/pot respectively for gypsum and farmyard manure treatments. The organic amendments alone as well as in combination with Zn fertilisers recorded higher shoot and root dry matter yield as compared to gypsum. Zn application tended to increase the total dry matter and the increase was more pronounced at 5 ppm level of Zn. However, farmyard manure recorded better shoot and root dry matter yield in the absence of any addition of Zn.

The concentration of N in shoot and root was the highest in gypsum treatment, persumably due to comparatively low dry matter yield. The mean total N uptake varied as 232, 220 and 213 mg/pot respectively for gypsum, farmyard manure and green manure treatments and thus there was no marked difference in total N uptake at tillering stage. The mean total N uptake for progressively increasing Zn levels were 174, 186, 219 and 158 mg/pot and this suggests that 5 ppm Zn level favoured greater N uptake. The effect of amendments and Zn fertiliser on P and K nutrition was

TABLE XXXVI. CONCENTRATION AND UPTAKE OF NUTRIENTS AT TILLERING PHASE

d- ts	Zinc levels (ppm)	NITROGEN Concentration (%)		NITROGEN Uptake (mg/pot)			PHOSPHORUS Concentration (%)		PHOSPHORUS Uptake (mg/pot)			POTASSIUM Concentration (%)		POTASSIUM Uptake (mg/pot)		
		Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	To
	0	1.74	3.50	90	105	195	0.22	0.24	12	6	18	0.66	0.62	34	18	5
	2.5	1.96	3.50	110	117	227	0.25	0.28	14	24	38	0.65	0.78	36	27	6
	5.0	2.46	1.70	172	66	238	0.23	0.26	16	12	28	0.70	0.80	50	30	8
	7.5	1.45	1.82	66	54	120	0.18	0.24	8	6	14	0.66	0.83	44	24	6
	0	1.01	1.12	102	81	183	0.23	0.34	24	24	48	0.66	0.68	66	48	11
	2.5	1.28	1.26	82	69	151	0.23	0.24	14	12	26	0.54	0.53	34	30	6
	5.0	1.84	1.84	162	87	249	0.25	0.22	22	12	34	0.44	0.50	38	24	6
	7.5	1.39	1.40	88	63	151	0.23	0.19	14	9	23	0.61	0.68	38	30	6
	0	1.34	1.68	88	57	145	0.26	0.34	18	12	30	0.65	0.70	42	24	6
	2.5	1.40	1.44	110	69	179	0.27	0.32	22	15	37	0.77	0.80	60	39	9
	5.0	1.23	1.12	126	45	171	0.23	0.28	24	12	36	0.65	0.88	66	33	9
	7.5	1.20	1.44	142	60	202	0.20	0.28	24	12	36	0.46	0.58	54	24	7

(Continued)

TABLE XXXVI (CONTINUED)

end- mts	Zinc levels (ppm)	MANGANESE Concentration (ppm)		MANGANESE Uptake (mg/pot)			COPPER Concentration (ppm)		COPPER Uptake (mg/pot)			ZINC Concentration (ppm)		ZINC Uptake (mg/pot)		
		Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total
	0	192	167	0.98	0.48	1.46	21	60	0.10	0.18	0.28	20	105	0.10	0.33	0.43
	2.5	163	160	0.92	0.54	1.46	27	65	0.16	0.21	0.37	36	125	0.20	0.42	0.62
YPSUM	5.0	161	143	1.12	0.57	1.69	15	43	0.10	0.18	0.38	38	127	0.26	0.51	0.77
	7.5	144	120	0.66	0.36	1.02	27	65	0.12	0.21	0.32	38	142	0.18	0.42	0.60
	0	264	108	2.64	0.72	3.36	17	80	0.18	0.57	0.75	38	87	0.38	0.63	1.01
	2.5	221	105	1.42	0.54	1.96	12	45	0.08	0.24	0.32	42	125	0.26	0.69	0.95
YM	5.0	200	118	1.76	0.54	2.30	18	75	0.16	0.36	0.52	40	125	0.36	0.60	0.96
	7.5	221	120	1.38	0.54	1.92	21	60	0.14	0.27	0.41	38	125	0.24	0.57	0.81
	0	200	180	1.32	0.60	1.92	24	35	0.16	0.12	0.28	26	123	0.18	0.39	0.57
	2.5	181	110	1.42	0.54	1.96	17	50	0.14	0.24	0.38	33	125	0.26	0.60	0.86
M	5.0	129	102	1.32	0.39	1.71	14	65	0.14	0.24	0.38	35	105	0.36	0.42	0.78
	7.5	124	90	1.46	0.39	1.85	17	65	0.20	0.27	0.47	40	118	0.48	0.51	0.99

not appreciable. However, the organic amendments tended to slightly increase the concentration and uptake of both P and K at tillering stage.

Farmyard manure and gypsum treatments recorded higher concentration of Ca. Farmyard manure recorded considerably more root uptake of Ca, which was reflected in the total Ca uptake as well. Zn fertilisation tended to decrease the concentration and uptake of Ca. The organic amendments as well as Zn fertilisation favoured greater accumulation and uptake of Mg as compared to gypsum and the effect was more pronounced in green manure. Zn application showed synergistic effect and concentration and uptake of Mg in shoot and root increased due to addition of Zn fertiliser.

Farmyard manure recorded the highest shoot Fe concentration while green manure recorded highest root Fe concentration. Zn fertilisation decreased Fe concentration of shoot but increased slightly the Fe concentration of root. Organic amendments recorded considerably more uptake of Fe than gypsum. The mean total Mn uptake was not markedly influenced by Zn fertilisation. Farmyard manure recorded highest mean shoot Mn concentration while gypsum recorded highest mean root Mn concentration. Organic amendments and Zn fertilisation tended to decrease the concentration of Cu in shoot. The enhanced dry matter yield in the above however accounted for increased uptake in the above treatments.

The gypsum treatment without addition of Zn fertilisers recorded Zn concentration of 20 and 105 ppm respectively in shoot and root. The concentration of Zn in root and shoot increased appreciably due to addition of even 2.5 ppm level of Zn. However, further increase in Zn levels showed no further appreciable increase. Both the organic amendments, more particularly farmyard manure showed higher concentration of Zn even in the absence of any addition of Zn as compared to gypsum. Zn application tended to increase Zn concentration slightly in these treatments as well. The concentration variations and dry matter yield differences reflected in uptake differences. The mean total Zn uptake for gypsum farm yard manure and green manure treatments worked out to 0.60, 0.93 and 0.80 mg/pot respectively. The addition of even 2.5 ppm of Zn accounted for appreciable increase in total Zn uptake at tillering phase.

3. <u>Dry matter yield at harvest</u>

The total dry matter yield and the individual yield of grain, straw and root observed for each of the twelve treatments are presented in Table XXXVII along with statistical parameters for comparison of means.

a. <u>Total dry matter yield</u>

The mean total dry matter produced differed significantly due to amendments. Green manure treatment caused a significantly higher dry matter yield of 41.0 g/pot representing

TABLE XXXVII. BIOMETRIC DATA, DRY MATTER YIELD AT TILLERING AND HARVEST

Amendment	Zn levels (ppm)	TILLERING					HARVEST			
		Plant height (cm)	Tillering capacity No/hill	Shoot weight (g/pot)	Root weight. (g/pot)	Total dry matter (g/pot)	Grain yield (g/pot)	Straw yield (g/pot)	Root yield (g/pot)	Total dry matter (g/pot)
GYPSUM	0	45	8	5.2	3.0	8.2	5.3	18.0	5.0	28.3
	2.5	49	8	5.6	3.3	8.9	7.2	20.7	5.5	33.4
	5.0	54	9	7.0	3.9	10.9	6.8	21.7	5.3	33.8
	7.5	49	9	4.6	3.0	7.6	6.5	23.6	5.6	35.7
FYM	0	50	10	10.0	4.2	17.2	6.9	26.3	5.0	38.2
	2.5	45	9	6.4	4.2	11.6	8.0	23.8	4.6	36.4
	5.0	53	9	8.8	3.8	12.6	7.8	21.5	4.3	33.6
	7.5	56	8	6.2	4.0	10.2	8.0	24.7	4.5	37.2
GM	0	48	8	6.2	3.3	9.5	6.4	21.2	5.5	33.1
	2.5	52	10	7.8	4.8	12.6	8.2	30.0	6.2	44.4
	5.0	50	10	10.2	3.9	14.1	8.8	28.8	5.2	42.8
	7.5	52	10	11.8	4.2	16.0	9.2	29.3	5.3	43.8
						CD. (Amend)	1.1	4.5	0.9	5.3
						CD. (Zinc)	1.5	4.9	N.S.	N.S.
						CD. (Amend x Zn)	N.S.	N.S.	N.S.	N.S.

24.6 per cent increase over gypsum and 13.2 per cent increase over farmyard manure. Zn fertilisation increased slightly but not significantly the total dry matter yield. The mean total dry matter yield for the increasing order of Zn levels were 32.9, 38.0, 36.6 and 39.0 g/pot respectively.

b. Grain yield

The mean grain yield differed significantly due to amendments as well as Zn levels. Green manure and farmyard manure with the mean grain yield of 8.2 and 7.7 g/pot were on par and represented a significant 26 per cent and 18 per cent increase respectively over gypsum. The grain yield increased significantly from 6.2 in control (no Zn) to 7.8 and 7.9 g/pot in Zn applied treatments all of which were on par.

c. Straw yield

The mean straw yield varied from 18.2 to 30.0 g/pot. The green manure treatment recorded a mean yield of 27.3 g/pot representing 14.2 per cent increase over farmyard manure and 29.4 per cent increase over gypsum. Farmyard manure also showed 13.2 per cent increased yield over gypsum but yet remained on par with it. The straw yield increased from 21.7 g/pot in control (no Zn) to 24.0 to 25.9 g/pot due to added Zn fertilisers representing 10.6 to 19.3 per cent increase.

d. Root dry matter yield

The mean dry matter yield of roots varied from 4.3 to 6.2 g/pot. A significant improvement of root dry matter yield was observed due to green manure and gypsum treatments as compared to farmyard manure.

4. Concentration and uptake of nutrients at harvest

The concentration and nutrient uptake individually by grain, straw and root and the computed total uptake as influenced by different treatments are summarised below.

a. Nitrogen (Table XXXVIII)

The grain N content varied from 1.25 to 1.63 per cent due to amendments and the difference was not significant. Addition of Zn fertilisers showed a significant positive effect. The mean N content was 1.28 per cent in control (no Zn) as against 1.46 per cent due to added Zn. While the use of different amendments caused no significant variation in N uptake it is Zn fertilisation again which accounted for variation in grain N uptake. Application of even 2.5 ppm of Zn could bring about substantial improvement in grain N uptake. Beyond this level, however, there was no further improvement.

Amendments alone and in combination with Zn brought about significant variation in straw N concentration. Farmyard manure and green manure caused greater N concentration than gypsum. The mean N concentration values observed were 0.98, 0.92 and 0.81 per cent respectively for farmyard manure, green manure and gypsum. From the interaction means the depressing effect of high levels of Zn when combined with green manure was brought out. While Zn fertilisation produced no marked variation in straw N uptake the different amendments employed caused significant variation. Organic amendments caused phenomenal enhanced uptake. The mean uptake values observed were 234 mg/pot for farmyard manure, 245 for green manure and 169 mg/pot for gypsum.

In respect of root N concentration neither the amendments nor Zn levels brought about any significant variation. The interaction effect however existed. Under conditions of added gypsum and farmyard manure, Zn application tended to increase root N concentration, while green manure plus Zn combinations tended to decrease. The uptake data revealed that gypsum and green manure could cause greater accumulation of N in root as compared to farmyard manure. The former two showed mean root N uptake values of 41.8 and 33.5 mg/pot as against 33.5 in the case of farmyard manure.

The total N uptake varied from 240 to 430 mg/pot. Combination of Zn with any amendment enhanced N uptake. Green manure plus 2.5 ppm Zn combination registered the maximum uptake.

ABLE XXXVIII. CONTENT AND UPTAKE OF N AND P BY RICE UNDER THE INFLUENCE OF DIFFERENT AMENDMENTS

end-nts	Zinc levels (ppm)	NITROGEN							PHOSPHORUS						
		Content (%)			Uptake (mg/pot)				Content (%)			Uptake (mg/pot)			
		G	S	R	G	S	R	T	G	S	R	G	S	R	T
	0	1.25	0.76	0.73	66	137	37	240	0.42	0.14	0.14	22	25	7	54
	2.5	1.48	0.81	0.69	106	166	39	311	0.38	0.18	0.15	28	39	9	76
	5.0	1.62	0.94	0.97	110	202	52	364	0.42	0.19	0.19	29	40	10	79
	7.5	1.63	0.73	0.74	107	173	42	322	0.21	0.17	0.15	14	40	8	62
	0	1.29	0.97	0.66	89	253	33	375	0.40	0.14	0.15	28	37	8	73
	2.5	1.43	0.99	0.92	115	233	41	389	0.42	0.16	0.12	33	37	5	75
	5.0	1.35	0.95	0.65	105	205	27	335	0.48	0.22	0.21	38	47	9	94
	7.5	1.48	1.02	0.69	118	250	32	400	0.43	0.19	0.16	35	48	7	90
	0	1.31	1.16	0.78	84	246	40	370	0.39	0.13	0.13	25	27	7	59
	2.5	1.46	0.92	0.61	117	275	38	430	0.36	0.13	0.14	29	38	8	75
	5.0	1.43	0.79	0.68	125	231	34	390	0.30	0.11	0.16	27	31	8	66
	7.5	1.26	0.79	0.71	115	232	38	385	0.26	0.12	0.14	24	34	7	65
D. mendment)	-	N.S.	0.09	N.S.	N.S.	34	6	32	0.08	0.05	N.S.	4.4	N.S.	N.S.	15
D.(Zinc)	-	0.15	N.S.	N.S.	15	N.S.	N.S.	37	N.S.	N.S.	0.02	5.2	N.S.	1.3	N.S.
D. m. x Zn)	-	N.S.	0.18	0.20	N.S.	N.S.	N.S.	64	0.16	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

b. Phosphorus (Table XXXVIII)

The amendments caused significant difference in grain P concentration. Farmyard manure recorded a grain P content of 0.44 per cent as against 0.33 and 0.36 per cent for green manure and gypsum respectively. The interaction effect which also indicated significance revealed the depressing effect of high Zn level on grain P concentration, the effect being offset in the presence of farmyard manure. The uptake of P by grain differed significantly due to added amendments and Zn fertilisation. The uptake also was the highest in farmyard manure. While lower Zn levels enhanced, higher Zn levels depressed P uptake by grain.

The straw P content differed significantly due to differences in amendments. Farmyard manure favoured greater straw P concentration than others. Zn alone or in combination with amendments produced no marked difference in straw P concentration. Both the main as well as interaction effect failed to have any significant impact on straw P uptake. The mean uptake values for amendments were 36, 42 and 32 mg/pot and for Zn levels 27 to 30 mg/pot.

The mean P content in root varied from 0.12 to 0.21 per cent and the uptake ranged from 5.3 to 10.1 mg/pot. While amendments produced no significant difference in content and uptake, Zn at 5 ppm was observed to register the highest concentration and uptake of P as compared to other levels of Zn.

The total P uptake differed significantly due to amendments. The use of farmyard manure caused an uptake of 82 mg/pot and this was significantly more than 68 and 66 mg/pot observed in gypsum and green manure respectively. The application of Zn up to 7.5 ppm employed brought about no appreciable variation in total P uptake. It may be mentioned that much of the absorbed P was immobilised in root due to increasing Zn level.

c. <u>Potassium</u> (Table XXXIX)

The content of K in grain ranged from 0.38 to 0.47 per cent and was thus not markedly influenced by treatment effects. The uptake of the element, however, differed significantly due to amendments. Organic amendments favoured greater uptake. The mean uptake values were 28, 33 and 34 mg/pot.

The straw K content ranged from 0.37 to 0.49 per cent and application of gypsum tended to enhance straw K concentration. The straw K uptake was not influenced by any of the treatments imposed.

The different amendments employed brought about significant variation in root K concentration and uptake. The application of green manure caused greater concentration and uptake.

The total K uptake ranged from 121 to 167 mg/pot. Organic amendments caused a significantly higher uptake than gypsum. While main effect due to Zn was absent, interaction effect was significant. The means indicated the addition of Zn to decrease total K uptake when combined with gypsum and farmyard manure and increased the same when combined with green manure.

d. <u>Calcium</u> (Table XXXIX)

The concentration of Ca in grain varied from 0.36 to 0.57 per cent and there was no significant difference among treatments. The uptake, however, varied significantly owing to differential dry matter yield. Organic amendments recorded more uptake than gypsum. The significant interaction effect showed that Zn application increased the Ca content when combined with gypsum. All Zn levels were on par in respect of other amendments.

The differences in amendments and Zn levels alone and in combination with amendments caused significant variation in both concentration and uptake of Ca by straw. The green manure and gypsum treatments recorded higher Ca values of 0.74 per cent and 0.66 per cent over farmyard with the mean value of 0.58 per cent. The green manure treatment recorded more uptake i.e. 198 mg/pot as compared to 135 and 136 mg/pot. Although farmyard manure recorded less concentration than gypsum the comparatively enhanced dry matter yield compensated the uptake. Zn application produced no variation in Ca concentration and the mean values observed were 0.61, 0.68, 0.66 and 0.68 mg/pot respectively for increasing Zn levels. Here again the increased dry matter yield resulted in enhanced uptake which increased from 121 in control to 158, 170 and 178 mg/pot respectively for progressively increasing Zn.

The root contained greater concentration of Ca than grain and straw. The means ranged from 1.7 to 2.5 per cent and the differences were non significant. However, the uptake of Ca by root was significantly more in green manure and gypsum treatments. The mean uptake values recorded for gypsum, farmyard manure and green manure were 115,94 and 122 mg/pot respectively.

The total Ca uptake ranged from 215 to 380 mg/pot. Application of green manure resulted in the highest total mean Ca uptake of 356 mg/pot as compared to gypsum and farmyard manure which had mean Ca uptake values 281 and 266 mg/pot. The mean total Ca uptake of 257 mg/pot significantly increased to 322 and 328 mg/pot in 5 and 7.5 ppm Zn treatments.

e. Magnesium (Table XL)

The grain Mg concentration ranged from 0.18 to 0.30 per cent and neither the amendments nor the Zn levels brought about any significant variation in the grain Mg content.

BLE XL. CONTENT AND UPTAKE OF Mg AND Fe BY RICE UNDER THE INFLUENCE OF DIFFERENT AMENDMENTS

Zinc levels (ppm)	Mg							Fe						
	Content (%)			Uptake (mg/pot)				Content (ppm)			Uptake (mg/pot)			
	G	S	R	G	S	R	T	G	S	R	G	S	R	T
0	0.18	0.47	0.83	10	86	42	138	138	453	1252	0.74	8.05	6.29	15.06
2.5	0.28	0.44	0.97	20	92	54	166	161	600	1032	1.17	12.73	5.71	19.61
5.0	0.30	0.43	0.63	21	92	34	147	137	359	1000	0.92	7.90	5.29	14.11
7.5	0.27	0.41	0.50	16	98	28	142	134	347	935	0.88	8.43	5.21	14.52
0	0.26	0.41	0.90	18	108	44	170	179	730	1182	1.22	19.05	5.84	26.09
2.5	0.23	0.49	0.67	17	111	30	158	173	473	730	1.37	10.77	3.29	15.43
5.0	0.27	0.41	0.50	25	88	22	135	149	573	965	1.18	12.17	4.15	17.50
7.5	0.28	0.41	0.50	19	108	22	149	138	580	761	1.11	14.20	3.45	18.76
0	0.24	0.43	0.57	15	90	30	135	159	580	982	1.01	12.37	5.06	18.44
2.5	0.22	0.49	0.73	17	148	45	210	162	647	1228	1.29	18.83	7.78	27.90
5.0	0.23	0.45	0.57	20	128	31	179	149	627	1077	1.31	18.10	5.53	24.94
7.5	0.23	0.41	0.67	22	116	36	172	130	451	973	1.19	12.40	5.18	18.77
nt) -	N.S.	N.S.	N.S.	N.S.	19	7	26	N.S.	111	N.S.	0.15	2.77	1.06	3.54
e) -	N.S.	N.S.	N.S.	4	N.S.	8	N.S.	19	N.S.	168	0.17	N.S.	N.S.	N.S.
n) -	N.S.	N.S.	N.S.	N.S.	N.S.	14	N.S.	N.S.	N.S.	N.S.	N.S.	5.54	N.S.	7.30

In the matter of uptake Zn fertilisation favoured greater accumulation of the element. The mean uptake for increasing Zn levels were 14, 18, 22 and 19 mg/pot.

The straw Mg concentration varied within very narrow limits between 0.41 to 0.49 per cent and this variation in amendments and Zn levels failed to bring about any difference. The uptake data showed significant effect for amendments. Green manure and farmyard manure registered greater uptake than gypsum. In a similar way, while concentration remained on par for Zn levels there was increased uptake for increased Zn levels.

The Mg content of root ranged from 0.50 to 0.97 per cent and the differences among treatments were not significant. The uptake, however, varied considerably. Gypsum and green manure treatments brought about greater uptake of Mg. Higher levels of Zn reduced the root Mg uptake. The interaction effect indicated that with the use of farmyard manure as amendment, root Mg uptake decreased due to added Zn.

The total Mg uptake ranged from 135 to 173 mg/pot. Green manure application recorded significantly more Mg uptake over gypsum and remained on par with farmyard manure. The mean uptake values were 174, 153 and 148 mg/pot for green manure, farmyard manure and gypsum respectively. The mean uptake for Zn levels were 148, 178, 152 and 155 mg/pot for increasing levels of Zn, the differences, however, not being significant.

f. <u>Iron</u> (Table XL)

While amendments had no differential influence on grain Fe concentration, higher levels of Zn was observed to decrease the same. The mean Fe concentration values for amendments was observed to be 142, 160 and 150 ppm respectively for gypsum, farmyard manure and green manure. The Fe concentration from 158 ppm in control decreased to 134 ppm at 7.5 ppm Zn level. The uptake of the element differed due to amendments and Zn levels. Both the organic amendments registered greater uptake than gypsum. Fe uptake increased initially but decreased at high Zn levels. This is attributable not only to the dry matter yield differences but also concentration variations. At low Zn levels high Fe concentration and at high Zn levels reduced Fe concentration were primarily responsible for uptake differences.

The use of organic amendments favoured greater straw Fe concentration and uptake as compared to gypsum. The mean Fe concentration was 439 ppm for gypsum as against 589 and 571 ppm for organic amendments. The Zn fertilisation tended to decrease slightly but not significantly the Fe concentration of straw. The interaction effect which also indicated significance revealed that all levels of Zn remained on par under gypsum. Farmyard manure plus Zn combination decreased, while green manure plus Zn combination enhanced Fe uptake by straw.

Zn fertilisation caused significant decrease of root Fe concentration but not uptake. Amendments brought about variation in uptake but not in concentration. Gypsum and green manure favoured higher Fe uptake by root as compared to farmyard manure.

g. Manganese (Table XLI)

The concentration of Mn by grain, straw and root was not markedly influenced by any of the treatment effects. However, the uptake of the element by each of the above revealed significant differences due to differences in treatments. In all cases green manure tended to show higher uptake than the other two amendments. Zn fertilisation showed no appreciable variation in uptake of Mn by straw and root but favoured greater uptake of the element by grain.

The total Mn uptake varied from 32.7 mg/pot to 49.8 mg/pot and the interaction effect alone showed statistical significance. The green manure plus 7.5 ppm Zn combination recorded significantly higher uptake than others.

TABLE XLI. CONTENT AND UPTAKE OF Mn AND Cu BY RICE UNDER THE INFLUENCE OF DIFFERENT AMENDMENTS

nd- nts	Zinc levels (ppm)	MANGANESE							COPPER						
		Content (ppm)			Uptake (mg/pot)				Content (ppm)			Uptake (mg/pot)			
		G	S	R	G	S	R	T	G	S	R	G	S	R	T
PSUM	0	123	102	213	0.65	1.82	1.09	3.56	40	21	50	0.21	0.37	0.25	0.85
	2.5	127	99	142	0.92	2.05	0.79	3.76	19	18	68	0.14	0.36	0.38	0.88
	5.0	125	98	174	0.84	2.11	0.88	3.83	23	15	51	0.15	0.33	0.27	0.75
	7.5	117	116	174	0.77	2.78	0.78	4.33	23	15	38	0.16	0.36	0.21	0.73
M	0	121	115	157	0.82	3.00	0.78	4.60	44	16	58	0.30	0.41	0.29	1.00
	2.5	118	81	151	0.95	1.92	0.69	3.56	26	12	41	0.20	0.29	0.20	0.69
	5.0	123	89	175	0.96	1.93	0.74	3.63	24	11	39	0.18	0.24	0.17	0.59
	7.5	120	92	145	0.96	2.26	0.65	3.87	26	13	34	0.21	0.31	0.15	0.67
	0	125	80	153	0.80	1.67	0.80	3.27	39	11	73	0.25	0.23	0.37	0.85
	2.5	124	94	145	0.95	2.76	1.11	4.82	27	12	54	0.22	0.34	0.34	0.90
	5.0	123	86	189	1.08	2.49	0.98	4.55	29	10	59	0.25	0.29	0.28	0.82
	7.5	122	99	177	1.12	2.92	0.94	4.98	24	8	65	0.22	0.23	0.35	0.80
D. mendment)	-	N.S.	N.S.	N.S.	0.15	N.S.	2.38	1.41	N.S.	2	9	0.04	0.06	0.06	0.75
D.(Zinc)	-	N.S.	N.S.	N.S.	0.18	N.S.	N.S.	N.S.	6	2	11	0.05	N.S.	0.06	0.87
D. m. x Zn)	-	N.S.	N.S.	N.S.	N.S.	1.14	N.S.	N.S.	N.S.	N.S.	18	N.S.	N.S.	N.S	N.S.

h. Copper (Table XLI)

While the amendments brought about very little variation in the Cu concentration of grain, Zn fertilisation caused a pronounced and significant depression. Even the low dose of 2.5 ppm employed brought about decrease in grain Cu concentration and further levels caused no further reduction. The pronounced decrease of Cu uptake may be attributed to the amendments as well as Zn fertilisation. The organic amendments registered greater uptake than gypsum. The decreases of uptake from 0.255 mg/pot in control to 0.186 to 0.196 mg/pot were due to added Zn levels.

Organic amendments and Zn fertilisation decreased the straw Cu concentration, the decrease being more pronounced in green manure and higher levels of Zn employed. The mean straw Cu concentration were 17 ppm for gypsum, 13 and 10 ppm for organic amendments. The concentration of Cu decreased significantly from 16 ppm in control to 12 to 14 ppm in Zn treated cases. The straw Cu uptake was the lowest in green manure treatment. The straw Cu uptake was decreased slightly but not significantly by Zn application.

Amendments, Zn levels and the interaction effect brought about differential copper concentration in root. Green manure application favoured greater root Cu concentration. Increasing Zn levels progressively decreased Cu content of root, the highest level causing a significant reduction over others. Interaction effect revealed that in the absence of any added Zn fertiliser organic amendments tended to show enhanced Cu concentration of roots. In all cases added Zn decreased the concentration, the decrease being more pronounced in farmyard manure and gypsum as compared to green manure.

Total Cu uptake varied from 2.1 to 4.3 mg/pot. The mean Cu uptake for farmyard manure was 2.6 mg/pot as compared to 3.3 in gypsum and 3.9 in green manure treatments. For Zn levels the total Cu uptake from a value of 3.7 and 3.6 mg/pot in no Zn and 2.5 ppm Zn levels got decreased to 2.9 mg/pot in 5 and 7.5 ppm Zn levels.

i. Zinc (Table XLII)

The grain Zn concentration increased slightly but yet significantly due to the use of farmyard manure. The mean concentration values were 22.5 ppm for gypsum and 22.8 ppm for green manure as against 24.8 ppm for farmyard manure. The application of Zn caused an increase in the grain Zn concentration, the effect, however, being confined for gypsum and farmyard manure amendments. The uptake of the element was significantly more due to use of organic amendments. Zn fertilisation also caused a significant enhanced uptake but all the Zn applied treatments were on par.

TABLE XLII. CONTENT AND UPTAKE OF ZINC UNDER THE INFLUENCE OF DIFFERENT AMENDMENTS

Amendments	Zinc levels (ppm)	Content (ppm)			Uptake (mg / pot)			
		G	S	R	G	S	R	T
Gypsum	0	18	17	89	0.10	0.31	0.44	0.85
	2.5	23	20	89	0.17	0.41	0.49	1.07
	5.0	24	24	94	0.16	0.52	0.53	1.21
	7.5	24	29	100	0.16	0.70	0.56	1.42
FYM	0	24	26	82	0.17	0.67	0.41	1.25
	2.5	26	32	96	0.20	0.77	0.45	1.42
	5.0	24	36	73	0.18	0.77	0.32	1.27
	7.5	26	28	87	0.21	0.67	0.41	1.29
GM	0	24	20	94	0.15	0.44	0.49	1.08
	2.5	21	28	85	0.17	0.84	0.53	1.54
	5.0	23	24	91	0.20	0.70	0.47	1.37
	7.5	23	30	97	0.21	0.90	0.52	1.63
C.D.(Amend)	-	2.25	1.08	N.S.	0.03	0.16	0.10	0.28
C.D.(Zinc)	-	N.S.	1.24	N.S.	0.04	0.18	N.S.	0.32
C.D.(AmxZn)	-	4.46	2.16	N.S.	N.S.	N.S.	N.S.	N.S.

The straw Zn content varied from 17 ppm to 36 ppm. While green manure caused a significant improvement of straw Zn concentration, use of farmyard manure showed further significant increase. The mean values observed for the three amendments in the order mentioned were 22, 26 and 31 ppm. The straw concentration of Zn significantly increased from 21 ppm in control to 27 to 29 ppm as a result of Zn fertilisation. The interaction effect also indicated significance. Gypsum combined with high level of Zn brought about significant improvement. Even the low levels of Zn could cause such an effect when combined with organic amendments. The uptake of the element by straw ranged from 0.31 to 0.90 mg/pot. The effect due to amendments and Zn application were significant. Organic amendments showed mean uptake of 0.72 mg/pot as compared to gypsum recording 0.48 mg/pot. The mean uptake value of 0.47 mg/pot increased to 0.67 to 0.76 mg/pot as a result of Zn fertilisation.

The concentration of Zn in the root varied from 73 ppm to 100 ppm. The use of farmyard manure tended to decrease the Zn concentration of root as compared to the other ammendments. The effect due to Zn fertilisation proved to be nonsignificant. The mean values observed were 88, 90, 86 and 90 ppm for the increasing Zn levels. Farmyard manure recorded much less uptake of Zn i.e. 0.40 mg/pot as compared to 0.50 mg/pot in the other two cases. The root uptake of Zn was also not markedly increased due to Zn application.

The total Zn uptake varied from 1.15 to 1.45 mg/pot. Amendments and Zn levels influenced the total Zn uptake significantly. Green manure plus 7.5 ppm Zn recorded the highest uptake of 1.45 mg/pot as compared to 1.09 mg/pot in control.

5. Ratio of nutrients to Zn on equivalent basis

The computed nutrient ratios of various nutrients in relation to Zn calculated on the basis of equivalent concentration, as influenced by the amendments and Zn fertilisation at tillering stage are presented in Fig. 13 and 14.

In the absence of addition of Zn fertiliser organic amendments tended to cause greater depression of most ratios in shoot as compared to gypsum and the effect was more pronounced in farmyard manure treatment. Addition of Zn caused further lowered ratios but the effect was more pronounced in the presence of green manure. The net result was that green manure plus Zn combination favoured comparatively lower ratios. However, Mg/Zn ratio was comparatively wider in organic amendments and combination of Zn particularly with green manure tended to further widen the ratio. Another point of interest is that mere application of organic amendments could cause narrow ratios of N/Zn, K/Zn, Fe/Zn, Mn/Zn Cu/Zn. Zinc fertilisation tended to decrease the ratios in general.

The effect of amendments and Zn fertilisation on the nutrient ratios in respect of root showed that organic amendments favoured narrower ratios in the root as well. Addition of Zn tended to depress the ratios further. Farmyard manure recorded the highest P/Zn ratio in the absence of addition of Zn. But Zn addition for the treatment brought about more marked depression of the ratio. The addition of Zn fertiliser on K nutrition showed that when Zn fertiliser was combined with green manure the K/Zn ratio tended to widen while combination with farmyard manure the ratio tended to narrow down. Zn application also influenced the Ca/Zn ratio. In the absence of addition of Zn fertiliser green manure showed the lowest and the farmyard manure the highest ratios. With progressively increasing Zn levels, the ratio decreased and the decrease was more pronounced with farmyard manure and ultimately at higher levels of Zn they had more or less same ratio. Addition of Zn fertiliser tended to widen Mg/Zn ratio when combined with green manure while the reverse effect was observed when combined with farmyard manure. A similar effect was observed for Fe/Zn ratio also. A notable feature was that both the organic amendments recorded wider Fe/Zn ratio as compared to gypsum. The reverse was however true in respect of Mn/Zn ratio. The addition of Zn fertiliser whatever may be the amendment, lowered the ratio, the decrease being more pronounced in gypsum. Cu/Zn ratio widened in root as a consequence of green manure plus Zn combination.

D. Sources and methods of zinc fertilisation for rice

The growth and nutrition of rice as influenced by different sources and methods of application of Zn with variety Bhavani as test crop were studied. The analytical data of soil samples and plant samples and the biometric data recorded are presented below.

1. <u>Soil analysis</u>

The physico-chemical characteristics of the initial soil and those collected at tillering and harvest are presented in Tables XLIII and XLIV respectively.

The Zn deficient soil (available Zn 0.8 ppm) employed for the first phase was employed. The soil has a pH of 7.8 and EC of 0.8 m mhos/cm. The soil texture being sandy loam, the soil is well supplied with P and K but poor in available N.

The pH of the soil sample at tillering ranged from 6.8 to 7.7 and EC from 0.74 to 1.12 mmhos/cm and the different treatments employed caused no appreciable change in the above values. The status of available NP and K as well as water soluble plus exchangeable Ca and Mg varied within very small limits in different treatments. There was build up Fe in all

TABLE XLIII. AVAILABILITY OF PLANT NUTRIENTS IN DIFFERENT TREATMENTS AT TILLERING

Treatment No.	pH	E.C. (mmhos/cm)	Available nutrients (ppm)								
			N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
1.	7.7	0.74	84	6.3	290	1810	568	20.4	8.4	3.2	0.8
2.	7.1	1.12	92	7.4	325	1010	624	20.2	11.2	4.1	3.2
3.	7.2	1.14	96	9.5	310	1950	686	22.4	14.0	3.8	4.3
4.	7.4	0.86	88	9.2	315	1980	702	24.1	8.8	2.8	2.2
5.	6.8	0.84	68	7.0	360	1960	640	20.0	8.4	2.8	2.8
6.	7.6	0.78	75	7.0	300	1740	740	22.0	7.2	3.1	1.2
7.	7.5	0.70	88	5.3	375	1830	620	24.1	8.4	3.2	1.2
8.	7.4	0.68	90	7.3	295	1730	710	26.8	6.8	3.0	1.2
9.	7.5	0.68	90	7.6	315	1840	645	20.8	7.0	4.6	3.6
10.	7.4	0.78	84	7.7	400	1840	672	20.0	8.6	3.0	1.4
11.	7.5	0.74	82	6.5	320	1880	660	21.2	8.4	3.6	1.0

TABLE XLIV. AVAILABILITY OF PLANT NUTRIENTS IN DIFFERENT TREATMENTS AT HARVEST

Treatment No.	pH	E.C. (m mhos/cm)	Available nutrients (ppm)								
			N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
1.	7.4	0.80	65	4.8	212	1740	602	9.4	4.8	1.8	0.3
2.	7.0	0.94	74	3.4	246	1896	644	7.2	6.4	2.3	2.5
3.	7.1	0.98	65	3.2	218	1846	682	5.4	5.6	2.2	1.7
4.	7.0	0.92	58	6.8	244	1888	686	5.8	3.8	1.6	2.2
5.	7.2	0.82	38	4.8	268	1904	682	8.4	4.8	1.2	2.4
6.	7.2	0.84	52	4.2	208	1712	586	6.4	5.2	2.4	0.9
7.	7.4	0.84	53	5.2	224	1746	590	6.8	4.8	1.8	2.6
8.	7.4	0.74	73	5.4	210	1810	624	8.8	4.2	1.6	1.7
9.	7.4	0.72	66	3.8	200	1710	642	7.4	3.8	2.4	1.9
10.	7.6	0.74	67	4.2	262	1704	664	6.2	6.4	1.8	1.9
11.	7.5	0.80	45	3.8	244	1818	586	7.4	5.8	2.2	0.7

treatments including control. The treatments which received sulphate and chloride forms of Zn tended to show slightly enhanced Mn concentration compared to others. The effect on Zn availability was more conspicuous. While control showed low availability soil application of any form of Zn enhanced the DTPA extractable Zn. There was no such increase in available Zn in other treatments.

In the post harvest soil samples there was no appreciable variation in different treatments and the EC tended towards a common value of 0.7 to 0.9 m mhos/cm. There was decrease in available N, P and K in all treatments. There was no pronounced change in the status of available Ca, Mg, Fe and Mn, the concentration however drastically lowered as compared to tillering phase. There was further fall of available Zn in control. Application of Zn in any form and by any method showed greater Zn availability in the post harvest soil samples and the effect was more pronounced in $ZnSO_4$, Zn $(CH_3COO)_2$ and $Zn_3(PO_4)_2$ treatments.

2. Dry matter yield and nutrition at tillering stage

The shoot and root dry matter yield for the different treatments at tillering stage are presented in Table XLV. The concentration and uptake data are furnished in Table XLVI.

The more vigerous growth of rice as judged from shoot and root dry matter yield in seed soak treatment was evident even at tillering stage. This treatment recorded shoot and root dry matter yield of 4.4 and 1.4 g/pot respectively. The total dry matter yield varied from 2.9 to 5.8 g/pot. The highest shoot dry matter yield was associated with ZnEDTA soaking treatment. Control and $Zn(CH_3COO)_2$ treatment showed very low shoot and root dry matter yield.

The concentration of N in shoot varied from 1.65 to 1.98 per cent and seed soak technique both in ZnEDTA and $ZnSO_4$ favoured comparatively higher concentration of N. The N concentration of the root was however comparatively less. Increased N content combined with enhanced dry matter yield accounted for twofold increase in N uptake as compared to control. As a general rule Zn fertilisation in any form and by any method favoured higher uptake of N. There was no appreciable difference in the concentration of P and K in shoot and root and uptake differences resulted due to dry matter yield variations.

Seed soaking treatment tended to show comparatively less Ca concentration in shoot and root. The uptake of Ca varied markedly. With the exception of $Zn(CH_3COO)_2$ all other treatments recorded more uptake of Ca than control. Zn fertilisation in general favoured greater accumulation of Mg than control. However application of $Zn_3(PO_4)_2$ depressed the Mg concentration, in shoot. The differences in root Mg concentration were not appreciable.

Addition of Zn fertiliser irrespective of the source and method tended to decrease Fe concentration in shoot and increase it in root. The concentration differences combined with dry matter yield variations accounted for differences in total Fe uptake which varied from 2.58 to 5.65 mg/pot. There was no appreciable difference in the concentration of Mn both in root and shoot and uptake differences are attributable to dry matter yield variations. Zinc fertilisation tended to decrease Cu content of root but increase the same in shoot. The uptake varied from 0.08 to 0.20 mg/pot. The Zn content of shoot and root increased due to Zn fertilisation. A comparatively high Zn concentration of straw relating to ZnEDTA soak method is a note worthy feature. However, the concentration of Zn in root in this treatment was comparatively less. The above treatment recorded the highest total Zn uptake.

3. Dry matter yield at harvest

Total dry matter yield as well as individual dry matter yield of grain, straw and root for each of the treatments involved are furnished in Table XLV along with the results of statistical analysis.

a. Total dry matter yield

The total dry matter yield ranged from 19.2 to 29.3 g/pot. Seed soaking in 0.1 per cent ZnEDTA gave the highest total dry matter yield. This treatment, however, was on par

TABLE XLV. DRY MATTER YIELD AS INFLUENCED BY SOURCES AND METHODS OF Zn APPLICATION

Treatment No.	TILLERING			HARVEST			
	Shoot dm yield g/pot	Root dm yield g/pot	Total dm yield g/pot	Grain yield g/pot	Straw yield g/pot	Root dm yield g/pot	Total dm yield g/pot
1	2.0	0.9	2.9	5.97	13.80	2.73	22.50
2	3.1	1.3	4.4	7.40	17.30	3.60	28.30
3	3.7	1.4	5.1	7.43	18.03	3.60	29.06
4	4.0	1.6	5.6	7.43	16.05	4.47	27.95
5	2.0	0.8	2.8	4.05	12.40	1.43	17.88
6	3.8	1.4	5.2	7.00	16.10	3.93	27.05
7	3.6	1.3	4.9	6.77	16.97	3.10	26.84
8	2.6	1.2	3.8	6.53	17.50	2.90	26.93
9	3.2	1.4	4.6	6.77	17.07	3.40	27.24
10	2.8	1.0	3.8	6.40	16.47	3.93	26.80
11	4.4	1.4	5.8	7.73	17.43	4.17	29.33
C.D.				1.00	1.71	0.78	2.19

with soil application of chloride, sulphate and phosphate forms of Zn. The application of $Zn(CH_3COO)_2$ proved deleterious and yield was reduced significantly even when compared to control. Application of ZnEDTA to soil even at as small a dose as 0.5 kg/ha could account for dry matter yield on par with soil application of several sources of Zn at 5 ppm.

b. <u>Grain yield</u>

The grain yield ranged from 4.05 to 7.73 g/pot. All the Zn applied treatments with the exception of $Zn(CH_3COO)_2$ recorded higher yield over control. The percentage of increase ranged from 7.2 to 29.4. Soaking of the seeds in ZnEDTA registered the highest increase of 29.4 per cent. The conventional methods of application of $ZnSO_4$, $ZnCl_2$ and $Zn_3(PO_4)_2$ gave yield on par with ZnEDTA. The application $Zn(CH_3COO)_2$ caused a significant depression and even control recorded significantly higher yield than this treatment.

c. <u>Straw yield</u>

The straw yield varied from 12.4 to 18.0 g/pot. $ZnCl_2$ treatment recorded the highest yield of 18.0 g/pot. Soil application and seed soaking methods employing $ZnSO_4$ and ZnEDTA also recorded straw yield on par with $ZnCl_2$ treatment. The straw yield increase ranged from 16 to 30.4 per cent. The control and $Zn(CH_3COO)_2$ treatments recorded significantly lower straw yield than others.

d. Root dry matter yield

The mean root dry matter yield ranged from 1.4 to 4.5 g/pot. The Zn $(CH_3COO)_2$ treatment recorded the lowest yield of roots. All the other treatments showed better root growth than control. The increase ranged from 7.4 to 55.5 per cent. Control, $Zn(CH_3COO)_2$ and nursery feeding method recorded significantly less root dry matter yield than others. Seed soaking methods employed in the experiment which showed enhanced grain and straw yield also showed root growth on par with soil application of sulphate, chloride and phosphate forms of Zn. Among the two soaking methods the effect was more pronounced for ZnEDTA than for sulphate form.

4. Concentration and uptake of nutrients

The concentration and nutrient uptake individually by grain, straw and root as well as the computed total uptake as influenced by the different sources and methods of application, are presented in Tables XLVI. The statistical parameters for comparison of means are also indicated.

a. Nitrogen (Table XLVII)

The concentration and uptake of N by grain were not influenced to any significant extent by the different treatments. While the mean concentration varied from 1.37 to 1.51 per cent the uptake varied from 79 to 111 mg/pot. The grain uptake of N was the highest in ZnEDTA soak method.

TABLE XLVI. CONCENTRATION AND UPTAKE OF NUTRIENTS AT TILLERING PHASE

Treat-ment No.	NITROGEN					PHOSPHORUS					POTASSIUM				
	Concentra-tion(%)		Uptake (mg / pot)			Concentra-tion (%)		Uptake (mg/pot)			Concentra-tion (%)		Uptake (mg/pot)		
	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total
1.	1.75	1.84	35	16	51	0.31	0.31	6	3	9	1.42	0.45	28	4	32
2.	1.79	1.90	55	25	80	0.23	0.35	7	5	12	1.44	0.77	44	10	54
3.	1.75	2.30	64	32	96	0.27	0.41	10	6	16	1.25	0.75	46	11	57
4.	1.68	2.10	67	34	101	0.32	0.32	13	5	18	1.18	0.66	47	11	58
5.	1.65	2.80	33	22	55	0.24	0.23	5	2	7	1.52	0.70	30	6	36
6.	1.90	1.68	72	24	96	0.26	0.24	10	3	13	1.20	0.74	46	10	56
7.	1.70	1.67	61	22	83	0.28	0.25	10	3	13	1.54	0.70	55	9	64
8.	1.82	2.15	47	26	73	0.28	0.33	7	4	11	1.35	0.77	35	9	44
9.	1.90	2.22	61	31	92	0.31	0.27	10	4	14	1.24	0.75	40	11	51
10.	1.68	2.30	47	23	70	0.20	0.21	6	2	8	1.46	0.86	41	9	50
11.	1.98	1.68	87	24	111	0.30	0.30	13	4	17	1.48	0.63	65	9	74

(Continued)

TABLE XLVI (CONTINUED)

Treatment No.	CALCIUM					MAGNESIUM					IRON				
	Concentration (%)		Uptake (mg/pot)			Concentration (%)		Uptake (mg/pot)			Concentration (%)		Uptake (mg/pot)		
	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total
1.	0.72	2.20	14	19	33	0.24	0.80	5	7	12	348	2090	0.70	1.88	2.58
2.	0.68	2.16	21	28	49	0.30	1.10	9	14	23	273	2330	0.85	3.02	3.87
3.	0.76	2.91	28	41	69	0.32	0.84	12	12	24	247	2050	0.91	2.87	3.78
4.	0.74	2.06	30	33	63	0.20	0.86	8	14	22	268	2400	1.07	3.84	4.91
5.	0.74	1.80	15	14	29	0.33	0.80	7	6	13	342	1240	0.68	0.99	1.67
6.	0.64	2.00	24	28	52	0.32	1.08	12	15	27	323	2620	0.87	3.67	4.54
7.	0.68	2.00	24	26	50	0.26	1.00	9	13	22	210	2650	0.76	3.44	4.20
8.	0.80	1.84	21	22	43	0.38	1.08	10	13	23	380	2965	0.99	3.56	4.55
9.	0.74	2.00	24	28	52	0.30	1.00	10	14	24	309	2850	0.99	3.99	4.98
10.	0.75	1.64	21	16	37	0.32	0.85	9	9	18	340	2800	0.84	2.80	3.64
11.	0.62	1.66	27	23	64	0.32	1.12	14	16	30	286	3140	1.25	4.40	5.65

(Continued)

TABLE XLVI (CONTINUED)

Treatment No.	MANGANESE					COPPER					ZINC				
	Concentration (ppm)		Uptake (mg/pot)			Concentration (ppm)		Uptake (mg/pot)			Concentration (ppm)		Uptake (mg/pot)		
	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total	Shoot	Root	Shoot	Root	Total
1.	224	195	0.45	0.18	0.63	18	80	0.04	0.07	0.11	16	77	0.03	0.07	0.10
2.	186	204	0.58	0.38	0.95	27	72	0.08	0.09	0.17	29	116	0.09	0.15	0.24
3.	158	131	0.58	0.18	0.76	23	82	0.09	0.11	0.20	27	130	0.10	0.18	0.28
4.	186	132	0.74	0.21	0.95	20	64	0.08	0.10	0.18	22	98	0.09	0.16	0.25
5.	182	160	0.36	0.32	0.68	22	45	0.04	0.04	0.08	20	60	0.04	0.05	0.09
6.	264	90	1.00	0.34	1.34	28	55	0.11	0.08	0.19	48	75	0.18	0.11	0.29
7.	212	100	0.76	0.13	0.89	28	63	0.10	0.08	0.18	40	108	0.14	0.14	0.28
8.	196	120	0.51	0.14	0.65	28	54	0.07	0.06	0.13	32	80	0.08	0.09	0.17
9.	172	108	0.55	0.15	0.70	24	67	0.08	0.09	0.17	26	117	0.08	0.16	0.24
10.	200	136	0.56	0.13	0.69	22	66	0.06	0.06	0.12	23	98	0.06	0.09	0.15
11.	214	86	0.94	0.12	1.06	28	53	0.12	0.07	0.19	66	60	0.29	0.08	0.37

The content of N in straw varied considerably from 0.50 to 0.92 per cent. Excepting Zn dust treatment all other treatments caused a significant increase in straw N concentration over control. The increase was more pronounced in $Zn_3(PO_4)_2$, $ZnSO_4$, nursery fed, $ZnSO_4$ soaking and root dip treatments. $Zn(CH_3COO)_2$ treatment also favoured greater N concentration in straw. ZnEDTA soak method also enhanced N content significantly if not as appreciably as the above mentioned treatments. These concentration differences coupled with enhanced dry matter yield values accounted for the significant uptake differences. The straw N uptake varied from 77 to 148 mg/pot. All but Zn dust treatment registered significantly higher N uptake than control.

The N content in root varied from 0.56 to 0.90 per cent. While the root N content showed an increase due to application of chloride, phosphate and acetate forms of Zn, the root dipping method, nursery feeding technique and use of ZnEDTA caused a significant decrease.

The total N uptake ranged from 180 to 294 mg/per pot. Zn dust and $Zn(CH_3COO)_2$ treatments recorded N uptake on par with control. Other treatments showed significant improvement over control and remained on par within themselves.

b. <u>Phosphorus</u> (Table XLVII)

The grain P concentration ranged from 0.18 to 0.24 per cent. The differences among treatments were nonsignificant.

TABLE XLVII. CONCENTRATION (%) AND UPTAKE (mg/pot) OF NPK AT HARVEST

Treat-ment No.	NITROGEN							PHOSPHORUS							POTASSIUM						
	Concentration			Uptake				Concentration			Uptake				Concentration			Uptake			
	G	S	R	G	S	R	T	G	S	R	G	S	R	T	G	S	R	G	S	R	T
1.	1.38	0.55	0.70	82	77	21	180	0.20	0.12	0.09	12	17	2	31	0.65	0.73	0.67	39	101	18	158
2.	1.37	0.84	0.70	101	145	25	271	0.21	0.14	0.12	16	24	4	44	0.65	0.77	0.67	48	134	24	206
3.	1.47	0.73	0.85	108	131	31	270	0.22	0.09	0.10	16	17	4	37	0.67	0.78	0.67	49	141	24	214
4.	1.43	0.92	0.90	106	148	40	294	0.24	0.14	0.14	18	22	6	46	0.71	0.81	0.59	53	129	26	208
5.	1.45	0.84	0.84	79	105	12	196	0.18	0.08	0.09	10	10	2	22	0.71	0.79	0.61	38	97	9	145
6.	1.51	0.84	0.70	104	137	28	269	0.24	0.12	0.10	17	19	4	40	0.67	0.75	0.67	45	121	26	192
7.	1.39	0.84	0.56	92	145	18	255	0.22	0.10	0.10	15	18	3	36	0.69	0.71	0.68	47	126	21	194
8.	1.39	0.87	0.56	91	147	17	255	0.19	0.08	0.10	13	15	3	31	0.67	0.75	0.71	44	138	21	203
9.	1.43	0.67	0.56	98	115	15	228	0.20	0.10	0.12	14	18	4	36	0.65	0.79	0.68	44	134	23	201
10.	1.46	0.50	0.70	95	83	28	204	0.22	0.08	0.12	14	13	5	32	0.67	0.69	0.73	43	118	29	190
11.	1.43	0.70	0.48	111	122	21	254	0.22	0.12	0.08	17	22	3	42	0.71	0.82	0.72	55	143	30	228
S.D.	N.S.	0.11	0.13	N.S.	23	7	41	N.S.	0.05	0.02	3	6	1	6	N.S.	N.S.	N.S.	10	19	5	24

The uptake of the element, however, differed significantly and varied from 10 to 18 mg/pot. $Zn_3(PO_4)_2$, $ZnCl_2$, $ZnSO_4$, treatments and both the Zn soaking methods recorded significantly higher uptake than control.

The concentration of P in straw ranged from 0.08 to 0.14 per cent. $ZnCl_2$, $ZnSO_4$, nursery feeding and Zn dust treatments significantly decreased the P content of straw as compared to the control. Other treatments were on par with the control. The uptake of the element ranged from 10 to 24 mg/pot. $ZnSO_4$, $Zn_3(PO_4)_2$, and the soaking techniques registered greater uptake values than $Zn(CH_3COO)_2$ and Zn dust.

The content of P in the root varied from 0.08 to 0.14 per cent. $Zn_3(PO_4)_2$ treatment showed the highest root P content. The soaking techniques whether it be $ZnSO_4$ or ZnEDTA caused much less root P concentration than $ZnSO_4$ or $Zn_3(PO_4)_2$ applied to soil. The uptake of P ranged from 2 to 6 mg/pot. Addition of Zn, in general, tended to enhance the root uptake of P as compared to the control.

The mean total P uptake worked out to 31 to 46 mg/pot for the different treatments. With the exception of $Zn(CH_3COO)_2$ which showed an uptake of 22 mg/pot all other treatments showed higher total P uptake over the control, the increase being more pronounced in $Zn_3(PO_4)_2$, $ZnSO_4$ and both the soaking treatments employed.

c. Potassium (Table XLVII)

The concentration of K in grain, straw and root was not influenced to any significant extent by the different treatments. However, the uptake varied markedly and significantly on account of dry matter yield variations. The highest total as well as individual uptake was observed in ZnEDTA soak treatment. Control and $Zn(CH_3COO)_2$ treatments recorded low K uptake values.

d. Calcium (Table XLVIII)

The mean Ca content of grain varied from 0.36 to 0.45 per cent and the uptake ranged from 22 to 32 mg/pot. The two characters were not influenced to any significant extent by the treatments imposed. The straw concentration values were also not different to any significant extent and remained within the limits of 0.52 to 0.63 per cent. The uptake of Ca, however, differed significantly.With the exception of $Zn(CH_3COO)_2$ all treatments favoured greater uptake of Ca by straw. The content of Ca in the root varied from 1.05 to 1.53 per cent the differences between treatments not being significant. The uptake of the element by root in different treatments worked out to 19 to 69 mg/pot. The control and $Zn(CH_3COO)_2$ treatments recorded significantly lower uptake of Ca.

The total Ca uptake ranged between 102 to 195 mg/pot. There was increased total Ca uptake in $ZnSO_4$, $ZnCl_2$, $Zn_3(PO_4)_2$ and/Zn dust treatments as compared to the control.

TABLE XLVIII. CONCENTRATION AND UPTAKE (mg/pot) OF Ca, Mg AND Fe AT HARVEST

Treatment No.	CALCIUM							MAGNESIUM							IRON						
	Concentration (%)			Uptake				Concentration (%)			Uptake				Concentration (ppm)			Uptake			
	G	S	R	G	S	R	T	G	S	R	G	S	R	T	G	S	R	G	S	R	T
1.	0.45	0.57	1.18	27	79	41	147	0.15	0.39	0.88	11	40	24	75	89	330	2250	0.52	4.55	0.61	5.68
2.	0.43	0.55	1.21	32	94	56	182	0.17	0.49	0.65	13	85	23	121	73	260	1750	0.54	4.47	0.50	5.51
3.	0.45	0.63	1.05	33	113	49	195	0.18	0.47	0.65	13	84	23	120	59	210	1666	0.44	3.76	0.58	4.78
4.	0.41	0.54	1.53	30	87	69	186	0.18	0.35	0.66	13	57	30	100	106	260	1660	0.84	4.16	0.78	5.78
5.	0.41	0.51	1.32	22	61	19	102	0.18	0.42	0.71	10	53	10	73	82	390	1330	0.56	4.79	0.18	5.53
6.	0.40	0.53	1.35	28	90	53	171	0.18	0.51	0.71	12	82	28	122	54	330	1673	0.37	5.00	0.66	6.03
7.	0.40	0.54	1.43	27	93	42	162	0.17	0.35	0.68	12	59	21	92	41	233	1080	0.28	3.93	0.30	4.51
8.	0.43	0.58	1.35	28	107	39	174	0.21	0.41	0.75	14	72	22	108	74	220	2000	0.37	3.85	0.58	4.80
9.	0.39	0.59	1.31	27	101	45	173	0.18	0.49	0.65	12	84	22	118	71	170	1750	0.49	2.92	0.60	4.01
10.	0.42	0.63	1.43	27	103	56	186	0.21	0.43	0.76	14	70	30	114	93	353	2000	0.60	5.84	0.79	7.22
11.	0.36	0.52	1.34	28	92	55	175	0.20	0.57	0.51	16	99	21	136	102	140	1850	0.79	2.43	0.78	4.01
S.D.	N.S.	N.S.	N.S.	N.S.	27	14	29	N.S.	0.12	0.16	N.S.	22	7	25	28	N.S.	N.S.	0.23	1.53	0.37	1.19

e. <u>Magnesium</u>: (Table XLVIII)

The different treatments imposed produced no marked variation in grain Mg concentration which varied from 0.15 in control to 0.20 per cent in ZnEDTA. This trend was reflected in the uptake as well which varied from 33 in control to 47 mg/pot ZnEDTA. The straw Mg concentration was also found to be higher in the presence than in the absence of Zn. The mean Mg concentration significantly increased in all except $Zn_3(PO_4)_2$, root dip and nursery fed treatments. The increase was considerably high in both the soaking methods. The increased concentration of the element combined with enhanced dry matter yield have contributed to wide and significant variation in Mg uptake. Control recorded the least uptake of 40 mg/pot. This increased to 53 to 99 mg/pot in various treatments. The increase was significant and comparatively high in both the soaking procedures employed. The use of $ZnSO_4$, $ZnCl_2$ and nursery application methods also increased Mg uptake significantly though not as appreciably as soaking techniques.

f. <u>Iron</u> (Table XLVIII)

The concentration of Fe varied from 41 to 106 ppm. The content decreased significantly due to the use of $ZnCl_2$, root dip and $ZnSO_4$ soaking methods. Other treatments were on par with the control. The uptake varied from 0.28 to 0.79 mg/pot. $Zn_3(PO_4)_2$ and ZnEDTA soaking methods recorded greater uptake, while the other treatments remained on par with control. The content of Fe in straw varied from 140 to 390 ppm. With the exception of $Zn(CH_3COO)_2$ and Zn dust treatments all the other treatments tended to depress straw Fe concentration, the effect being more pronounced for ZnEDTA soaking treatment. The uptake of Fe varied from 2.43 to 5.84 mg/pot. Use of ZnEDTA, whether applied to soil or through seed soaking technique decreased straw Fe uptake significantly over the control. Roots of control treatment contained the highest concentration of Fe. Any addition of Zn irrespective of the form and method tended to decrease slightly if not significantly the root Fe concentration. The content varied from 1330 ppm to 2250 ppm. The uptake of the element by root differed significantly. $Zn_3(PO_4)_2$, Zn dust and seed soaking in ZnEDTA showed relatively greater uptake.

There was considerable variation in total Fe uptake. Control recorded an uptake of 5.69 mg/pot. All but ZnEDTA (Soil application as well as seed soaking) treatments were on par with control.

g. Manganese (Table XLIX)

The grain Mn concentration varied from 106 ppm to 158 ppm. Excepting root dip method of Zn application, all others recorded a slight but nonsignificant increase of grain Mn concentration. The uptake of the element varied from 0.70

TABLE XLIX. CONCENTRATION AND UPTAKE OF Mn, Cu AND Zn AT HARVEST

-at- -nt .	MANGANESE							COPPER							ZINC						
	Concentration (ppm)			Uptake (mg/pot)				Concentration (ppm)			Uptake (mg/pot)				Concentration (ppm)			Uptake (mg/pot)			
	G	S	R	G	S	R	T	G	S	R	G	S	R	T	G	S	R	G	S	R	T
.	125	164	171	0.74	2.00	0.47	3.21	6	10	50	0.04	0.14	0.13	0.31	9	9	34	0.05	0.13	0.10	0.28
.	158	194	208	1.17	3.37	0.75	5.29	7	8	28	0.05	0.14	0.10	0.29	16	21	34	0.12	0.36	0.12	0.60
.	140	235	232	1.05	4.24	0.83	6.12	7	8	20	0.06	0.15	0.07	0.28	14	26	38	0.11	0.47	0.14	0.72
.	133	257	255	0.99	4.13	1.14	6.26	6	6	26	0.05	0.10	0.12	0.27	12	15	38	0.09	0.22	0.17	0.48
.	126	199	189	0.69	2.27	0.27	3.23	7	6	30	0.04	0.07	0.04	0.15	13	15	47	0.07	0.19	0.07	0.33
.	149	239	240	1.04	3.87	0.95	5.86	8	8	12	0.05	0.13	0.05	0.23	15	11	38	0.10	0.18	0.15	0.43
.	106	216	166	0.70	3.67	0.53	4.90	9	6	42	0.06	0.10	0.13	0.29	14	16	22	0.09	0.28	0.07	0.44
.	134	206	218	0.87	3.60	0.63	5.10	8	8	30	0.05	0.14	0.09	0.28	13	14	34	0.09	0.23	0.09	0.41
.	155	179	161	1.05	3.04	0.54	4.63	11	8	30	0.07	0.14	0.10	0.31	15	16	31	0.10	0.28	0.11	0.49
.	147	228	233	0.94	3.19	0.91	5.04	7	8	20	0.05	0.13	0.08	0.26	11	11	44	0.07	0.19	0.17	0.43
.	138	148	186	1.07	2.58	0.78	4.43	6	12	12	0.07	0.20	0.05	0.32	17	23	22	0.13	0.39	0.09	0.61
D.	N.S.	48	43	0.28	0.91	0.24	1.12	2.4	2.2	10	N.S.	0.03	0.03	0.05	2.5	4.5	11	0.03	0.09	0.05	0.12

to 1.17 mg/pot. Soil application of $ZnSO_4$, ZnEDTA, $ZnCl_2$ and seed soaking technique employing $ZnSO_4$ and ZnEDTA recorded significantly greater uptake values over the control. Straw Mn concentration ranged from 164 to 257 ppm. $ZnCl_2$, $Zn_3(PO_4)_2$, seed soaking in $ZnSO_4$ and Zn dust treatments showed significantly greater Mn concentration than the control. The uptake of the element by straw varied from 2.00 to 4.24 mg/pot. All Zn applied treatments showed greater uptake. $Zn(CH_3COO)_2$ and ZnEDTA soaking methods showed uptake values on par with the control. The root concentration of Mn varied from 166 to 255 ppm. Soaking of seeds in $ZnSO_4$ and soil application of $Zn_3(PO_4)_2$ favoured greater root Mn concentration. The uptake of the element by root increased in all but $Zn(CH_3COO)_2$ treatment, the effect being more pronounced in $Zn_3(PO_4)_2$.

The total Mn uptake ranged from 3.21 to 6.27 mg/pot. All the treatments recorded more uptake than the control, the increase being more pronounced in $ZnCl_2$ and $Zn_3(PO_4)_2$ treatments. As a general rule the Zn - Mn interaction was observed to be synergistic.

h. Copper: (Table XLIX)

The concentration of Cu varied from 5.7 ppm to 10 ppm in grain. All the treatments recorded greater Cu concentration than control. The increase was pronounced in treatments involving root dipping, nursery feeding and ZnEDTA (Soil application) treatments. The uptake, however, varied within small range of 0.04 to 0.07 mg/pot and was nonsignificant. The effect on straw Cu concentration was just the reverse as observed for grain. The control recorded 10 ppm. All but ZnEDTA soaking more particularly phosphate, acetate and oxide forms of Zn decreased the straw Cu content. The ZnEDTA soaking actually registered increased straw Cu concentration. The uptake of the element by straw also was influenced significantly by treatment effects and ranged from 0.07 to 0.20 mg/pot. $Zn(CH_3COO)_2$ recorded the least uptake. While all others showed uptake of Cu on par with control, it is ZnEDTA which showed significant improvement in straw Cu uptake. The Cu content of roots ranged from 12 to 50 ppm. Zn irrespective of the form tended to decrease root Cu concentration, ZnEDTA treatment recording the least. The Cu uptake by root also differed significantly due to treatments and a pronounced decrease was observed in ZnEDTA and $Zn(CH_3COO)_2$ as compared to the control.

The total Cu uptake varied from 0.15 to 0.32 mg/pot. Zn $(CH_3COO)_2$ recorded the lowest, while ZnEDTA the highest total Cu uptake.

i. Zinc (Table XLIX)

The concentration of Zn in grain varied from 9 to 17 ppm. Application of Zn irrespective of the form and method of application enhanced the Zn concentration of grain. The increase however, was not significant in Zn dust and $Zn_3(PO_4)_2$ treatments as compared to the control. Both the soaking techniques employed, root dip method and soil application of $ZnSO_4$ and $ZnCl_2$ treatments registered marked increases in grain Zn concentration. Zn $(CH_3COO)_2$ although associated with low grain and straw yield could cause a higher Zn concentration in grain. These concentration and dry matter differences resulted in marked and significant uptake differences. Thus ZnEDTA soaking method could register two to threefold enhanced Zn uptake than the control. The uptake of the element by grain ranged from 0.05 to 0.13 mg/pot. The lower dry matter yield compensated for higher concentration in $Zn(CH_3COO)_2$ treatment and it could also register higher uptake as compared to the control.

The straw Zn concentration varied from 9 to 26 ppm. Whatever be the source and whichever be the method, application of Zn caused enhanced straw Zn content. The increase was, however, more marked with the use of $ZnSO_4$, $ZnCl_2$ and ZnEDTA soaking method. The concentration of the element in other treatments also increased slightly and significantly. The uptake of the element obviously varied conspicuously. It varied from 0.13 to 0.47 mg/pot. All the treatments showed enhanced uptake over the control. There was two to threefold increased uptake in $ZnCl_2$, $ZnSO_4$ and ZnEDTA soak methods.

The mean root Zn concentration for the different treatments varied from 22 to 47 ppm. The $Zn(CH_3COO)_2$ treatment recorded the highest root Zn concentration. ZnEDTA soaking method and root dipping in ZnO suspension recorded the least concentration of 22 ppm. $ZnSO_4$, $ZnCl_2$ and other methods tended to increase the root Zn concentration slightly though not significantly. The result of these concentration differences was that while most treatments increased root Zn uptake, it was not true for ZnEDTA soaking method and root dip method. The mean Zn uptake varied from 0.07 to 0.17 mg/pot.

The total uptake of Zn varied from 0.54 to 1.42 mg/pot. Control recorded the least uptake. Soil application of $ZnSO_4$, $ZnCl_2$ and seed soaking in ZnEDTA were associated with more than double the uptake as compared to the control. $Zn(CH_3COO)_2$ treatment showed no significant improvement over the control and much of the absorbed Zn was concentrated in the root.

E. Correlation studies

The soil and plant analytical data collected from second, third and fourth phases of the investigation were utilised for studying the interrelationships among the different parameters by working out the correlation co-efficients. Such of those relationships which showed statistical significance are presented in Table L along with 'r' values and regression equations. The important points arising out of the studies are as follows.

(i) The relative concentration of zinc on equivalent basis showed significant relationships. The nutrient ratios of N/Zn, K/Zn, Ca/Zn, Fe/Zn, Mn/Zn and Cu/Zn in straw at tillering on equivalent basis (concentration of nutrient divided by equivalent weight of respective nutrient prior to working out the ratios) showed significant negative correlation with grain yield. The above ratios were also related to straw yield values. The negative relationship in both the cases suggests that Zn requirement increase with increased concentration of N, K, Ca, Fe and Cu.

(ii) The concentration of Zn in straw at tillering was observed to have significant positive relationship with dry matter yield of straw and root at tillering as well as grain, straw and root dry matter yield at harvest. This suggests the greater significance of tillering straw Zn concentration in influencing the growth of rice.

(iii) The concentration of Zn in root at tillering also showed significant positive relationship with dry matter yield of grain and straw at harvest. Thus the amount of Zn entering into plant upto tillering has a bearing on the growth of rice. This effect however is decided by the relative concentration of other nutrients ions in the system as revealed by the significant relationship existing between nutrient ratios and yield of grain, straw and root as indicated earlier.

(iv) The increased concentration of N and Mn in the root at tillering tended to depress the concentration of Zn in straw at tillering. The possibility of more and more of Zn getting locked up in root with increase in N concentration of root was revealed.

(v) The relative importance of available Zn in soil at tillering was well brought out. Significant positive relationships were found to exist between available Zn at tillering and the total and straw dry matter yield at harvest. Tillering phase available Zn also influenced the nutrition of rice. The grain N and Zn concentration were positively related to the status of available Zn. The straw and root Fe contents were found to be negatively related to available Zn status at tillering. The significant Zn-Fe antagonism was well evidenced. Straw and root concentration and uptake of Fe were depressed with increasing amounts of Zn in the medium.

TABLE L. RESULTS OF CORRELATION STUDIES

No.	Relationship between X		Y	Correlation co-efficient 'r'	Level of significance	Regression equation
1.	Shoot N/Zn ratio at tillering	X	Grain yield	-0.640	**	Y = 19.210 - 0.010 X
2.	Shoot K/Zn ratio at tillering	X	Grain yield	-0.474	**	Y = 7.550 - 0.004 X
3.	Shoot Ca/Zn ratio at tillering	X	Grain yield	-0.582	**	Y = 8.630 - 0.009 X
4.	Shoot Fe/Zn ratio at tillering	X	Grain yield	-0.323	*	Y = 7.430 - 0.090 X
5.	Shoot Mn/Zn ratio at tillering	X	Grain yield	-0.464	**	Y = 8.020 - 0.223 X
6.	Shoot Cu/Zn ratio at tillering	X	Grain yield	-0.669	**	Y = 9.300 - 0.370 X
7.	Shoot N/Zn ratio at tillering	X	Straw yield	-0.780	**	Y = 41.510 - 0.020 X
8.	Shoot K/Zn ratio at tillering	X	Straw yield	-0.551	**	Y = 24.290 - 0.028 X
9.	Shoot Ca/Zn ratio at tillering	X	Straw yield	-0.485	**	Y = 25.750 - 0.059 X

(Continued)

S.No.	Relationship between X		Y	Correlation co-efficient 'r'	Level of signi-ficance	Regression equation
10.	Shoot Cu/Zn ratio at tillering	X	Straw yield	-0.645	**	Y = 30.550 - 0.185 X
11.	Shoot Zn concentration at tillering	X	Total dry matter at tillering	0.429	*	Y = 1.180 + 0.080 X
12.	Shoot Zn concentration at tillering	X	Root dry matter yield at tillering	0.396	*	Y = 0.440 + 0.019 X
13.	Shoot Zn concentration at tillering	X	Straw yield at tillering	0.440	*	Y = 0.765 + 0.061 X
14.	Shoot Zn concentration at tillering	X	Total dry matter yield at harvest	0.386	*	Y = 13.260 + 0.392 X
15.	Shoot Zn concentration at tillering	X	Straw yield at harvest	0.352	*	Y = 6.920 + 0.275 X
16.	Shoot Zn concentration at tillering	X	Grain yield at harvest	0.497	**	Y = 3.900 + 0.075 X
17.	Root Zn concentration at tillering	X	Total dry matter yield at harvest	0.448	*	Y = 4.970 + 0.204 X
18.	Root Zn concentration at tillering	X	Grain yield at harvest	0.335	*	Y = 3.990 + 0.022 X

(Continued)

TABLE L (CONTINUED)

S.No.	Relationship between X		Y	Correlation co-efficient 'r'	Level of signifi-cance	Regression equation
19.	Root N concentration at tillering	X	Straw Zn concentration at tillering	-0.361	*	Y = 46.880 - 7.440 X
20.	Root Mn concentration at tillering	X	Straw Zn concentration at tillering	-0.497	**	Y = 43.860 - 0.094 X
21.	Root N concentration at tillering	X	Root Zn concentration at tillering	-0.401	*	Y =138.900 -18.370 X
22.	Root Mg concentration at tillering	X	Root Zn concentration at tillering	-0.505	**	Y =130.060 -38.780 X
23.	Available Zn at tillering	X	Total dry matter yield at harvest	0.329	*	Y = 18.950 + 3.200 X
24.	Available Zn at tillering	X	Straw yield at harvest	0.359	*	Y = 9.940 + 2.690 X
25.	Available Zn at tillering	X	Root dry matter yield at tillering	0.328	*	Y = 0.712 + 0.156 X
26.	Available Zn at tillering	X	Grain N concentration	0.534	**	Y = 1.336 + 0.082 X
27.	Available Zn at tillering	X	Grain Zn concentration	0.650	**	Y = 18.670 + 3.250 X
28.	Available Zn at tillering	X	Shoot K concentration at tillering	0.347	*	Y = 0.789 + 0.121 X
29.	Available Zn at tillering	X	Shoot Fe concentration at tillering	-0.573	**	Y =104.690 -48.350 X

(Continued)

TABLE L (CONTINUED)

S.No.	Relationship between X		Y	Correlation co-efficient 'r'	Level of signi-ficance	Regression equation
50.	Available Zn at tillering	X	Root N concentration at tillering	0.597	**	Y = 1.391 + 0.277 X
51.	Available Zn at tillering	X	Root Fe concentration at tillering	-0.422	*	Y = 544.580 - 0.251 X
52.	Available Zn at tillering	X	Root Zn concentration at tillering	0-627	**	Y = 99.510 + 1.340 X
53.	Available Zn at tillering	X	Total Cu uptake at harvest	-0.322	*	Y = 2.340 - 0.485 X
54.	Available Zn at tillering	X	Straw P uptake at harvest	-0.384	*	Y = 31.820 - 4.730 X
55.	Available Zn at tillering	X	Straw Fe uptake at harvest	-0.351	*	Y = 10.780 - 1.640 X
56.	Available Zn at tillering	X	Straw Cu uptake at harvest	-0.401	*	Y = 0.269 - 0.042 X
57.	Available Zn at tillering	X	Total Fe uptake at tillering	-0.387	*	Y = 4.620 - 0.700 X
58.	Available Zn at tillering	X	Total Mn uptake at tillering	-0.388	*	Y = 0.931 - 0.129 X

(Continued)

TABLE L (CONTINUED)

S.No.	Relationship between			Correlation co-efficient 'r'	Level of significance	Regression equation
39.	Available Zn at tillering	X	Shoot Fe uptake at tillering	-0.407	*	Y = 1.319 - 0.214 X
40.	Available Zn at tillering	X	Root Fe uptake at tillering	-0.359	*	Y = 3.320 - 0.493 X
41.	Available Cu at tillering	X	Total Zn uptake at tillering	-0.424	*	Y = 1.250 - 0.209 X
42.	Available N at tillering	X	Root Zn concentration at tillering	-0.404	*	Y = 137.900 - 0.438 X
43.	Available Mn at tillering	X	Root Zn concentration at tillering	0.563	**	Y = 81.980 - 0.798 X
44@.	Root dry matter yield	X	Grain yield	0.801	**	Y = 1.740 + 2.620 X

Nutrient ratios (1 to 10) are expressed on equivalent concentration basis

@ Data confined to first phase of the studies

DISCUSSION

DISCUSSION

CHAPTER V

DISCUSSION

The influence of varieties, soil conditions, sources and methods of Zn fertilisation on the growth and nutrition of rice were studied. The studies were carried out in four well defined phases viz. growth and mineral nutrition of rice (i) as influenced by varieties and Zn fertilisation (ii) as influenced by soil conditions and Zn fertilisation (iii) as influenced by amendments and Zn fertilisation in sodic soil and (iv) as influenced by sources and methods of application of Zn. Detailed laboratory studies were made to assess the progressive changes in the availability of macro and micro nutrients, their content and uptake by rice.

A brief discussion on the salient features of observations is presented in this Chapter.

A. Influence of Zn fertilisation on the growth and mineral nutrition of genetically variable popular rice varieties of Tamil Nadu

In this phase of the study the comparative yield behaviour and concentration and nutrient uptake in respect of ten genetically variable rice varieties (Table I) were studied. The soil representing Perur series (Perur, Coimbatore) and possessing sandy loam texture and having 0.8 ppm of available Zn was employed. N, P_2O_5 and K_2O at the rate of 120:60:60 kg/ha and four levels of Zn (0, 5, 10 and 15 ppm) were imposed. The plants were grown up to maturity and the dry matter yield of grain, straw and root as well as the concentration and uptake of different nutrients were determined.

1. Dry matter yield

The genetic variability among varieties caused substantial differences in the total as well as individual dry matter yield of grain, straw and root. Long duration varieties in general produced higher straw and root dry matter yield. Zn fertilisation enhanced root growth, straw yield, grain production and total dry matter. This effect was, however, confined to the varieties IR 8, RP 4-14, Bhavani, Co 38, TNAU 13493 and TNAU 658 and these may be considered as Zn responsive varieties. Incidentally these varieties had either IR 8 or Peta as one of the parents. The soil employed contained very low available Zn and the added Zn fertilisers could naturally be expected to respond. The objective contemplated in the study was how the popularly grown genetically variable rice varieties react to the added Zn fertilisers and the results have thrown light on the highly tolerant nature of IR 20 and Co 37 and the significant improvement in grain yield of IR 8, RP 4-14 and Bhavani. Based on the degree of responses IR 8, RP 4-14 and Bhavani may be grouped as highly responsive, Co 38, TNAU 13493 and culture TNAU 658 as medium responsive and Co 39, Co 37, IR 20 and Ponni as non responsive. The grain yield increases ranged from 20 to 60 per cent in responsive varieties. The tolerant nature of IR 20 and the susceptibility of IR 8 for Zn deficiency have also been observed by Ponnamperuma and Casro Ruby (1973). The suitability of IR 20 under Zn deficient conditions was also indicated (Anonymous, 1972). A point to note was that the variety Co 37 which showed much less total dry matter yield ranked foremost in grain yield. The straw and root dry matter yield, however were considerably less than other varieties. In other words a relatively narrow grain: straw ratio existed in this variety which appears to be a genetic potential of the variety. Although Co 39 and TNAU 658 also showed such narrow grain:straw ratios they could not bring about such yield because of short duration nature of the former and poor tillering in the latter. Although the total dry matter, straw and root dry matter yield revealed a positive correlation with grain yield (Table L) the variety Co 37 appears to be an exception to the general rule. A point of gratification was that this variety could produce as much grain yield under deficiency conditions as under sufficiency conditions suggesting that it is ideally suited for Zn deficient soil. IR 20 also stood on par with this and can be considered to be a good substitute for Zn deficiency conditions. Co 38, TNAU 658 also recorded identical yield to Co 37 and IR 20 under Zn deficiency conditions but their yield significantly increased further upon Zn fertilisation. RP 4-14 and IR 8 showed very poor yield under deficiency conditions and tended to register phenomenal increased yield due to added Zn fertiliser. Thus, in the approach to maximise the yield potential of such varieties like Co 38, TNAU 658, IR 8, RP 4-14 and Bhavani, Zn fertilisation will be of great use.

A consideration of the straw yield brought out the fact that long duration varieties (Co 38, IR 8 and TNAU 13493) as a general rule produced higher straw yield as compared to short duration varieties (Co 39, Co 37 and TNAU 658) and that Zn fertilisation could enhance straw yield irrespective of the genetic variability of the varieties. The relative grain and straw yield values revealed that the straw producing ability is not a true reflection of grain producing ability. Co 37 for example produced not much straw and root growth but stood foremost in grain yield as against the variety TNAU 13493 which produced nearly double the straw yield as that of Co 37 but recorded only sixty per cent of its gain yield. Thus it is perhaps the physiological activity per unit area/weight which count much more than total area/weight.

Varietal differences were reflected in the amount of root weight as well. As a general rule long duration varieties tended to record greater root weight than short duration varieties. Zn application also brought about enhanced root growth and consequently the computed total dry matter yield was more due to Zn application. A plethora of evidences have accumulated on the beneficial effect of Zn on the growth of rice (Pillai, 1967; Badrachalam, 1969; Bora et al., 1977).

2. Nutrition

The genetic variability and Zn fertilisation brought about no marked change in grain, straw and root N concentration. In otherwords the N concentration had been maintained in spite of enhanced dry matter yield. Zn fertilisation enhanced the dry matter yield and this was accompanied by enhanced N uptake. Nene (1962) observed a severe reduction of N concentration in rice plant under conditions of Zn deficiency. In the present study the concentration and uptake of N by grain and straw tended to increase slightly though not significantly in general and particularly in Zn responsive varieties like IR 8 and RP 4-14. Randhawa (1973) reported a significant improvement in protein content of rice due to application of 5 ppm of Zn.

The consideration of uptake of P individually by grain, straw and root both positive and negative influence were revealed. The grain P uptake was increased in varieties RP 4-14, Bhavani and IR.8 and a negative effect was noticed in IR 20 at 15 ppm level of Zn. Application of 15 ppm Zn depressed straw P uptake in all varieties. Zn-P antogonism is well evidenced by several workers.

The antogonistic effect was evident from uptake values. There was increased accumulation of P in root with increasing Zn levels. While there was no marked effect on total P uptake there was a tendency for more P to get locked up in root as a result of Zn fertilisation.

K nutrition was found to be independent of varieties as well as Zn application. The uptake differences are attributable to dry matter yield variations. Nene (1962) observed increased K concentration under Zn deficiency conditions. It may, however, be noted that increased dry matter yield has not caused any dilution effect and the plants could derive their requirement in tune with the dry matter yield. Variety TNAU 658 recorded the highest grain Ca concentration, while IR 20 the highest straw Ca concentration. The concentration differences coupled with dry matter yield variation accounted for marked variation in total as well as individual uptake of the element. The Zn responsive varieties like Co 38, IR 8, Bhavani etc. tended to accumulate more Ca in straw as compared to others.

In view of the dominating influence of Ca on the regulation of micronutrient nutrition this increase of Ca concentration in straw assumes greater significance and a proper Ca/Zn ratio appears to have a bearing on growth and response. A higher Zn uptake under conditions of high Ca accumulation appears to be necessary. The dominating influence of Ca in the absorption and translocation of micronutrients have been evidenced by several workers (Joffee, 1936; Khan and Manson, 1957). Roots recorded two to three fold increased Mg concentration as compared to grain and straw. Zn fertilisation while increasing Mg concentration in grain and straw had a depressing influence on root Mg concentration. Increased dry matter yield on one hand and enhanced concentration on the otherhand resulted in increased Mg uptake. As a general rule Zn responsive varieties and long duration varieties showed greater grain and straw Mg uptake.

The Fe nutrition of the rice plant was also observed to be influenced markedly by the varietal differences and Zn fertilisation. The mean Fe content varied from 104 to 147 ppm in grain, 396 to 576 ppm in straw and 1062 to 1500 ppm in root. For any variety the concentration varied in the order root $>$ straw $>$ grain. Dry matter yield variation coupled with concentration differences resulted in considerable uptake differences. The highest uptake of 48.46 mg/pot was observed in Co 38 and the least uptake of 10.44 mg/pot in

Co 39. Grain, straw and root uptake also varied and in each of the above Co 38 ranked first. These uptake differences may be attributed to the inherent genetic potential of the variety and dry matter yield variations. A clear cut relationship between Zn and Fe was also revealed. The concentration of Fe in grain, straw and root decreased and the decrease was more pronounced in straw. The interaction effect "varieties x Zn" was also seen in respect of straw Fe concentration. The decrease in respect of Fe was pronounced even with addition of 5 ppm Zn and not so marked with further increase in Zn levels. The Fe uptake decreased in proportion with the concentration. However, the high dry matter associated with increasing Zn levels compensated the decreased grain, straw and root Fe concentration. Yet the decreases were significant, marginally in grain and markedly in straw and root. The cumulative result was that the total uptake progressively and significantly decreased with increasing Zn levels. The fact that Zn fertilisation tended to decrease the concentration of Fe in grain, straw and root suggest that both absorption and translocation of Fe is influenced by Zn. Similar antagonistic effects were also reported by Deb and Zeliang (1975) and Venkatasubramanyam and Mehta (1975).

Varietal differences and Zn fertilisation brought about changes in Mn nutrition as well. The highest Mn concentration in grain, straw and root were observed in IR 8, TNAU 658 and Co 39 respectively. Roots of all varieties contained higher Mn concentration than grain and straw and in long duration varieties the differences narrowed. The effect due to Zn levels revealed a synergistic Zn-Mn interaction. Grain Mn concentration tended to increase, while that of straw decreased as a result of Zn fertilisation. Root content of Mn was not influenced by Zn fertilisation. These point to the possible role of Zn in mobilising the element from straw to root. The total uptake remained more or less the same. Significant variation in individual uptake has occurred providing further evidence for the possible role of Zn in the translocation of Mn.

The effect of varieties and Zn fertilisation on Cu nutrition revealed the concentration and uptake of Cu to be influenced by the above factors. The concentration of Cu varied from 7 to 15 ppm in grain, 15 to 38 ppm in straw and 45 to 91 ppm in root. The higher Cu concentration in grain, straw and root were observed in IR 20, Ponni and RP 4-14 respectively. The uptake of the element varied from 0.45 to 2.79 mg/pot, long duration types registering more total uptake than short duration varieties. These uptake differences are attributable to dry matter yield differences coupled with the variation in the concentration. The root uptake of Cu increased while that of straw uptake decreased as a result of Zn fertilisation. The ultimate effect was that the total uptake of Cu was more as a result of Zn fertilisation. Chaudhry *et al.* (1973) and Kausar *et al.* (1976) observed an antagonistic effect of Zn on Cu uptake. In the present study also the depression was noticed but was confined to straw.

The genetic variability and Zn fertilisation brought about pronounced changes in concentration and uptake of Zn. The mean Zn concentration varied from 7.2 to 18.9 ppm for grain, 10.4 to 33.0 ppm for straw and 37.9 to 64.9 ppm in root. Thus for any variety roots recorded two to three fold increased concentration as compared to grain and straw. The differences in concentration between grain, straw and root narrowed with long duration varieties. In the absence of any added Zn, TNAU 13493 recorded the highest grain and straw Zn concentration while IR 20 the highest root Zn concentration. Zn application caused a progressive increase in Zn concentration of grain, straw and root. The mean increase in concentration ranged from 47 to 80 per cent in grain, 32 to 60 per cent in straw and 10 to 21 per cent in root. In the short duration varieties like Co 39 and Co 37 there was no improvement in grain Zn concentration, while in others marginal to high increases were noted. Irrespective of the variety Zn application tended to increase straw Zn concentration. Zn concentration of root also increased and this was more pronounced when the level of Zn increased from 10 to 15 ppm. IR 20, Co 39, RP 4-14, IR 8 and TNAU 13493 recorded higher root concentration than others. IR 20 which was included under non responsive group showed the highest root Zn concentration in the absence of any added Zn and this further increased upon application of Zn. Thus this variety appears to have an inherent ability to absorb Zn more efficiently than others. The uptake of Zn obviously differed since the dry matter yield varied. CO 38 recorded the maximum Zn uptake. The magnitude of increase in the uptake of Zn worked out to 70 to 98 per cent in grain, 48 to 70 per cent in straw and 27 to 70 per cent in root as a result of Zn fertilisation.

From the foregoing discussion it is apparent that there is high genetic variability towards responses for Zn fertilisation. Co 37 and IR 20 were found to be tolerant from among the ten varieties tested and are ideally suited for the marginally Zn deficient soil types of the series. Zn application will be helpful in increasing the yield potential of such varieties like IR 8, RP 4-14, Bhavani and TNAU 658. Zn application had a favourable interaction with N and Mg nutrition and antagonistic effect on Fe and Cu nutrition. P uptake was decreased at higher level of Zn employed.

B. Growth and mineral nutrition of rice as influenced by soil conditions and Zn fertilisation

In this phase of the study the progressive changes in available nutrients in the soil, dry matter yield and the nutrition of rice were investigated under the influence of varying soil conditions and Zn fertilisation. Soil conditions studied were normal soil, calcareous soil, organic matter enriched soil and submerged soil and Zn treatments imposed were no Zn, $ZnSO_4$ and ZnEDTA. The Zn responsive variety RP 4-14 was employed as the test crop.

1. Soil studies

The pH, EC, organic carbon and $CaCO_3$ values of the initial soil samples were 7.7, 0.62 mmhos/cm/, 0.50 per cent and 0.14 per cent respectively. The imposition of various treatments and incubation for a period of ten days brought about considerable changes not only in the above properties but also in the availability of plant nutrients. The pH of the soil decreased in all but the calcareous soil. This may be ascribed to the saturation due to the flooding conditions which prevailed during the incubation period. This tends to move the pH towards neutrality. The absence of such an effect in calcareous soil may be due to the dissolution of $CaCO_3$ which tends to raise the pH. The pH in calcareous soil remained greater than 8 during all the stages. Chandrasekaran (1962) also observed increase in pH values due to the addition of $CaCO_3$. Turner and Clark (1956) and Yaalon (1957) observed the pH of the calcareous soil to extend up to 8.5. The EC values slightly increased due to organic matter enrichment as well as due to submergence. The increased solubilisation of soil constituents during the process of decomposition in the former case and increased availability of most of the nutrients due to submergence (Ponnamperuma, 1964) in the latter case might have accounted for such effects. The enrichment of the soil with organic matter obviously showed a high organic carbon status, while calcareous soil increased the Ca concentration of the soil solution. Apart from the above, all soil conditions showed increased availability of N, Fe and Mn. The undesirable effect of $CaCO_3$ and submergence in depressing the available Zn was also revealed. Jurinak and Thorne (1955), Sikhaulidge et al. (1973), Misra and Pandey (1977) have also indicated poor availability of Zn in calcareous soil due to the formation of insoluble Ca ZnO_2. Jackson (1967), Badrachalam (1969) and Ponnamperuma (1972) observed poor availability of Zn under flooded conditions.

The studies on the progressive changes in the availability of nutrients revealed an overriding superiority of organic matter enriched soil over others. With the exception of Cu whose availability was not far different from other soil conditions the availability of all other nutrients were maintained at comparatively higher levels. This enhanced availability may be ascribed to both direct and indirect effects, directly in the sense that the constituents of the organic matter getting released into soil solution and indirectly the solubilisation, chelation and maintenance of available nutrients in the soil solution.

Islam and Elahi (1954), Mandal (1964), Ponnamperuma (1964), Patrick and Mahapatra (1971) have observed an increase of available P due to submergence. The influence of organic matter in increasing the available P in soil was evidenced by several workers (Bromfield, 1960; Chiang, 1965; and Singh and Patiram, 1977). Increased availability of Fe and Mn due to submergence was indicated by Jaggi and Russell (1973). Mandal and Khan (1977) also recorded increase of available P due to saturated soil conditions. The build up of Fe and Mn concentration was also seen and in fact the main difference between this soil and normal soil was the increase in Fe and Mn and decrease of Zn apart from slight increase in P, Ca and Mg. Nearly 45 to 50 per cent reduction in the concentration of available Zn and uptake of the element by rice (Var. Jaya and HR 19) was observed by workers at Hyderabad under flooded conditions

(Anonymous, 1973). The calcareous soil showed depression of available P and Zn conspicuously. The increase of Fe and Mn availability as observed in other soil conditions was not observed in calcareous soil. Emil (1948) reported decreased availability of Zn in carcareous soil. Boischot and Durroax (1950) observed lowering of availability of Fe in calcareous soil and attributed it to fixation by chemical precipitation. Jurinak and Thorne (1955) indicated $CaZnO_2$ could be an important factor in decreasing Zn solubility in calcareous soil. Saeed and Fox (1976) felt the inherent high pH of calcareous soil to be responsible for Zn deficiency. The lowered diffusion of Zn in calcareous soil due to intense competition between Ca and Zn was observed by Prasad et al. (1976).

The pH obtained at transplanting was maintained during further stages of sampling. The available N, P and K at the tillering stage were higher in all treatments as compared to the transplanting stage owing to NPK fertilisation and during this stage the availability of the above nutrients were higher in organic matter enriched soil. There was further increase in the availability of Fe, Mn and Cu under all soil conditions including calcareous soil. The application of Zn in either form increased the available Zn irrespective of the soil conditions.

In calcareous soil and submerged soil the availability of Zn was considerably less in the absence of addition of Zn. Such decrease in Zn availability due to submergence was also recorded by Katyal (1972), Takkar and Sidhu (1977) and Maskina (1977). Ponnamperuma (1977) observed that sulphides, carbonates and phosphates formed following submergence lowered the availability of Zn.

Six et al. (1969) observed a positive correlation between clay and organic matter and available Zn. Sharpless et al. (1969) attributed poor availability of Zn at higher pH to formation of $CaZnO_2$. Prasad and Pagel (1970) registered decreased availability of Zn with increased pH and Ca saturation.

The application of Zn in the form of ZnEDTA caused enhanced availability of Zn both in calcareous soil and submerged soil. This may be ascribed to the little fixation of the chelate by clay (Wallace and Luni, 1956) and more effective supplying ability of the chelate at higher pH as compared to $ZnSO_4$ (Segars, 1973). Kang and Okoro (1976) observed greater mobility of Zn from ZnEDTA under flooded conditions. The work of Prasad et al. (1976) also showed that the chelated form is more effective in being able to supply the element by overcoming rate limiting steps of solution, desorption and diffusion.

In the post harvest soil samples the availability of all the nutrients decreased. There was decrease in available Fe and increase in available Mn as compared to the initial soil. This variation can be ascribed to slight differences in oxidation-reduction potential normally encountered in rice culture. Venkatasubramanyam and Mehta (1975) also reported such a phenomenon due to application of Zn. A point of interest was that Zn availability was reduced to a very low level in calcareous soil in the absence of added Zn. The submerged soil showed an increase at harvest stage in available Zn even in the absence of any added Zn.

2. Dry matter yield

The differences in soil conditions and Zn application brought about differences in shoot and root dry matter yield at tillering as well as at harvest. The mean shoot dry matter yield at tillering stage for normal, calcareous, organic matter enriched and submerged soils were 3.40, 2.60, 3.60, 2.90 g/pot respectively. The root dry matter yield observed were 1.50, 0.95, 1.50 and 1.20 g/pot respectively. Thus, a slight reduction in the root and shoot growth relating to the calcareous soil was observed. In the absence of any added Zn, the calcareous soil and submerged soil produced much lower shoot and root dry matter yield. It may be mentioned that in these two soils the Zn availability was limited. The addition of Zn fertiliser could enhance the dry matter yield in both the above cases. The usefulness of Zn addition to calcareous soil was also reported elsewhere (Peterson, et al., 1974). Tiwari *et al.* (1976) observed application of Zn fertilisers to black soil to be beneficial in increasing rice yield. The plants grown in calcareous soil showed slightly decreased P, K, Mg, Mn and Zn concentration in shoot and root as compared to other soil conditions and this was particularly so in the absence of any added Zn. This may be ascribed to enhanced solution concentration of Ca and poor Zn availability. The dominating influence of Ca in the absorption complex on the utilisation of other cations was also evidenced by Joffee (1936). In the absence of Zn addition submerged soil also sufferred. The shoot and root relating to submerged soil recorded higher concentration of Fe and Mn and lower concentration of Zn as compared to those of normal soil. Thus the reduced availability of Zn due to submergence was aggravated further by enhanced availability and absorption of Fe. According to Brar and Sekhon (1976), decrease in absorption and translocation of Zn was partly due to increased concentration of Fe. Chaudhry and Wallace (1976) also observed a competitive inhibition of Fe on Zn absorption in solution culture experiments. Zn application under the above conditions enhanced the availability and absorption of the element and this was more pronounced for the chelated form of Zn. The uptake of the element varied in tune with dry matter yield differences. The organic matter enriched soil showed comparatively higher uptake of N, P, K Ca and Mg. The mean shoot uptake was the highest in organic matter enriched soil and the least in calcareous soil. The mean root Zn uptake was also low in calcareous soil and submerged soil. The dry matter yield differences have accounted for the above. But in the case of calcareous soil and submerged soil the available Zn was less than the critical limit. Although no clearcut deficiency symptoms were observed the dry matter yield went down considerably, perhaps due to "hidden hunger."

The investigations on the total as well as individual dry matter yield of grain, straw and root at maturity revealed the outstanding superiority of organic matter enriched soil over other soil conditions in being able to produce the highest total as well as individual dry matter yield. This may be attributed to both direct and indirect benefits which follow organic matter addition. The direct effects include possible structural modifications and release of extra plant nutrients, and indirect effects include prolonged nutrient availability, enhanced diffusion and mobilisation of nutrients in the soil-plant system.

Schatz (1963) showed the chelating ability of organic matter and Brown (1958) observed that apart from influencing the availability of nutrients organic matter also regulated the concentration of micronutrients in plants. The fertility value of organic matter has been indicated by several workers (Unambuoparah, 1973; Balla, 1974; Asmus, 1974).

In the present study also a comparatively higher fertility environment as a result of organic matter addition is evident accompanied by enhanced concentration and uptake of nutrients both at tillering and maturity phases. As far as Zn availability is concerned unlike calcareous and submerged soil conditions the addition of organic matter enhanced availability even in the absence of added Zn, and any addition of Zn tended to cause further increase. Thus, plants grown in organic matter enriched soil enjoyed comparatively better nutritional environment in the ambient soil solution. Thus in this soil condition grain, straw and root dry matter registered increases of the order of 40, 29 and 56 per cent as compared to normal soil. Application of Zn in either form although caused enhanced availability of the element there was no further appreciable increase in dry matter yield as compared to no Zn treatment. A similar case was also observed in normal soil where Zn fertilisation enhanced available Zn in soil but no increase in dry matter yield resulted. The yield of grain, straw and root dry matter yield was significantly less in calcareous and submerged soil in the absence of added Zn. Zn application to these soils whether it be organic or inorganic, brought about appreciable increase in yield of grain and straw. Such increase in the dry matter yield was also recorded by Skoog (1940). He attributed this effect to the direct influence of Zn on the quantity of auxin. A more beneficial effect of ZnEDTA in increasing grain, straw and root dry matter yield was observed in the present study. The more effective nature of ZnEDTA in Zn supplying ability as compared to $ZnSO_4$ was also observed by Segars (1973).

Elgawhary <u>et al.</u> (1970) reported enhanced diffusion of Zn in soil on addition of EDTA. In calcareous soil also ZnEDTA showed additional advantage in respect of straw dry matter yield. Gangwar and Mann (1972) reported Fe-Zn and Mn-Zn antagonism and since there was greater build up of availability of Fe and Mn it is reasonable to expect an inhibition on inorganic Zn added under submerged soil.

Ishizuka and Ando (1968) observed in their solution culture experiment a considerable reduction in Zn absorption due to increased Mn concentration. Chelated form of Zn probably was less susceptible for such an interaction. This was further confirmed in the present experiment by the enhanced availability of the element when applied as chelated form.

A consideration of chaff percentage revealed that relatively higher percentage of chaff was associated with submerged soil in the absence of any added Zn. The percentage observed was 24.6 as against 11.3 and 16.4 per cent for $ZnSO_4$ and ZnEDTA respectively. Thus Zn application in either form was of particular advantage in this soil condition in decreasing chaff percentage and increasing dry matter yield, a feature not so conspicuous in other soil conditions. This suggests that it is a question of enzyme activity and translocation which limit the grain yield under submerged soil condition and added Zn could influence the above phenomenon. Evidences for the role of Zn in enzyme system (Wallace, 1962) was reported earlier. It may be added that the total dry matter produced was not much different in normal, calcareous and submerged soil and it is a question of their relative distribution which accounted for grain yield differences (Fig.4).

It follows from the above that Zn fertilisation brought about beneficial effects in general and the effects were more pronounced in calcareous and submerged soil. In these soil conditions 40 to 45 per cent increased grain yield and considerable reduction in chaff percentage were brought about due to Zn fertilisation. In normal soil and in soil enriched with organic matter the dry matter yield was not influenced to any significant extent. With the exception of normal soil there was enhanced root growth due to the addition of Zn fertiliser whether it was organic or inorganic form. The application of both forms of Zn, particularly chelated form, caused a marked reduction in the chaff percentage. This brought to light the fact of how the added Zn could bring about beneficial effects under conditions which limit its availability. The lowering of availability of Zn due to the formation of insoluble carbonate of Zn (Udo et al., 1970 and Sikharulidse, 1973) due to adsorption (Navrot and Ravikovitch, 1971), due to formation of $CaZnO_2$ (Misra and Pandey, 1977), lowering of diffusion (Prasad et al.,1976) in calcareous soil were well established. In the present study also the impact of added $CaCO_3$ in depressing the availability of added Zn was well revealed. The application of Zn to calcareous soil brought about sufficient Zn concentration in spite of the tendency for fixation. Addition of Zn at as high a dose of 5 ppm to the calcareous soil could register much less increase in availability as compared to the normal soil. Neverthless the rice plants showed considerable enhanced Zn accumulation and uptake than control. The chelated form of Zn showed greater availability under all soil conditions. Although the amount of Zn added is negligibly small as compared to inorganic form, yet it appeared considerably efficient in maintaining a fairly appreciable concentration of Zn in solution and favouring greater mobility and uptake by the plant. Thus chelated form enjoyed better diffusion, lesser adsorption, greater absorption and easy translocation within the plant.

3. <u>Nutrition</u>

The nitrogen concentration and uptake were greater in plants grown in organic matter enriched soil even during the tillering phase of the crop in tune with the enhanced availability of the nutrient in the soil. The harvest stage straw and root in this soil condition registered higher concentration and uptake of N than other soil conditions. Zn application had no influence on N concentration of straw and root but, however, tended to slightly and significantly increase the N concentration of grain. The total and individual uptake of N by grain, straw and root were highest in this soil condition in proportion with the dry matter yield. The total N uptake did not vary much due to Zn fertilisation. The N nutrition showed more or less a similar pattern in normal soil as well. In calcareous soil the straw showed less N concentration as compared to organic matter enriched and submerged soil condition. Zn application tended to increase

N concentration, but the effect was confined to straw and root. It may be mentioned that Zn application in either form to calcareous soil increased the grain yield. But, however, the enhanced grain yield had not caused any dilution effect on N concentration as compared to control suggesting that there has been more N mobilisation to grain on account of Zn fertilisation. A similar trend and explanation also hold good for submerged soil. Thus, irrespective of the soil condition there seems to be a definite role of Zn on N nutrition. The beneficial effect of Zn in increasing the energy value of grain was reported by Thompson et al.(1962) and Dwivedi and Randhawa (1973).

Neither the soil conditions for Zn application brought about any significant difference in grain and root P concentration. The uptake differences can be attributed to dry matter yield differences. The P content of straw showed the trend of submerged soil > organic matter enriched soil > normal soil > calcareous soil. It may be mentioned that the availability of P in the above soil conditions follow similar trend. Burd and John (1948) observed that increased Ca concentration reflected ~~on~~ low P availability. The Zn-P interaction was found to be non existent. The level of 5 ppm Zn employed perhaps was not sufficient enough to produce any appreciable antagonistic effect with P.

As in the case of P, the grain K concentration was not influenced by soil conditions as well as Zn fertilisation. Enrichment of the soil with organic matter caused ehnanced straw and root K concentration. The higher availability of the element caused by release of K from added green leaves and that from soil due to enhanced dissolution may have contributed to the above. The added green leaves, apart from directly contributing its own tissue K may be expected to bring more K into soil solution. This is supported by the fact that the status of available K was comparatively more in organic matter enriched soil than in others. Thus, increased concentration combined with enhanced dry matter yield accounted for two to three fold increased uptake. Another fact brought to light is the impact on K absorption brought about in calcareous soil. Concentration and uptake in straw and root were least in this soil condition and Ca seemed to inhibit K absorption. Although the availability of K was not limiting, the presence of increased Ca hindered absorption. A similar effect of enhanced Ca concentration in soil solution to decrease K accumulation in the plant was also reported by Khan and Hanson (1957). The submerged soil condition and normal methods of rice culture seem to have no appreciable difference in the matter of K nutrition. Neither the concentration nor the uptake, whether it be grain, straw or root, showed any appreciable difference under the above said conditions. A consideration of the effect of Zn fertilisation revealed the absence of any appreciable effect on K concentration. The uptake differences observed can be attributed to dry matter yield differences.

Calcareous soil and soil enriched with organic matter showed higher availability of Ca. The dissolution of added $CaCO_3$ in the former and solubilisation of soil Ca during the process of decomposition in the latter have contributed to the above. These differences in availability have not altered the Ca concentration of grain and root. The Ca concentration of straw was, however, low in normal soil as compared to other soil conditions. The specificity of greater Ca concentration confining to straw is of special significance in view of the dominating influence of Ca in mobilising nutrients, particularly micronutrients. Zn fertilisation also tended to enhance Ca concentration of straw.

Pathak et al. (1975) also observed increased Zn supply to result in higher Ca content. It may perhaps be due to the possible interaction of Ca and Zn ions resulting in the formation of $CaZnO_2$. It is supported by the fact that root and straw contained more Zn and Ca as compared to grain.

Aliyn (1927), Bennett and Oserkowsky (1940) stated that the chloresis of plants was associated with the physiological role of Ca within the plant. The total uptake of the element was more in organic matter treated soil in tune with dry matter yield. In all cases it is the dry matter yield that has contributed to the differences in uptake.

The studies on Mg nutrition revealed the straw and root concentration of the element to be enhanced by green manure treatment and Zn fertilisation. The increase in Mg content of straw in spite of increase in dry matter yield as a result of the above treatment point to enhanced absorption of the element. The relative higher availability of the element under the above soil condition accounted for the above. The contribution of Mg by organic matter and submerged condition were also found to operate. The net result was that both content and uptake of the element increased in the above treatment. Further added Zn fertilisers showed a synergistic effect. The inhibiting effect of Ca on Mg absorption was however observed in calcareous soil and perhaps the level of available Ca build up in other soil conditions was not sufficient enough to affect the Mg nutrition. Even in calcareous soil use of ZnEDTA brought about substantial increase in Mg content further confirming positive ZnMg interaction.

The influence of soil conditions and Zn fertilisation on Fe nutrition appeared to be of greater significance than others. The availability of this element was found to be considerably high irrespective of soil condition and Zn application. The conditions of rice culture which involved saturation to flooding favoured greater build up of Fe concentration in the soil solution. Enrichment of the soil with organic matter and submerged soil caused comparatively higher availability than others. Calcareous soil recorded the least concentration of the element in grain and root. This may be ascribed to both the specific and non-specific effect of Ca on Fe absorption. Handley et al. (1965) observed antagonistic effect of Ca upon Fe uptake. Zn application decreased the concentration of Fe in grain, straw and root and this was more pronounced in straw and root and more so with ZnEDTA.

Hewitt (1949) observed antagonistic relationship of Zn with Fe in the process of absorption and translocation although no valency change is associated with oxidation-reduction. Rediske and Biddulph (1953) noticed enhanced mobility of Fe when the tissue level of Zn was the lowest. Lingle et al. (1963) and Adriano et al. (1971) also reported mutual antagonism between Fe and Zn. Further evidence was provided by the work of Tiwari et al. (1976).

Venkatasubramanyam and Mehta (1975) observed decreased availability of Fe due to the application of Zn in their incubation experiment. Both Fe and Zn interfere with the absorption of each other. Rosell and Ulrich (1964) and Brown and Tiffin (1962) also observed Zn inhibition on Fe concentration of plants.

The Mn nutrition revealed that there was depression on shoot and root concentration of the element in calcareous soil at tillering. Application of Zn favoured greater concentration of Mn in shoot and a decrease in root. At maturity the trend further widened and calcareous soil tended to show lower concentration of the element in grain, straw and root. The Mn content of grain and straw increased while that in root decreased due to application of Zn. The concentration differences and dry matter yield variations were responsible for uptake differences, which was nearly twice in organic matter enriched soil. The use of Zn fertilisers has not caused much difference and appeared to be favouring greater translocation of Mn from root to shoot. It may be mentioned that in the first phase of the experiment a similar effect was observed.

As observed in the case of Fe the roots contained greater concentration of Cu than straw and grain irrespective of the soil condition. The effect of soil condition and Zn application on Cu concentration was confined to root. As is the case with many other nutrients, soil enriched with organic matter and submerged soil condition favoured greater

Cu concentration in the root in addition to remaining parallel in respect of grain and straw Cu content with other soil conditions. Application of Zn in either form tended to decrease Cu concentration of root. The Cu content of grain and straw increased while that in root decreased in normal soil as a result of Zn application. It was observed that the total Cu uptake remained more or less the same whether Zn was applied or not. However, application of Zn tended to increase the Cu content of grain and straw and decrease it in the root. This suggests the possible influence of Zn on translocation of Cu from the root to straw and grain. However, there are evidence for strong depression on Cu uptake by Zn (Kansar *et al*., 1976). Perhaps the level of Zn employed in the present experiment was not sufficient to exercise its antagonistic effect. The Zn-Cu antagonism however, was notseen under other soil condition. Perhaps the complexing agents in organic matter enriched soil released during decomposition and enhanced Ca concentration in calcareous and submerged soil prevented any possible translocating effect of Zn by inactivating either Zn or Cu. The uptake was the highest in organic matter enriched soil and the least in calcareous soil.

The influence of soil conditions and Zn fertilisation on Zn nutrition of rice assumed greater significance than others. With the background of root and shoot concentration of Zn at tillering and that of grain, straw and root at maturity it was obvious that the normal soil and organic matter enriched soil showed better availability of the element, even in the absence of any addition of Zn. However, Zn application increased the availability of Zn and improved the concentration of Zn in plant both at tillering at harvest stages. The significant influence of Zn in calcareous soil and submerged soil was well brought out. In the absence of any added Zn, the availability of Zn in these two soils suffered most and the concentration and uptake of Zn at tillering and maturity were considerably low. This may be ascribed to low availability of Zn. Application of Zn in either form to these soils tended to enhance the availability of Zn and in turn improved the concentration and uptake of the element in plant both at tillering and maturity.

Aymond (1972) observed the application of Zn to flooded soil to increase the concentration and uptake of the element by rice. Tiwari et al. (1976) observed increased Zn levels to increase Zn content regardless of Fe levels. They observed lowest concentration of Zn in rice under waterlogged conditions without Zn application and increase in uptake upon Zn application. However, Gangwar and Mann (1972) observed higher uptake of Zn by rice in flooded soil conditions than at field capacity.

The decrease in availability, concentration and uptake in calcareous soil may be ascribed to increased Ca concentration in soil solution which tend to precipitate Zn ions. In submerged soil apart from increased Ca availability enhanced Fe concentration of soil solution also accounted for reduced Zn availability and uptake by rice. However, the above antagonistic effect of Ca and Fe on availability and uptake of Zn by rice was not observed when chelated form of Zn was applied to soil. Persumably chelated Zn could overcome the rate limiting steps of precipitation and immobilisation in soil/plant system. The organic matter enriched soil recorded the highest Zn uptake irrespective of the fact whether Zn is applied or not. In the absence of any added Zn calcareous soil and submerged soil showed comparatively less uptake. The uptake considerably improved due to added Zn fertilisers (Fig. 5).

4. Equivalent concentration of nutrients in relation to Zn

The studies on the influence of soil conditions and Zn fertilisation on relative equivalent concentration of various nutrients in relation to Zn gave evidence for the favourable role played by Zn fertiliser. In the absence of addition of Zn fertiliser the ratios were wider and Zn application in either form tended to narrow down the ratio. In view of the negative significant relationship existing between the nutrient ratios and grain and straw yield (Table L) this effect of Zn on the nutrient ratio assumes greater importance. The narrowing of the ratios in most cases resulted due to enhanced accumulation of Zn as a consequence of added Zn fertiliser. Persumably enhanced concentration of nutrients warranted enhanced accumulation of Zn as well as exercised their full influence on growth and physiological functions. In otherwords increasing concentration of nutrient elements increased the Zn requirement of rice. Gangwar and Mann (1971) studied the effect on Fe/Zn and Mn/Zn ratios at fifteen days intervel during early stages of rice growth and observed higher dry matter yield to be associated with narrower ratios especially under flooded conditions.

In respect of root, Zn application had the opposite effect of widening the ratios in general and this was more marked with ZnEDTA. The use of $ZnSO_4$ tended to decrease the ratio in respect of Mg, Fe and Mn. This effect may be ascribed to both increased mobilisation of the nutrient from root to shoot as well decreased absorption due to antagonistic effect. This is further evidenced by the fact that the concentration of the elements like N, P, K, Ca and Zn tended to increase while that of Mg, Fe and Mn tended to decrease due to Zn fertilisation. The above studies indicated that apart from Zn content <u>per se</u> the relative concentration of other nutrients also is of paramount importance.

C. Zinc nutrition of rice in sodic soil as influenced by amendments and zinc fertilisation

The influence of organic and inorganic amendments on the Zn nutrition of rice in sodic soil was investigated in this phase of the study. A non-saline calcareous sodic soil having pH and EC values of 8.95 and 0.42 m mhos/cm and ESP of 24 was employed and IR 8 was raised as the test crop. The status of available nutrients in the soil at transplanting, tillering and maturity stages of crop growth and dry matter yield, concentration and uptake of plant nutrients individually in grain, straw and root were determined. The amendments employed were gypsum, farm-yard manure and green manure each combined with four levels of Zn (0, 2.5, 5.0 and 7.5 ppm).

1. Soil studies

The soil analysis revealed that the incorporation of amendments and their incubation for ten days could bring about changes in pH, EC and available nutrients. The pH decreased from 8.9 to 8.1 in gypsum treatment and this was not the case with farm-yard manure and green manure. The increased availability of plant nutrients particularly N, P, K, Fe, Mn and Zn were noticed in farm-yard manure and green manure added treatments. Russel and Sieling (1952) also observed that addition of farm-yard manure and green manure increased the availability of nutrients. This may be ascribed to the release of nutrients from the added amendments as well as from the soil during the process of decomposition. The analysis of farm-yard manure and green manure used for the experiment also revealed, that these contained considerable amount of nutrients. The farm-yard manure contained 948 ppm Fe, 76 ppm Mn, 12 ppm Zn and 3.8 ppm Cu. The glyricidia used contained 212 ppm Fe, 52 ppm Mn, 32 ppm Zn and 6.5 ppm Cu. The analysis of soil samples at tillering and harvest stages also revealed a comparatively higher availability of nutrients due to treatment with organic amendments. The available Cu slightly decreased in farm-yard manure as compared to gypsum and green manure treatments. Thus increase or decrease in availability of Cu seems to depend on the nature of the organic matter. Farm-yard manure perhaps resisted more Cu entering into solution by forming insoluble complex, while green manure tended to cause an increase in available Cu through chelation. This may also be attributed to the pH reduction in gypsum treatment and release of Zn contained in the amendment itself in the others.

Application of Zn increased the available Zn and the increase was maintained throughout the crop growth. In the case of green manure there was further increase of available Zn at tillering stage in the Zn applied treatments. The combination of green manure and Zn was more favourable for maintaining a higher Zn availability than combination of Zn with farm-yard manure or gypsum. It may be mentioned that controversial views have been expressed in literature as to the possible role of organic matter in influencing available Zn. The available Zn tended to decrease with stages and this was more pronounced in gypsum treatment. In the absence of any added Zn, the level of available Zn decreased to the point of deficiency. Workers at Philippines (Anonymous, 1969) and Katyal (1972) observed that added organic matter to soils with high pH depressed the Zn availability. They attributed this to the formation of fulvic acid (Randhawa and Broadbent, 1965) with low stability constant (Schnitser and Skinner, 1966) and due to immobilisation of Zn by decomposing bacteria. Milapchand et al. (1977) compared the dithiozone extractable Zn as affected by different amendments in a highly sodic soil and observed lowest Zn in plots with $Al_2(SO_4)_3$ and gypsum and highest in plots treated with pressmud and farm-yard manure.

2. Dry matter yield

The application of green manure to the sodic soil proved to be more beneficial and economical. This treatment registered grain and straw yield increases of 26 and 29 per cent over gypsum and 6 and 14 per cent increases over farm-yard manure treatment. Highest root dry matter yield was also associated with this treatment. The computed total dry matter yield was 25 per cent more than gypsum and 13 per cent more than farm-yard manure. Thus both the organic amendments appear to provide a much favourable soil environment in sodic soils for rice growth. This is supported by the fact that the availability of plant nutrients was comparatively better in these cases as compared to gypsum. Zn application brought about grain and straw yield increases of 27 and 19 per cent over control. Root dry matter also increased slightly but not significantly. In the absence of any added Zn farm-yard manure and green manure showed better grain and straw yield over gypsum (Fig. 7).

Prasad et al. (1976) indicated that organic amendments and chelated Zn fertilisers were more effective than soluble Zn salts in alleviating Zn deficiency. Addition of Zn even at 2.5 ppm level brought about enhanced yield and this was more pronounced in green manure treatment. In other words, the grain and straw yield observed in gypsum plus Zn combination was observed in green manure treatment even without any added Zn. The addition of Zn further widened the yield difference between gypsum and green manure treatments. Thus green manure plus Zn combination may be considered as better suited than gypsum plus Zn. Farm-yard manure also recorded dry matter yield on par with green manure in the absence of any added Zn but Zn addition could not prove to be as much advantageous as it did with green manure. Govinda Iyer (1963) recommended application of 5 t/ha of gypsum and 5000 kg/ha of green manure for sodic soils of Tanjore.

Dargan *et al*. (1976) studied the effect of gypsum, farm-yard manure and Zn on rice yields in sodic soil and found 50 t/ha of farm-yard manure to give parallel yields to that of application of 45 kg per hectare of $ZnSO_4$.

3. Nutrition

The investigation on N nutrition revealed the highest total N uptake to be associated with "green manure plus 2.5 ppm Zn" treatment. This treatment recorded only less root and shoot N concentration at tillering as compared to gypsum owing to the dilution effect on account of increased dry matter yield. At maturity grain and root N concentration were not far different in this treatment with others but straw concentration was more. Thus enhanced grain yield with parallel N concentration and enhanced straw yield with increased N concentration were primarily responsible for the highest N uptake. Zn application favoured greater N concentration in root and shoot at tillering as well as in grain at maturity. This effect of Zn in increasing grain N concentration was observed for all the three amendments employed. This suggests that Zn has definite influence on N metabolism and mobilisation. The role of Zn as metalloenzyme for a number of anhydrases, dehydrogenases and proteinases was evidenced by Vollee and Wacker (1970).

Farmyard manure treatment recorded the highest P uptake by registering higher concentration of the element in grain and straw. Singh and Pati Ram (1977) observed more P uptake with farmyard manure. The availability of P was comparatively greater when P was applied along with organic amendments as compared to gypsum. Chhabra _et al_. (1976) observed reduction of available P as a result of reduction in pH in sodic soil due to application of amendments. The total uptake of P was not significantly different for different zinc levels. However Resell and Ulrich (1964) indicated Zn to increase P utilisation by its effect on P metabolism. The Zn-P interaction was found to be operating in grain. The reduction in P concentration in grain was counteracted by enhanced concentration of P in root. The farmyard manure amendment could offset this effect and grain P concentration remained parallel in all Zn levels. It is again the indirect beneficial effect of this amendment which probably could keep down the activity of those interacting with P mobilisation by supplying suitable chelating/complexing substances.

The root and shoot K concentration at tillering were not influenced by treatments and the uptake differences can be attributed to dry matter yield differences. At maturity, higher K uptake was associated with organic amendments. This may be due to the enhanced initial available K due to added amendments. The concentration of K in grain and straw were not influenced to any significant extent by amendments. Green manure caused greater K concentration and uptake in root. Zn fertilisation tended to show no interaction with K and the uptake difference can be attributed to dry matter yield variations. Thus, there was no pronounced effect of treatments on K nutrition. However, it may be mentioned that the concentration and uptake of K were comparatively less in sodic soil as a general rule.

The total Ca uptake was again highest in green manure treatment. This treatment showed the least concentration and uptake in shoot and root at tillering. At maturity, however, this treatment recorded the highest uptake which was mainly contributed by grain. The concentration and uptake were more in grain, straw and root in this treatment. The availability of Ca was considerably high in all treatments and the uptake differences were caused by dry matter yield differences. There was increased total Ca uptake due to Zn application and again this has arisen due to dry matter yield variations rather than concentration differences. The treatments imposed, however, produced a pronounced impact on Mg nutrition. The status of available Mg was considerably high in all treatments.

Green manure application favoured higher concentration and uptake of Mg in shoot and root at tillering. The enhanced dry matter yield and increased Mg concentration assumes more importance in view of close relationship of Mg with photosynthetic apparatus. At tillering, Zn application also favourably interacted and Mg concentration in both shoot and root tended to increase. Thus, the synergistic effect of Zn on Mg nutrition observed in the earlier phases of the study was observed in sodic soil as well.

Burrows and Gammon (1960) observed mutual complimentary effects of Zn and Mg due to similarity of ionic sizes. The overall effect was that both greenmanure and farmyard manure showed greater total uptake of Mg than gypsum in tune with dry matter yield.

While the amendments had no differential influence on the concentration of Fe in grain and root there was increase in straw Fe concentration. The organic amendments registered higher uptake than gypsum. Interaction of organic matter with Fe through chelation in the former case and Ca-Fe antagonism in the latter case are primarily responsible for the above phenomenon. Zn application tended to decrease Fe concentration in grain, straw and root. Such depressing effect of Zn on Fe concentration was also observed by several workers as discussed in earlier phases. The uptake differences can be attributed to dry matter yield differences. The phenomenal role of organic amendments in enhancing Fe uptake and the effect of Zn fertilisation in decreasing the uptake were revealed even at the tillering stage.

The manganese nutrition was found to be not appreciably influenced by both amendments and Zn fertilisation in sodic soil in spite of differences in availability in soil. The uptake differences may be ascribed to dry matter yield differences. It may be mentioned that in the earlier phases of the study also the tendency on the part of Zn fertilisation to enhance Mn concentration in grain and straw and decrease of concentration in root were observed. In the present phase also concentration of Mn in grain, straw and root remained parallel in spite of increase in dry matter yield differences on account of Zn fertilisation and the absence of dilution effect point to the fact that Zn favoured greater absorption.

The differences in amendments and Zn fertilisation brought about variation in Cu nutrition. Green manure caused greater uptake and use of Zn beyond 5 ppm caused a significant depression of total Cu uptake. The interacting effect of Zn was observed irrespective of the amendments employed. However, green manure recorded the highest root concentration of Cu and the least straw Cu concentration.

Gypsum also was observed to cause uptake values on par with green manure and this was mainly contributed by straw. The beneficial effect of gypsum may be attributed to the pH effect, while that of green manure to chelating effect. Farm-yard manure showed low concentration and uptake values of Cu owing perhaps to formation of insoluble complexes.

The deficiency in sodic soil being one among the major factors which limit crop growth (Singh and Sekhon, 1977) the influence of amendments and Zn fertilisation is of great significance. In the present study the use of different amendments and addition of Zn fertiliser brought about differences in the concentration and uptake of Zn. At tillering phase farm-yard manure showed a relatively higher shoot Zn concentration as compared to gypsum and green manure in the absence of any added Zn. The concentration values observed were 20, 38 and 26 ppm respectively for gypsum, farm-yard manure and green manure. A leaf Zn concentration of 15 ppm (Katyal and Ponnamperuma, 1973) and 10 ppm (Krishnamurthy et al., 1973) in 50 days old plants were considered as critical. Mere application of the amendments without being supplemented by any Zn fertiliser appears to ensure marginal Zn concentration values. However, added Zn fertiliser proved useful in enhancing shoot Zn concentration which also relfected in increased dry matter yield both at tillering and at harvest.

Even in the absence of any added Zn no deficiency symptoms were exhibited and perhaps hidden hunger had existed. The amendments brought about significant differences in concentration of Zn in grain and straw at harvest. All amendments when accompanied by Zn fertiliser ensured better straw Zn concentration than when applied alone. The uptake of Zn was the highest in green manure treatment and increased due to Zn fertilisation. This is attributable to dry matter yield differences apart from variation in concentration. The uptake pattern (Fig.8) threw light on the fact that the organic amendments could help not only in keeping better availability of the element in the soil but also favour translocation within the plant. The percentage of total absorbed Zn mobilised into grain was not far different in different treatments but that accumulating in straw was considerably more due to addition of organic amendments particularly farmyard manure. This explains the possible role of chelating substances in rendering the element more free for mobilisation. Such beneficial effect of organic matter in regulating the micronutrients in plants apart from influencing the availability of nutrients was evidenced by Brown (1961). Heim (1966) though the use of isotopes indicated that plants are capable of absorption of different organic molecules via roots.

It is perhaps for this reason that the application of 50 t/ha of farmyard manure has been reported to have the same effect as application of 45 kg/ha of $ZnSO_4$ (Dargan *et al*. 1976).

It follows from the foregoing discussion that the use of organic amendments caused greater availability of most nutrients and Zn fertilisation could increase the availability of the element in sodic soil when applied in combination with amendments. Organic amendments (farmyard manure or green manure at 30 t/ha) plus Zn (2.5 ppm) was observed to be superior to gypsum (12t/ha). These treatments showed grain yield increase of 14 per cent over gypsum. The straw yield also increased by 11 per cent in farmyard manure and 44 per cent in green manure. The availability of Zn in the soil at planting, tillering and the concentration and uptake of the element by rice were comparatively better in the above treatments as compared to gypsum.

4. Equivalent concentration of nutrients in relation to Zn

The studies on the equivalent concentration of nutrients as a ratio with equivalent concentration of Zn gave evidence for the favourable influences of organic amendments as well as Zn fertilisation to sodic soil. The organic amendments tended to narrow down most ratios in shoot and when supplemented with Zn fertilisation they tended to cause further decrease of the ratio. The decreases may be ascribed mainly to enhanced concentration of Zn in shoot. It may be indicated that the grain and straw yield at harvest was negatively correlated with most of the ratios (Table L). However Mg/Zn ratio was contrary to what was observed in most other cases. This is because of appreciable increase in shoot Mg content in treatments receiving organic amendments and also the synergistic influence of Zn on Mg uptake. However mention may be made that this ratio failed to have any significant relationship with grain and straw yield.

The ratios in the root also varied considerably and the organic amendments tended to show low N/Zn ratio. This is due to relatively low N concentration of root as compared to gypsum treatment. The mean root N content was 1.42 for organic amendments as against 2.63 for gypsum. The two organic amendments behaved differently in respect of nutrient ratios in roots. Use of farmyard manure showed wide ratios of P/Zn, K/Zn, Ca/Zn, Mg/Zn, Fe/Zn and Cu/Zn in root. Combination of Zn with farmyard manure tended to decrease most ratios whereas the ratios widened when combined with green manure. The above effects are persumably due to the differences in composition and bio-chemical changes during decomposition.

D. Zinc nutrition of rice as influenced by sources and methods of zinc application

In this phase of the study the availability of nutrients in the soil at tillering and harvest stages as well as the growth and nutrition of rice (Var. Bhavani) during the above stages as influenced by different sources and methods of application of Zn were investigated by a pot experiment. The Zn deficient soil employed for the first phase of the study was used. Chloride, sulphate, phosphate, acetate, oxide, EDTA and elemental forms of Zn were compared. Dipping of seedling roots in ZnO suspension, application of $ZnSO_4$ to the nursery and seed soaking technique in $ZnSO_4$ and ZnEDTA were also included to study their comparative efficiency.

1. Soil studies

The studies on soil samples at tillering and harvest stages showed that whatever be the source of Zn, soil application of the material increased the availability of the element and the resulting availability was maintained up to harvest. In other treatments Zn availability was on par with control and Zn availability in these remained within critical to marginal levels. The soil had normal pH and was inherently deficient in Zn and hence the added Zn fertilisers to the soil caused an increase in availability of Zn. The availability of other plant nutrients were not affected to any appreciable degree due to the treatment differences.

2. Dry matter yield

The variation in the sources of Zn and differences in the modes of application brought about significant changes in the growth and nutrition of rice. Among the eleven treatments employed barring control, Zn dust, $Zn(CH_3COO)_2$ and nursery feeding treatments, the grain yield was on par. The choice, therefore, depends on practical and economic considerations. The percentage of increase ranged from 7.2 to 29.4 per cent over control in various treatments. The attention naturally is focussed on the seed soaking technique, particularly ZnEDTA. This treatment recorded grain, straw, root and total dry matter yield increases of 29.4, 30.4, 55.5 and 30 per cent over control. It is a matter of interest to note that Zn enrichment of the seed through soaking (Zn content of seed from an initial presoaking concentration of 8 ppm increased to 32 ppm after 24 hours of soaking in 0.1 per cent ZnEDTA) could satisfy the Zn need of the crop. Kang and Okoro (1976) also observed such Zn enrichment of seeds due to soaking in ZnEDTA and increase of plant dry matter. As was the case with the previous phases the typical Zn deficiency symptoms were not exhibited by the plant and perhaps there existed hidden hunger.

The status of available nutrients but for Zn in the above case remained parallel and the increased growth may be ascribed to enhanced Zn made available to the plant through seed soaking. Soaking of seeds in $ZnSO_4$ (1 per cent for 24 hours) also caused Zn enrichment (24 ppm) and accounted for almost identical increased total and individual dry matter yield (Fig. 9).

Sedberry et al. (1971) obtained higher rice yield with ZnO than with $ZnSO_4$ or ZnEDTA although the differences among the sources were not significant. Kang and Okoro (1976) recommended pre soaking of rice seeds with 0.5% Zn suspension to overcome Zn deficiency.

In the field experiments at Punjab (Anonymous, 1977) the highest response was observed in broadcast application of 7.5/10 ppm Zn. Seedling root dipping in 4 per cent ZnO suspension was equally efficient. However, the seed soaking technique was not tested and sodic soil was employed. The $Zn(CH_3COO)_2$ source deserves special mention in view of the fact that the total and individual dry matter yield in this treatment were much less even to control. While the availability of the nutrients was not far different from other treatments it is perhaps the acetic acid which can be expected to be produced following $Zn(CH_3COO)_2$ application proved harmful to the normal growth of root and shoot. Forno et al. (1975) observed addition of acetic acid at 0.3 mM to reduce Zn by 80 per cent and 10 to 30 mM to reduce the same by 94 per cent in the shoots of rice plant. In this treatment

N, K, Ca, Mg, Fe, Mn, Cu concentration seem to be not affected but P and Zn concentration of shoot and root suffered at tillering. The earlier poor vigour and nutrient uptake have accounted for poor uptake.

3. Nutrition

A consideration of the nutrient concentration at tillering revealed a comparatively higher shoot N concentration and lower root N concentration due to Zn enrichment of seeds. The possibility of Zn having definite interaction with N nutrition as was the case in other phases was evident in this phase also. These two treatments registered the highest shoot N uptake and comparatively less root N uptake as compared to other Zn receiving treatments. It is a question of more efficient utilisation of N absorbed by the plant. At harvest the grain N concentration was not much different but straw and root N concentration varied significantly. The latter effect may be ascribed to a possible dilution effect as increased shoot and root growth were observed in this treatment. Although many other treatments showed greater total uptake and could increase the grain, straw and root dry matter yield as compared to control, the seed enrichment technique particularly ZnEDTA could account for better if not significant uptake of N.

The concentration of P in shoot decreased while that in root increased as a result of soil application of Zn. This was observed both the tillering and harvest stages. The application of Zn dust had a severe impact on root and shoot P concentration both at tillering and harvest. $Zn_3(PO_4)_2$ and ZnEDTA soaking showed no such detrimental effect on P nutrition. $Zn_3(PO_4)_2$, $ZnSO_4$ and ZnEDTA showed more or less equal total Zn uptake values but root P concentration in the former two were considerably more. There is thus a tendency for inorganic Zn to cause immobilisation of absorbed P in root. There was no evidence for Zn-P antagonism, perhaps due to the low level of Zn employed. Thus ZnEDTA favoured better P nutrition apart from nitrogen discussed earlier. The variation in uptake values in respect of other treatments may be ascribed to dry matter yield variations rather than concentration differences.

In respect of K and Ca nutrition both at tillering and at harvest there was no conspicuous variation in uptake and slight differences in concentration are attributable to dry matter yield variations as well as dilution effects. Concentration as well as uptake of Mg by shoot and root tended to improve even at tillering due to Zn fertilisation, the effect being not observed in $Zn_3(PO_4)_2$ and nursery feeding with $ZnSO_4$ treatments. At harvest also the added Zn fertilisers accounted for enhanced Mg concentration in shoot but the concentration of the element in the root decreased. Control treatment registered the highest root Mg concentration. The increase in dry matter yield accompanied by increase in Mg concentration of straw and decrease of Mg concentration in root as a result of Zn fertilisation point to the fact that there is synergistic Zn-Mg interaction. This is further evidenced by the fact that in soaking procedure there was pronounced and significant increase in shoot Mg concentration perhaps due to increased activity of Zn ions in the plant system. Thus the influence of Zn on Mg nutrition as observed in other phases of the study was observed in this phase also.

The influence of sources and methods of Zn application on Fe nutrition were not of any great significance. The tendency for Zn to decrease Fe concentration of shoot and increase the same in root was however, observed in this phase as well. At harvest any concentration variation was confined to the root only. The uptake and concentration differences have arisen mainly due to dry matter yield differences. The Mn nutrition at tillering revealed Zn-Mn antagonism and this was more pronounced due to Zn enrichment of the seed through soaking. However, these two treatments recorded the highest uptake of Mn owing to enhanced dry matter yield. At harvest there was enhanced total Mn uptake due to Zn addition irrespective of the sources and methods.

The concentration and uptake in grain, straw and root revealed that there was increased accumulation of Mn in root due to Zn addition, the effect being more pronounced in treatments which received soil application of Zn fertilisers.

The Cu nutrition also showed significant variations. At tillering the control treatment recorded the lowest shoot but the highest root concentration of the element. Zn fertilisation, whatever may be the source and method of application, tended to decrease root Cu concentration but increase shoot Cu concentration. This suggests the possible role of Zn on Cu mobilisation. At harvest the above trend continued and grain concentration increased, straw and root concentration decreased in comparison to control. This indicates the further evidence for the possible role of Zn in mobilising Cu. An overall picture as evidenced from high concentration of Cu in root and shoot at tillering and grain at harvest and comparatively high uptake in control suggests that Zn-Cu antagonism have operated. However, seed soaking method employing chelated Zn appears to be ~~an~~ exempt from the above rule and caused as much uptake of Cu as was in control and ensured a high Cu concentration in straw both at tillering and at harvest.

The differences in the sources and methods of application obviously produced marked differences in the absorption and translocation of Zn. Control treatment registered the lowest root and shoot concentration at tillering. The concentration of 16 ppm Zn was perhaps sufficient to overcome deficiency but insufficient to completely satisfy Zn hunger. This is evidenced by the fact that no deficiency symptoms were exhibited although the growth vigour by visual appearance was not the same as in most other treatments. The Zn fertilisation irrespective of the sources and methods with the exception of $Zn(CH_3COO)_2$ caused an increase in shoot Zn concentration at tillering and harvest. The overriding superiority of ZnEDTA soaking method in being able to cause three to four fold increase in concentration of Zn over other treatments was a matter of interest. The next best was again seed soaking in $ZnSO_4$. Thus, enrichment of the seed with Zn through soaking more particularly in chelated Zn solution results in higher concentration of the element in shoot. Since the concentration of Zn in shoot at tillering has greater significance in influencing the yield this phenomenon assumes great value. It is also worthy to note that the high shoot concentration is attributable to the greater mobility enjoyed by chelated form as evidenced by comparatively less root Zn concentration. The concentration differences coupled with dry matter yield variation have accounted for uptake differences. At harvest the differential effect of treatments in influencing Zn nutrition was further brought out (Fig.10). The grain, straw and root concentration of the element was markedly improved due to added Zn fertiliser. Soil application of Zn fertilisers ensured comparatively higher total uptake. Among other treatments ZnEDTA soaking also showed uptake on par with the above treatments but registered greater mobility as evidenced by lower root, but higher grain and straw Zn concentration.

Greater utilisation of Zn from ZnEDTA than from $ZnSO_4$ is of considerable interest. Though plant absorption of ZnEDTA has not been studied, studies with Fe and Mn chelates have indicated that these complexes are absorbed and translocated to the top of plants. The soluble forms of Zn are rapidly converted to exchangeable or acid soluble forms both of which can be considered only as partly available for root absorption. Because of binding energies and immobilisation the EDTA complex could remain completely dissolved in soil solution. Acting as a mobile element it would have the advantage of moving with the soil solution to all parts of the soil mass.

It follows from the foregoing discussion that Zn application with the exception of $Zn(CH_3COO)_2$ brought about significant improvement in grain yield. Among the sources and methods, $Zn(CH_3COO)_2$ nursery feeding and Zn dust treatments proved to be not as much advantageous as others. Among the rest seven treatments the choice depended upon cost and ease of availability of the material. Naturally the focus lies on seed soaking methods. $ZnSO_4$ soaking method involves use of 400 g of $ZnSO_4$ in 40 litres of water costing Rs.15/ha while the cost for the use of ZnEDTA (40 g in 40 litres of water) being Rs.30/ha. Considering the overriding influence of Zn EDTA soaking method which apart from ensuring comparatively high Zn concentration at tillering phase of the crop also tended to show 29 per cent increased grain yield as compared to only 17 per cent for $ZnSO_4$ soaking it is reasonable to fix this as more efficient among the two. However under conditions of non-availability of ZnEDTA, soaking with $ZnSO_4$ may be employed.

SUMMARY

CHAPTER VI

SUMMARY

The influence of varieties, soil conditions, sources and methods of Zn fertilisation on the growth and nutrition of rice was investigated. The studies were carried out with four main objectives viz. (i) to study the responses of genetically variable popular rice varieties of Tamil Nadu for Zn fertilisation (ii) to study the influence of soil conditions and Zn fertilisation on the growth and nutrition of rice (iii) to study the growth and nutrition of rice in sodic soil under the influence of organic and inorganic amendments and Zn fertilisation and (iv) to study the relative efficacy of different sources and methods of application of Zn on the growth and nutrition of rice.

Ten rice varieties (viz. Co 39, Co 37, TNAU 658, IR 20, RP 4-14, Ponni, Bhavani, IR 8 , Co 38 and TNAU 13493) were raised in pots under four levels of Zn (viz. No Zn, 5, 10 and 15 ppm) employing a Zn deficient soil (0.8 ppm available Zn). The total and individual yield of grain, straw and root as well as concentration and uptake of nutrients were studied.

In the second phase, a pot experiment was carried out employing four soil conditions (viz. normal soil, calcareous soil, organic matter enriched soil and submerged soil) and three Zn treatments (No Zn, $ZnSO_4$ and ZnEDTA). Rice variety RP 4-14 was raised as test crop.

The third experiment involved twelve treatments formed from combinations of three amendments (gypsum, farmyard manure and green manure) and four levels of Zn (No Zn, 2.5, 5.0 and 7.5 ppm). The treatments were imposed on a calcareous non saline sodic soil (pH 8.[illegible] and ESP 23.4) in pots and IR 8 was grown as test crop.

The final phase represents another pot experiment employing eleven treatments. The different sources of Zn tried were Zn dust, $ZnCl_2$, $ZnSO_4$, $Zn_3(PO_4)_2$, $Zn(CH_3COO)_2$, and ZnEDTA and methods of application tested were application of $ZnSO_4$ to nursery, dipping of seedling roots in ZnO suspension and soaking of seeds in $ZnSO_4$ and ZnEDTA.

In all the above studies soil and plant samples at tillering and harvest stages were examined in detail. The total and individual dry matter yield of grain, straw and root and uptake data computed from percentage values were critically studied. Correlation coefficients were also worked out to study the interrelationship among various soil and plant characteristics.

The salient findings emanating from the investigation are summarised below.

(1) There is high genetic variability in rice varieties towards responses for Zn fertilisation. Based on the responses among the ten varieties tested, three groups were recognised (a) high responsive varieties (IR 8 and RP 4-14) (b) medium responsive varieties (Bhavani, Co 38, Co 40 and TNAU 658) and (c) non responsive varieties (Co 37, IR 20, Co 39 and Ponni).

(2) Growing of rice in different soil conditions such as normal soil, calcareous soil, organic matter enriched soil and submerged soil resulted in differential dry matter yield at tillering and harvest stages. Organic matter enriched soil even in the absence of any added Zn registered significant increase in grain, straw and root yields as compared to other soil conditions.

(3) While the application of Zn showed no response in normal and organic matter enriched soil, increased grain and straw yield were observed in calcareous and submerged soil. In either case ZnEDTA appeared to be more beneficial than $ZnSO_4$.

(4) A considerable reduction in the chaff percentage was observed due to the use of Zn fertiliser and this was particularly so in calcareous and submerged soil.

(5) For calcareous, non saline sodic soil application of organic amendments (farmyard manure and green manure) recorded higher grain and straw yield as compared to gypsum.

(6) Application of green manure (30 t/ha) plus 2.5 ppm of Zn to calcareous non saline sodic soil proved to be more beneficial than other treatments. The above treatment recorded grain yield increases of 26 and 6 per cent respectively over gypsum and farmyard manure treatments. There was increase in straw yield also to the extent of 29 and 14 per cent respectively.

(7) Enrichment of the rice seeds with Zn through soaking (0.1% ZnEDTA or 1% $ZnSO_4$ for 24 hours) recorded grain and straw yield on par with soil application of various sources of Zn.

(8) Application of Zn $(CH_3COO)_2$ (5ppm Zn) proved to be harmful as the grain and straw yield in this treatment were lower even to control persumably due to toxic accumulation of acetic acid in soil.

(9) Zinc fertilisation to Zn deficient soil favoured greater concentration and uptake of N. This beneficial effect was also observed in calcareous soil, submerged soil and sodic soil. A tendency for greater mobilisation of N into grain due to addition of Zn fertilisers was also observed.

(10) Among the rice varieties IR 8, Co 38 and Bhavani recorded comparatively higher P uptake. In all the varieties the P uptake decreased at 15 ppm level of Zn fertilisation.

(11) Zinc fertilisation had no marked influence on K nutrition of rice under all soil conditions. However, calcareous soil hindered K nutrition by decreasing absorption by the plant. Concentration and uptake of K were also comparatively lower in sodic soil. Enrichment of the soil with organic matter both in normal and calcareous soil favoured greater K uptake.

(12) A relatively higher accumulation of Ca in straw was observed in Zn responding rice varieties IR 8 and RP 4-14.

(13) Long duration varieties and Zn responding types recorded higher grain and straw Mg concentration. Zn fertilisation showed synergistic effect on Mg nutrition under all soil conditions.

(14) The highest total Fe uptake was observed in CO 38 and the least uptake in CO 39. Total uptake of Fe progressively and significantly decreased with the addition of Zn fertiliser.

(15) The uptake of Cu by root increased while that of straw uptake of Cu decreased as a result of Zn fertilisation.

(16) Enrichment of the soil with organic matter showed greater concentration and uptake of N at tillering as well

as at harvest. Calcareous soil showed less concentration of N. In sodic soil application of green manure plus 2.5 ppm Zn favoured higher N uptake at harvest. Zn fertilisation irrespective of soil condition had a favourable effect on N nutrition of rice.

(17) Neither the soil condition nor Zn fertilisation brought about any significant difference in grain and root P concentration. Submerged soil recorded highest straw P content while that relating to calcareous soil the least P content. In sodic soil the use of farm-yard manure recorded highest concentration and uptake of P by grain and straw as compared to gypsum and green manure.

(18) Addition of green manure to normal soil as well as sodic soil favoured greater concentration and uptake of Mg by the rice plant.

(19) Submergence as well as organic matter addition to normal and sodic soil resulted in enhanced concentration of Fe in soil solution and increased concentration and uptake of the element by rice.

(20) Zinc fertilisation under all soil conditions decreased the concentration of Fe in grain, straw and root, the effect being more pronounced with ZnEDTA.

(21) Calcareous soil recorded decreased concentration and uptake of Mn. Application of amendments to sodic soil had no influence on Mn nutrition.

(22) Zinc fertilisation under all soil conditions favoured greater absorption and translocation of Mn.

(23) Genetic variability and Zn fertilisation caused pronounced changes in the concentration and uptake of Zn by rice. In the absence of addition of Zn fertiliser to a Zn deficient soil, IR 20 recorded the highest root Zn concentration while CO 40 recorded highest grain and straw Zn concentration. As a general rule roots contained two to three fold higher concentration of Zn as compared to grain and straw.

(24) Zinc fertilisation progressively increased Zn concentration of grain, straw and root. The mean increase ranged from 47 to 80 per cent in grain, 32 to 60 per cent in straw and 10 to 21 per cent in root.

(25) Addition of organic matter to normal soil as well as calcareous sodic soil and Zn fertilisation caused enhanced availability of Zn and the resulting availability was maintained in the post harvest soil as well.

(26) Calcareous soil and submerged soil suffered most in respect of Zn nutrition in the absence of any added Zn.

Application of Zn in either form ($ZnSO_4$ or ZnEDTA) improved the concentration and uptake of the element at tillering as well as at maturity.

(27) In sodic soil all amendments when accompanied by Zn fertiliser ensured better Zn concentration than when applied alone. Green manure plus Zn combination recorded highest uptake.

(28) From the studies on comparative efficacy of different sources and methods of application, the overriding superiority of seed soaking procedure either with $ZnSO_4$ (1%) or with ZnEDTA (0.1%) was brought out. These treatments ensured higher grain and straw concentration of Zn and registered total Zn uptake on par with soil application of several sources of Zn.

(29) The correlation studies revealed the existance of significant positive relationship between shoot Zn concentration at tillering and grain, straw and root dry matter yields at harvest.

(30) The status of available Zn in soil at tillering showed positive relationship with total and straw dry matter yield at harvest.

(31) The status of available Zn in soil at tillering was found to have significant positive relationship with grain Zn concentration. The straw and root Fe content at harvest showed negative relationship with available Zn in the soil.

(32) The relative concentration of several nutrients at tillering (i.e. N/Zn, K/Zn, Ca/Zn, Fe/Zn, Mn/Zn and Cu/Zn worked out on equivalent basis) were negatively related to the grain and straw yield at harvest indicating higher Zn requirement with increasing levels of other nutrients.

Considering an over all picture, it may be indicated that there exists genetic variability in rice varieties of Tamil Nadu for responses to Zn fertilisation. IR 8 and RP 4-14 were observed to be highly responsive while IR 20, CO 37 are more tolerant under Zn deficiency conditions. Calcareous soil and submerged soil responded to Zn fertilisation and ZnEDTA even at very low dose appeared as efficient as $ZnSO_4$. Application of green manure plus 2.5 ppm Zn to calcareous sodic soil registered significant and marked improvement in grain and straw yields in rice var. IR 8 as compared to farmyard manure and gypsum, alone as well as in combination with Zn. Application of Zn fertilisers in general influenced N, K, Mg, Fe, Mn, Cu and Zn nutrition of rice. The increased Zn requirement with increasing concentration of most nutrients in straw was indicated. The seed soaking procedure either with $ZnSO_4$ or with ZnEDTA appeared to be very efficient and economical in satisfying the Zn hunger of rice in a Zn deficient soil.

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* Original not seen

FIGURES

VARIETAL RESPONSES TO ZINC FERTILISATION IN RICE

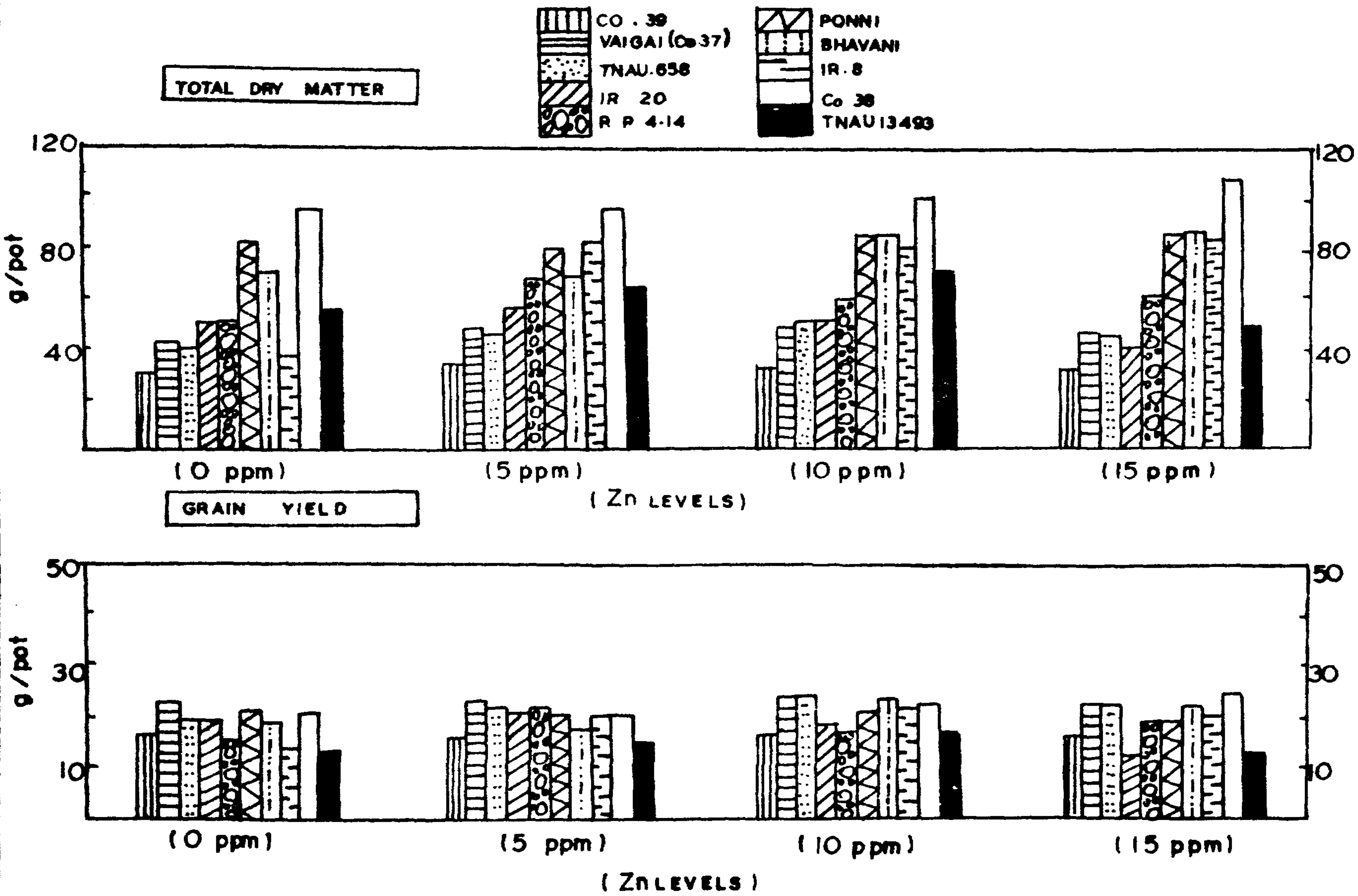


FIG. 1

VARIETAL RESPONSES TO ZINC FERTILISATION

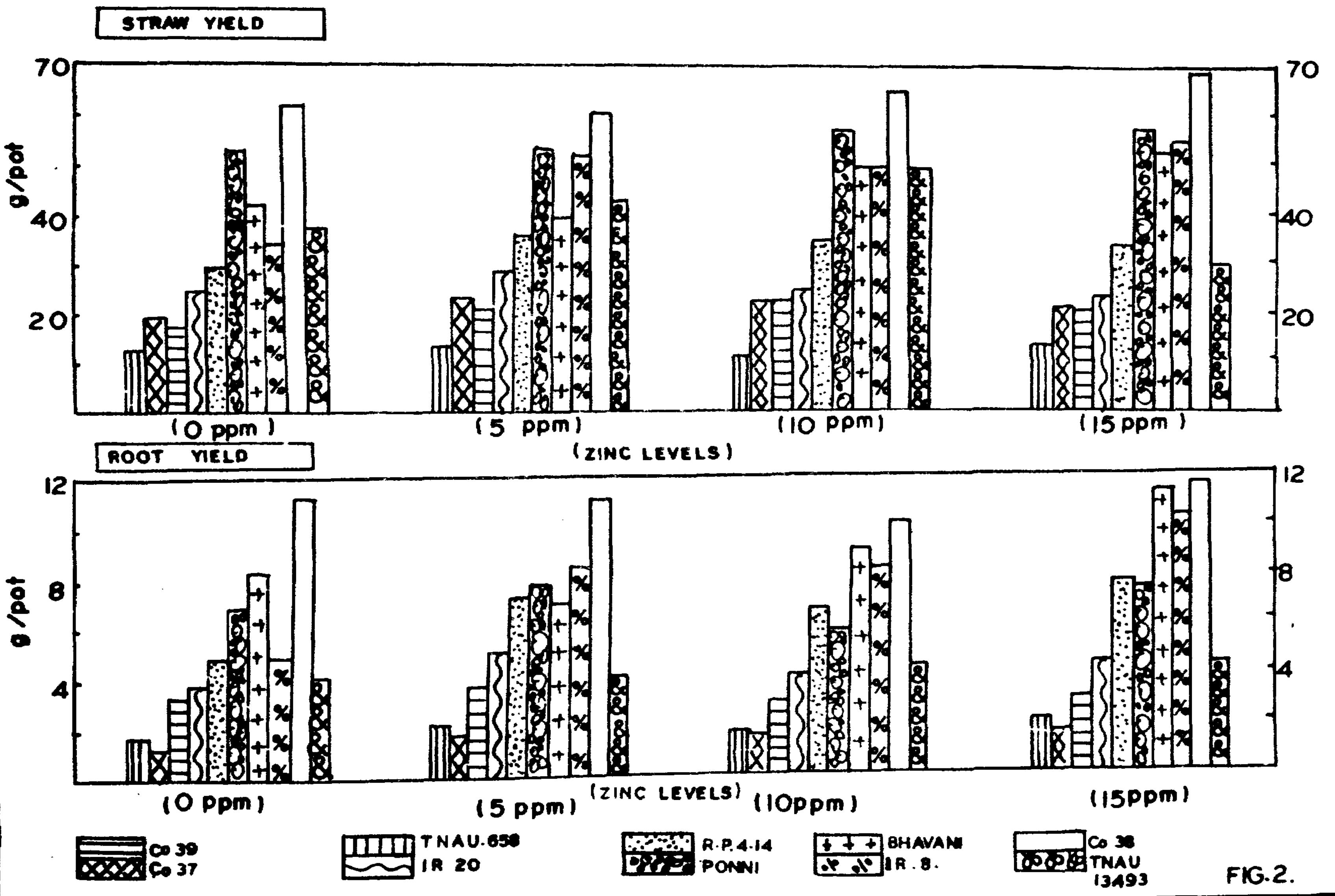


FIG.2.

CONC. OF Zn IN GRAIN, STRAW AND ROOT OF DIFFERENT RICE VARIETIES

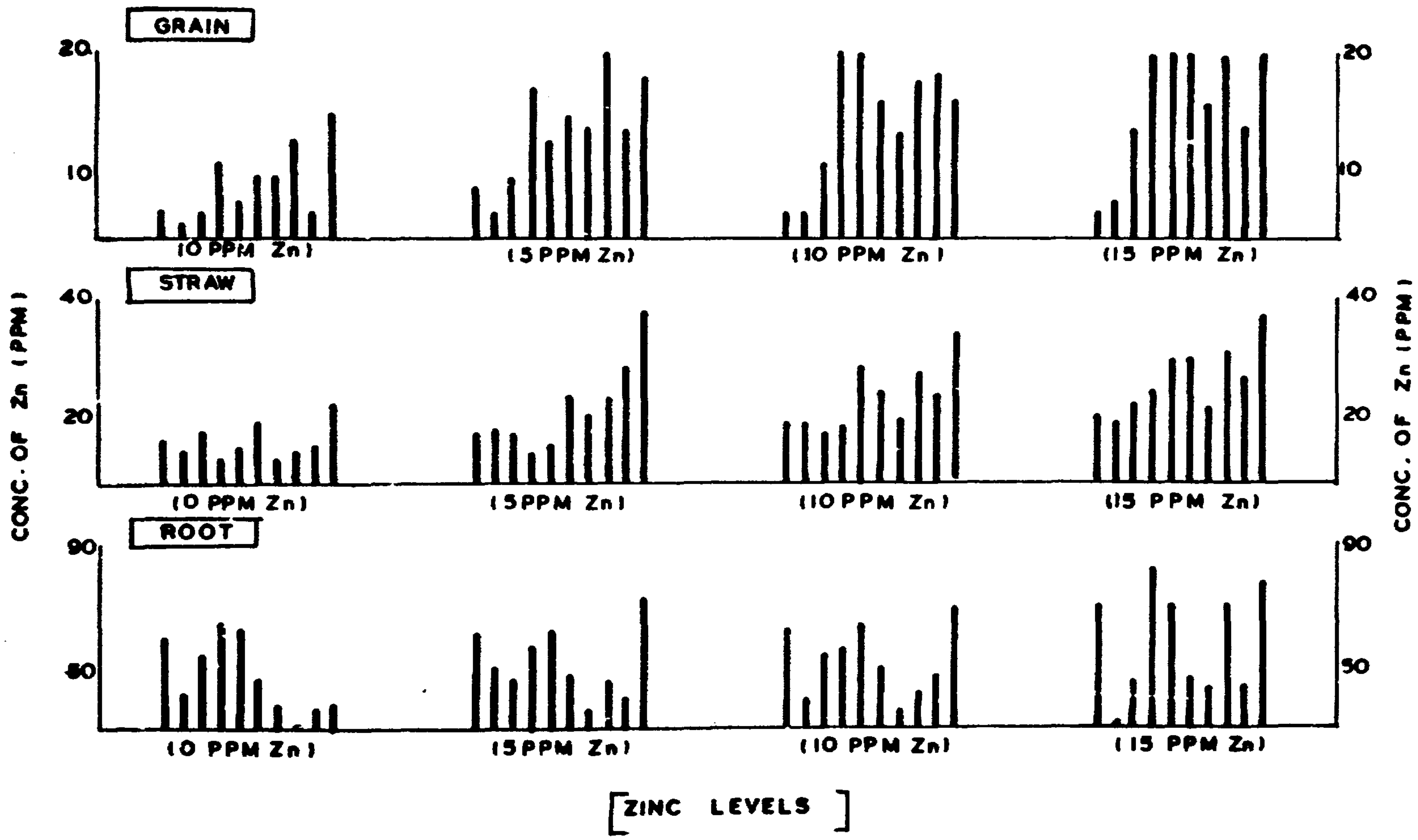


FIG.3

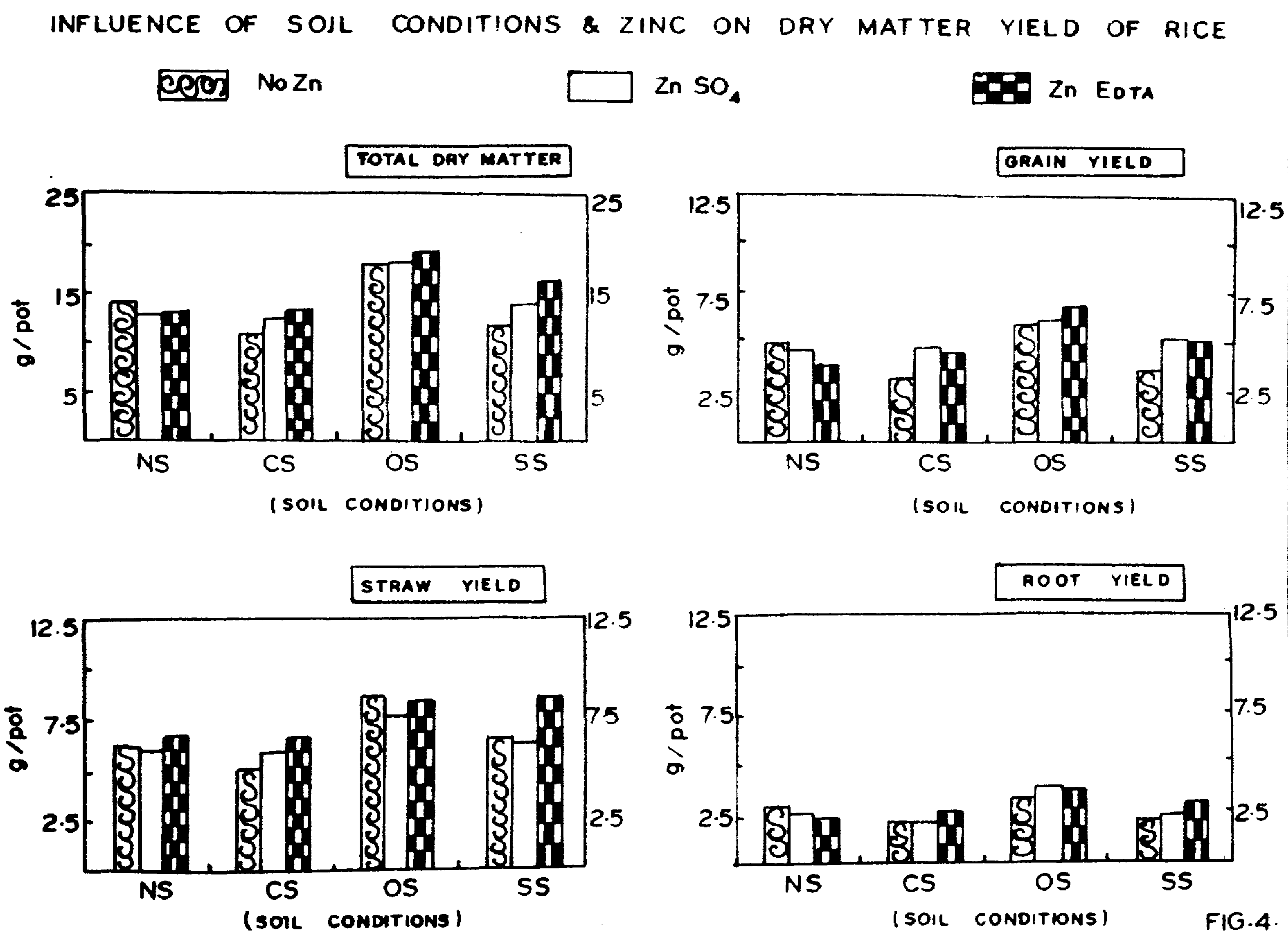

INFLUENCE OF SOIL CONDITIONS & ZINC ON DRY MATTER YIELD OF RICE
No Zn
Zn SO_4
Zn EDTA
TOTAL DRY MATTER
GRAIN YIELD
STRAW YIELD
ROOT YIELD
g/pot
25
15
5
12.5
7.5
2.5
NS
CS
OS
SS
(SOIL CONDITIONS)

FIG.4

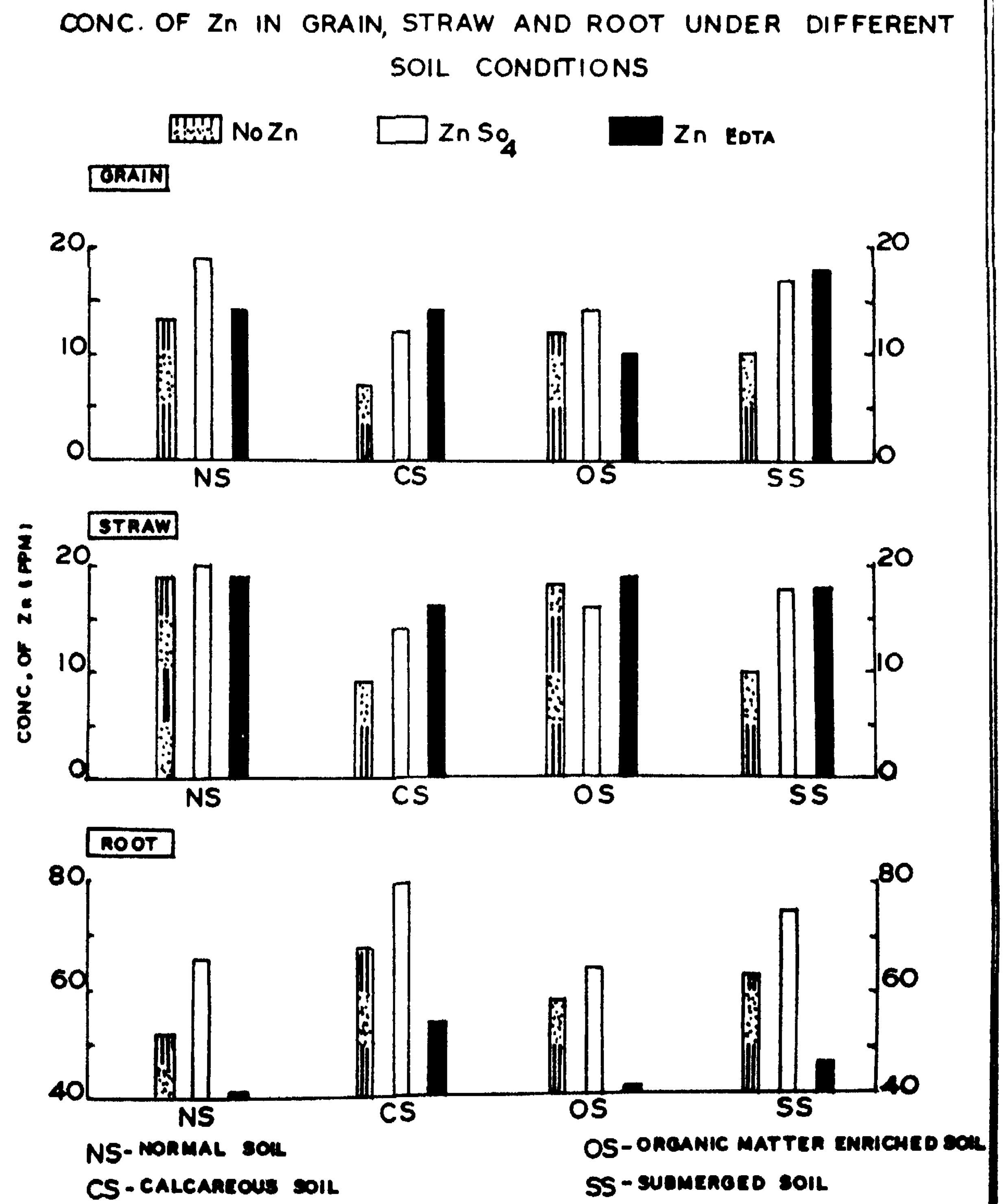

CONC. OF Zn IN GRAIN, STRAW AND ROOT UNDER DIFFERENT SOIL CONDITIONS
No Zn
Zn So4
Zn EDTA
GRAIN
STRAW
ROOT
CONC. OF Zn (PPM)
NS
CS
OS
SS
NS - NORMAL SOIL
CS - CALCAREOUS SOIL
OS - ORGANIC MATTER ENRICHED SOIL
SS - SUBMERGED SOIL

FIG.5.

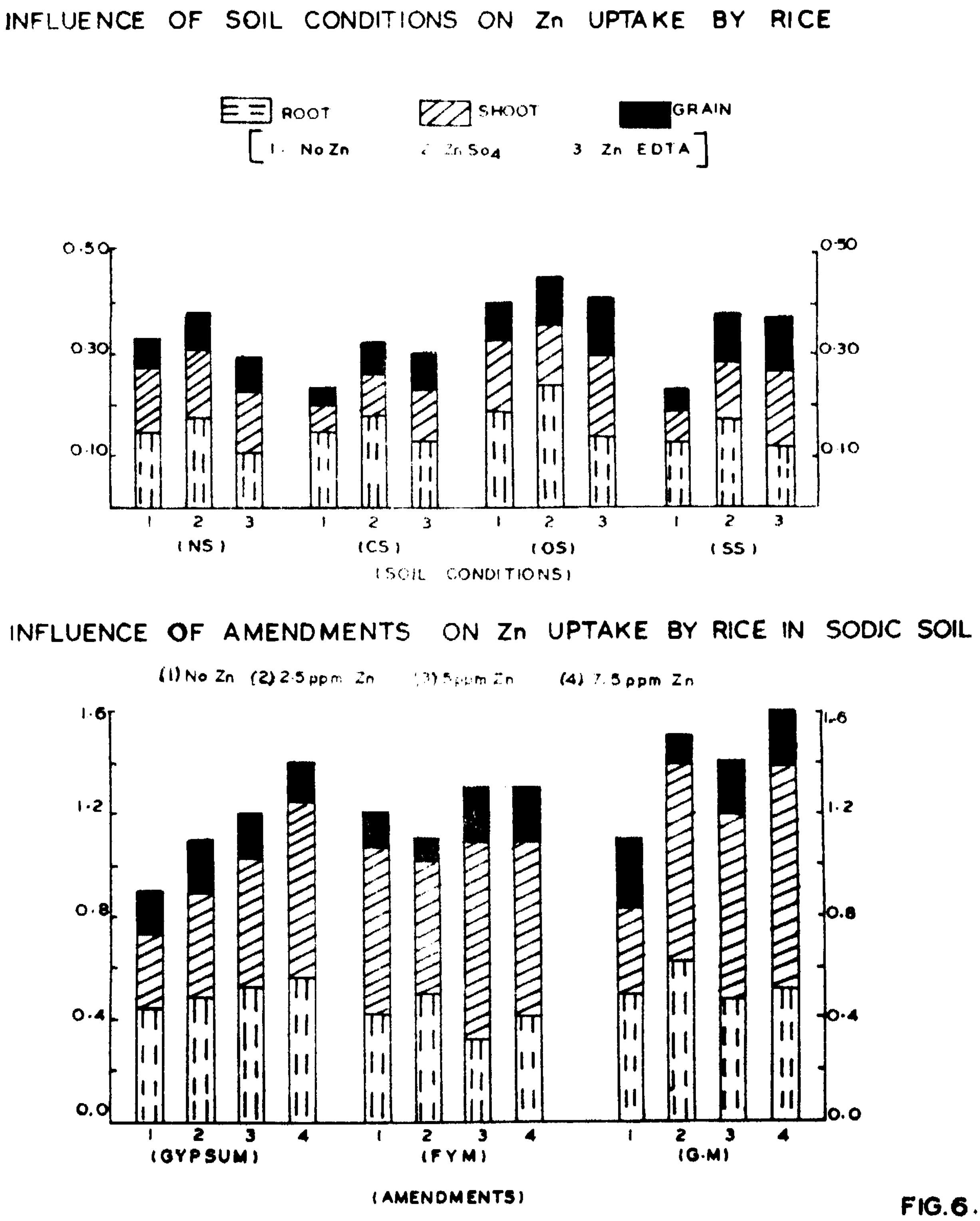

INFLUENCE OF SOIL CONDITIONS ON Zn UPTAKE BY RICE
ROOT
SHOOT
GRAIN
1. No Zn
2. Zn So4
3. Zn EDTA
0.50
0.30
0.10
1 2 3
(NS)
(CS)
(OS)
(SS)
(SOIL CONDITIONS)
INFLUENCE OF AMENDMENTS ON Zn UPTAKE BY RICE IN SODIC SOIL
(1) No Zn
(2) 2.5 ppm Zn
(4) 7.5 ppm Zn
1.6
1.2
0.8
0.4
0.0
1 2 3 4
(GYPSUM)
(FYM)
(G.M)
(AMENDMENTS)

FIG.6.

AMENDMENTS AND ZINC ON DRY MATTER YIELD OF RICE IN SODIC SOIL

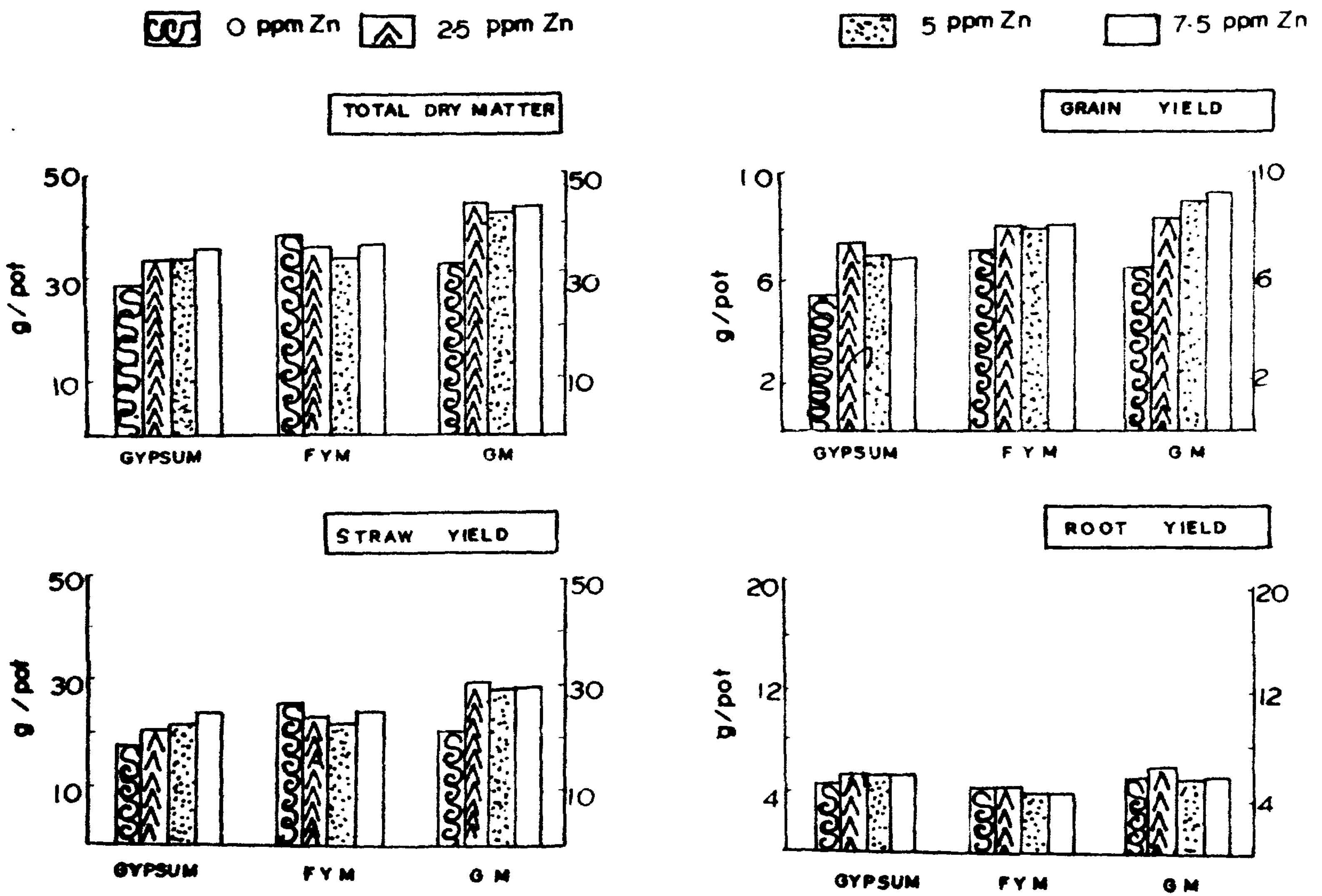
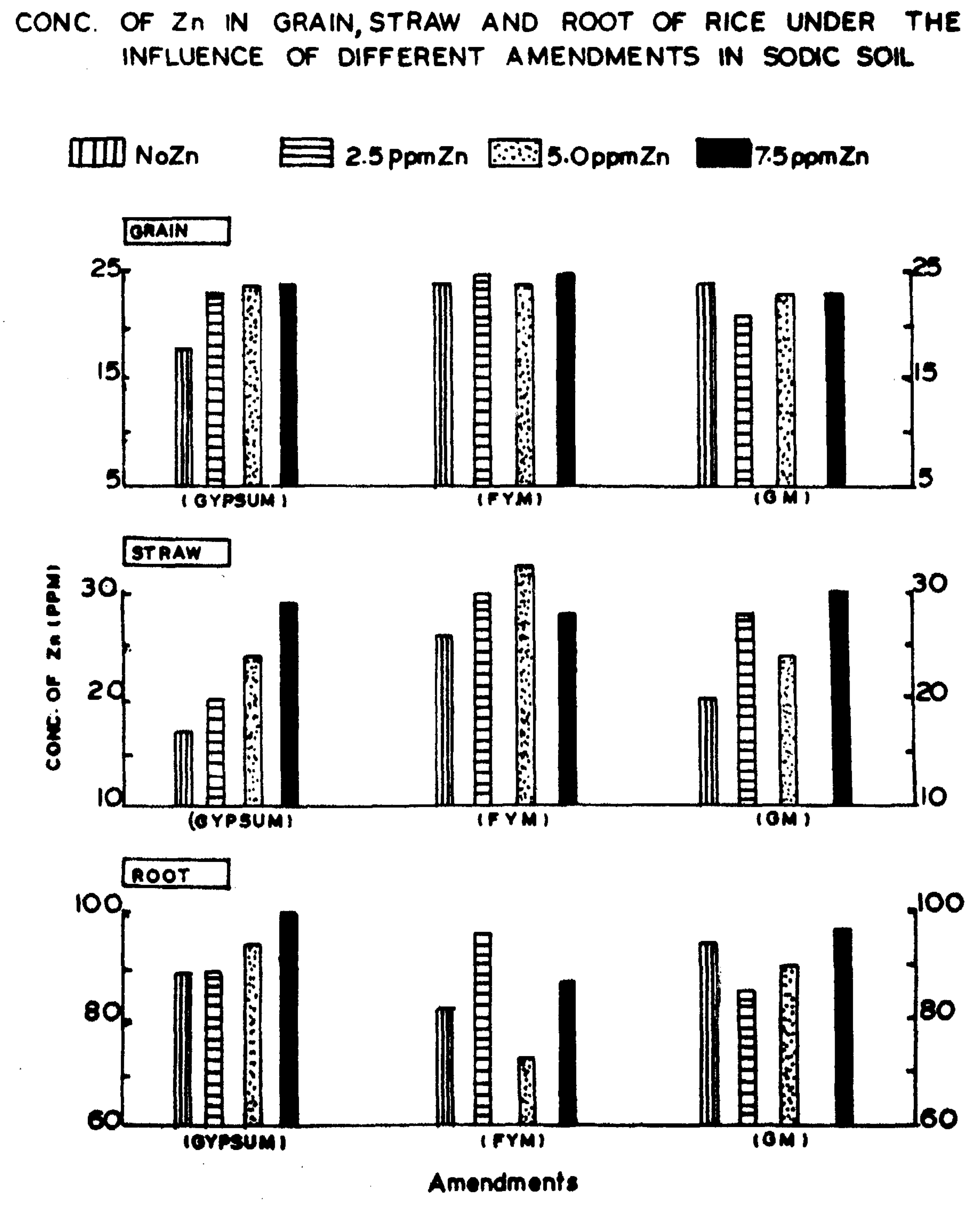


FIG.7.



CONC. OF Zn IN GRAIN, STRAW AND ROOT OF RICE UNDER THE INFLUENCE OF DIFFERENT AMENDMENTS IN SODIC SOIL
NoZn
2.5 ppm Zn
5.0 ppm Zn
7.5 ppm Zn
GRAIN
25
15
5
(GYPSUM)
(FYM)
(GM)
STRAW
30
20
10
ROOT
100
80
60
CONC. OF Zn (PPM)
Amendments

FIG. 8.

INFLUENCE OF SOURCES AND METHODS OF Zn APPLICATION ON DRY MATTER YIELD

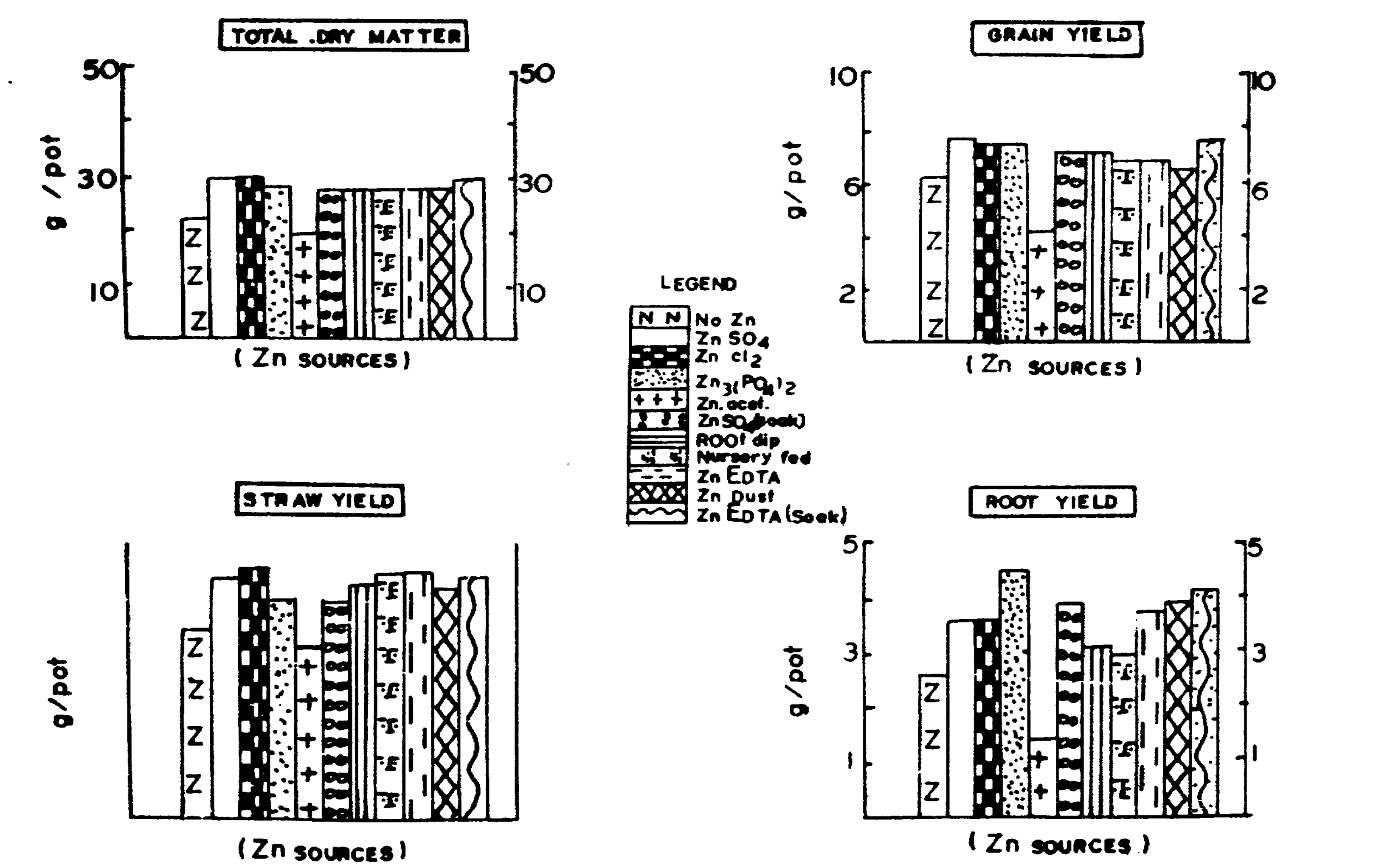


FIG.9.

CONC. & UPTAKE OF Zn IN GRAIN STRAW AND ROOT UNDER DIFFERENT SOURCES AND METHODS OF Zn FERTILISATION

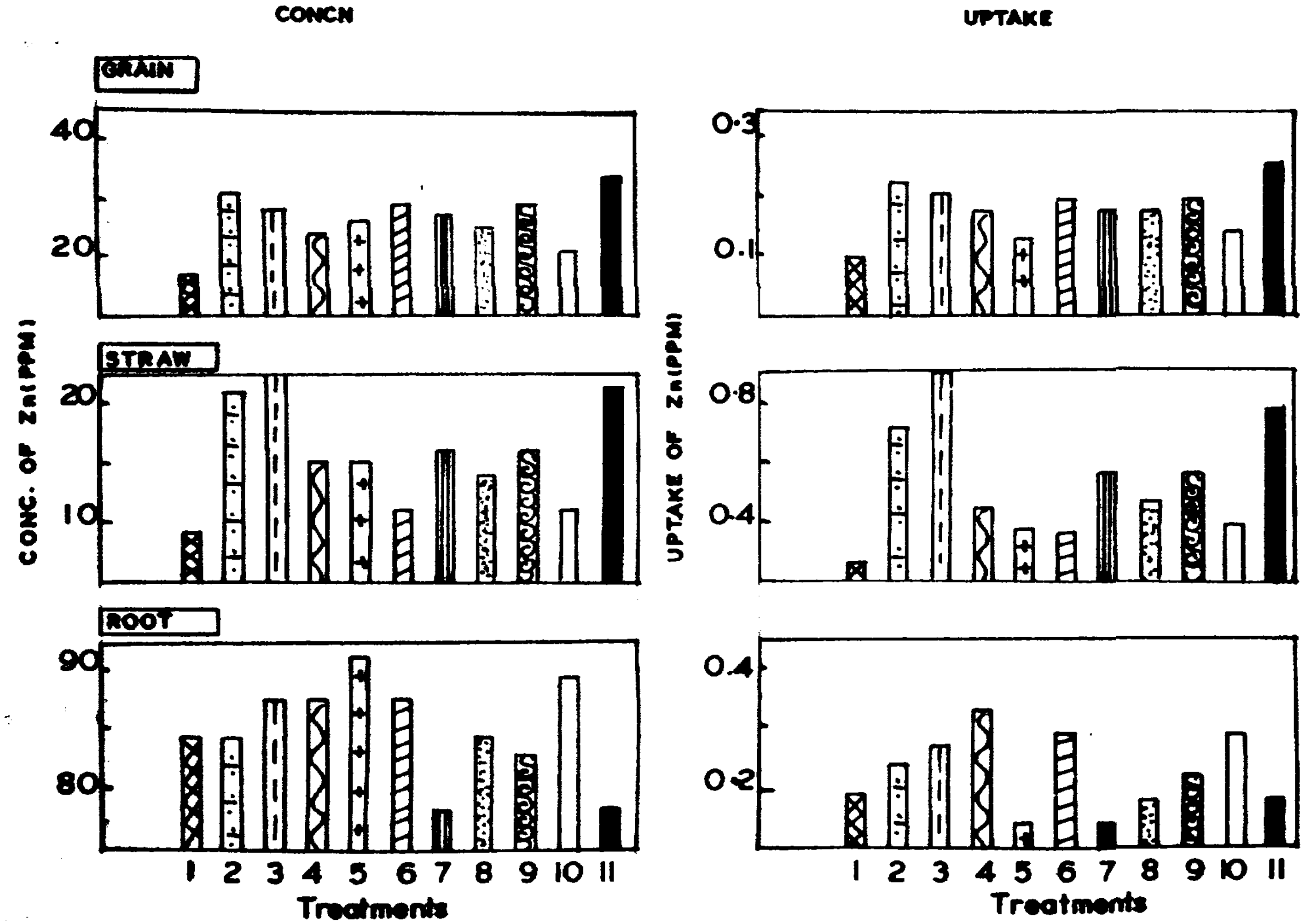


FIG.10.

EFFECT OF SOIL CONDITIONS AND Zn FERTILISATION ON NUTRIENT RATIOS (EQUIVALENT. CONC) IN SHOOT AT TILLERING STAGE IN RICE

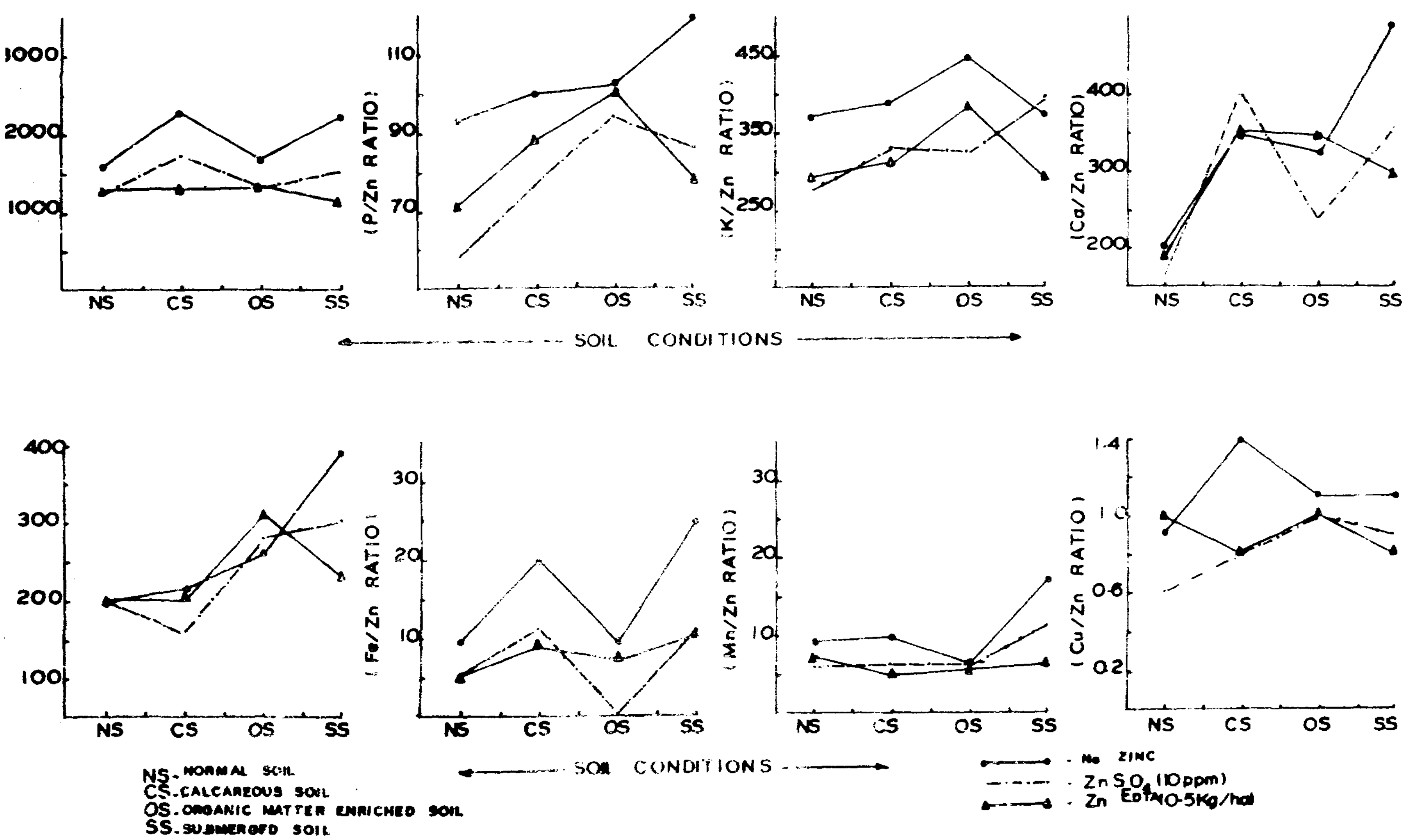


FIG.11

EFFECT OF SOIL CONDITIONS AND Zn FERTILISATION ON NUTRIENT RATIOS (EQUIVAL. CONC.) IN ROOT AT TILLERING STAGE IN RICE

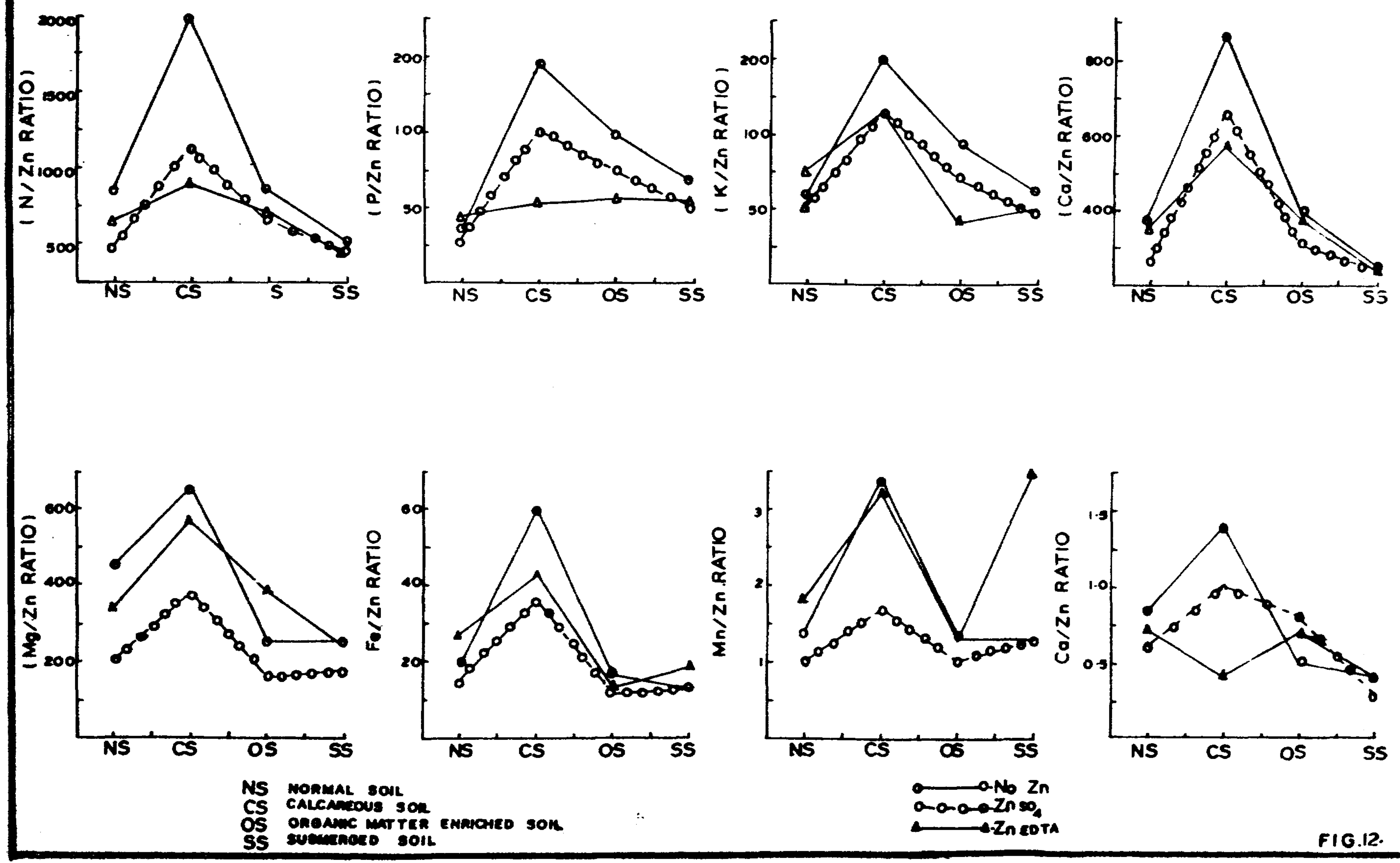


FIG.12.

EFFECT OF AMENDMENTS AND Zn FERTILISATION IN SODIC SOIL ON NUTRIENT RATIOS (EQUIVAL, CONC.) IN SHOOT AT TILLERING STAGE IN RICE

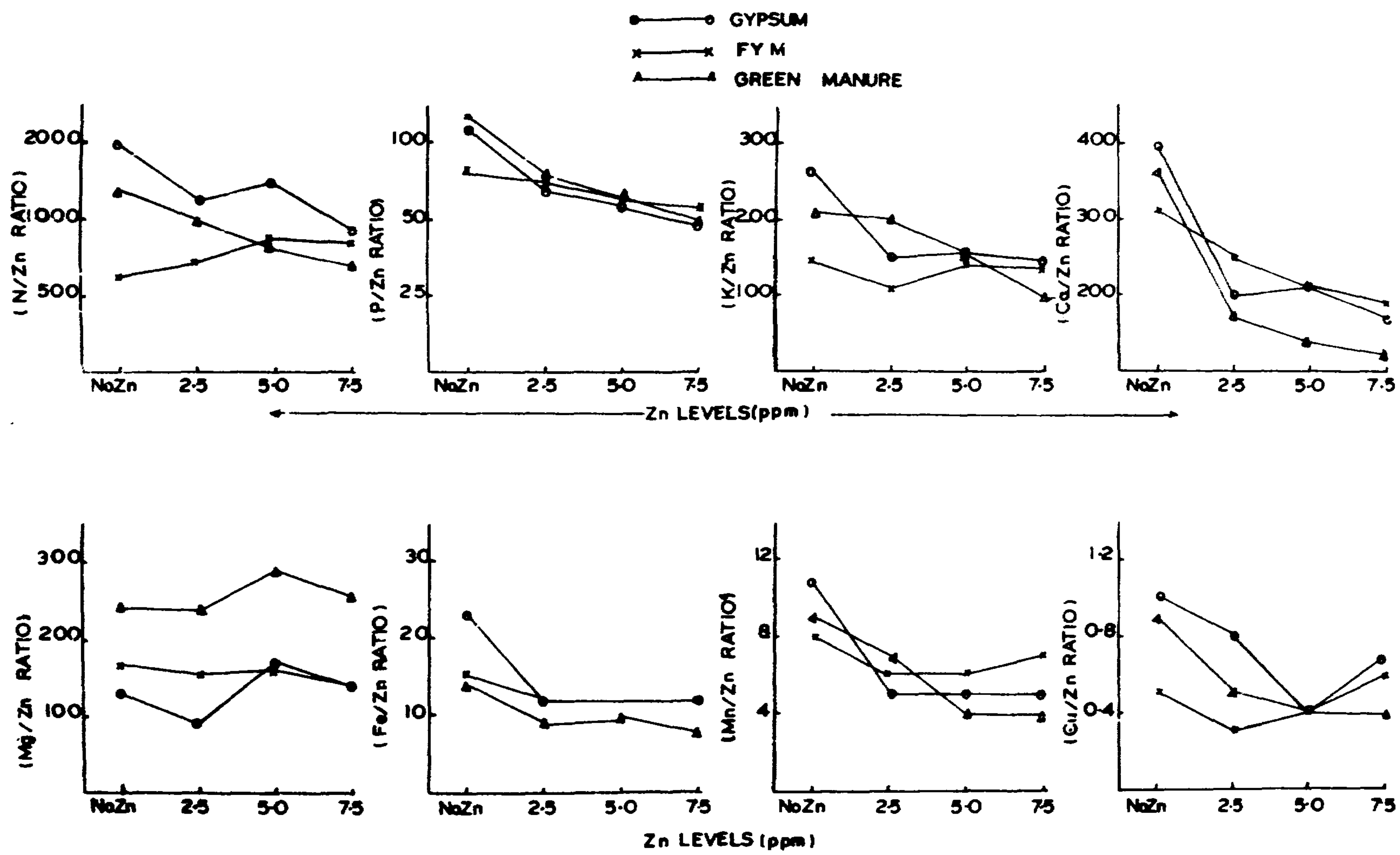


FIG.13.

EFFECT OF AMENDMENTS AND Zn FERTILISATION IN SODIC SOIL ON NUTRIENT RATIOS (EQUIVAL.CONC.) IN ROOT AT TILLERING STAGE IN RICE

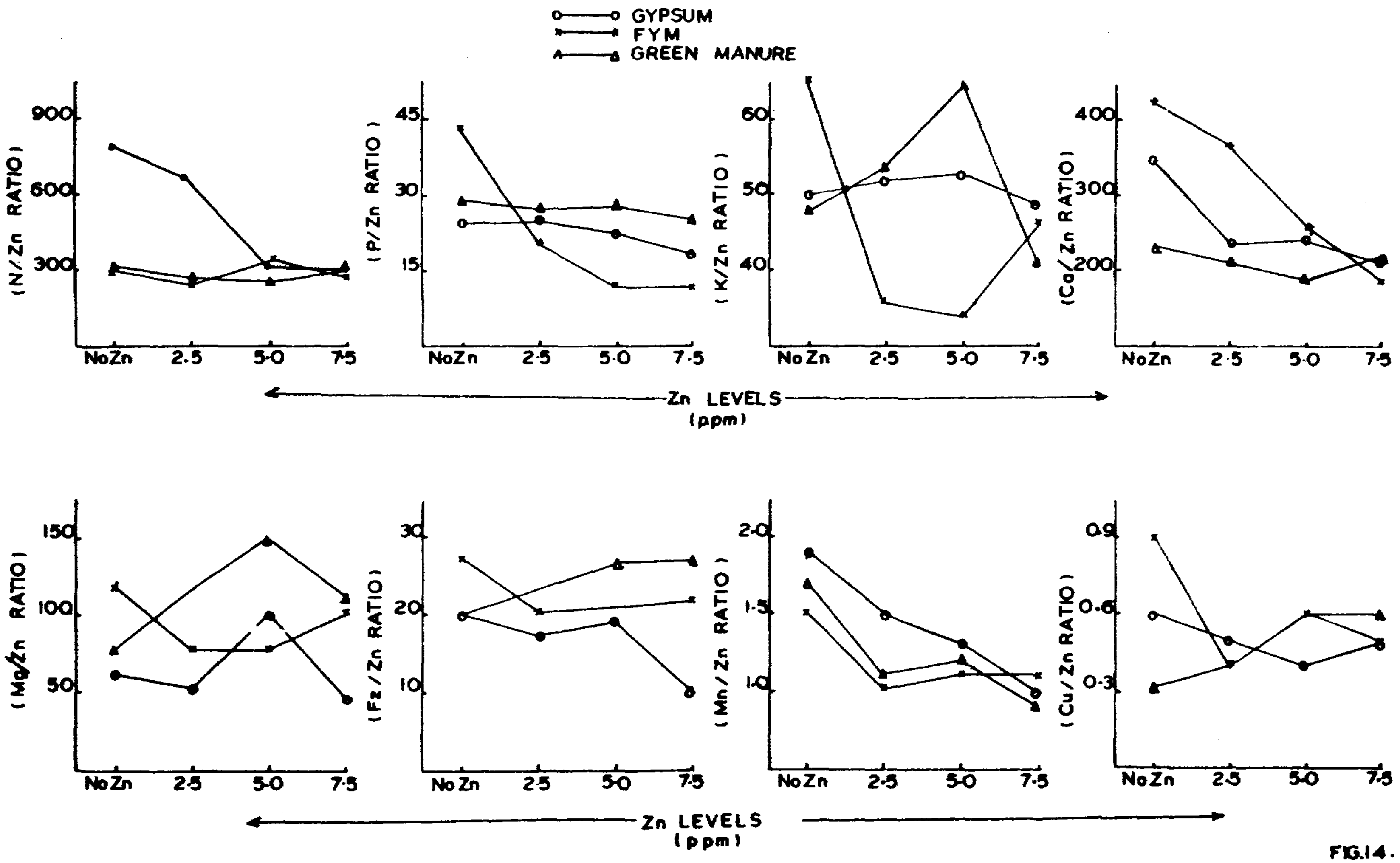


FIG.14.

APPENDICES

APPENDIX I

AREA, PRODUCTION AND PER HECTARE YIELD OF RICE*

Particulars	Area (m.ha)	Production (mt)	Yield (kg/ha)
World	140.8	343.8	2441
India	38.2	40.2	1061
Tamil Nadu	2.2	4.1	1855

* (Fertiliser statistics, 1976)

APPENDIX II

CRITICAL LEVELS FOR DEFICIENCY AND TOXICITY OF NUTRIENT ELEMENTS IN RICE

Element	Deficiency (D) or Toxicity (T)	Critical content	Plant part analysed	Growth stage
Nitrogen	D	2.50 %	Leaf blade	Tillering
Phosphorus	D	0.10%	Leaf blade	Tillering
Phosphorus	T	1.00 %	Straw	Maturity
Potassium	D	1.00 %	Leaf blade	Tillering
Potassium	T	1.00 %	Straw	Maturity
Calcium	D	0.15 %	Straw	Maturity
Magnesium	D	0.10 %	Straw	Maturity
Sulphur	D	0.10 %	Straw	Maturity
Iron	D	70 ppm	Leaf blade	Tillering
Iron	T	300 ppm	Leaf blade	Tillering
Manganese	D	20 ppm	Shoot	Tillering
Manganese	T	2500 ppm	Shoot	Tillering
Zinc	D	10 ppm	Shoot	Tillering
Zinc	T	1500 ppm	Straw	Maturity
Boron	D	3 - 4 ppm	Straw	Maturity
Boron	T	100 ppm	Straw	Maturity
Copper	D	6 ppm	Straw	Maturity
Copper	T	30 ppm	Shoot	Tillering

APPENDIX III

ANALYSIS OF PLANT SAMPLES OF RICE

Country	N %	P %	K %	Ca %	Mg %	Fe ppm	Mn ppm	SiO_2 %	Zn ppm
Korea	2.31	0.35	1.75	0.18	0.15	1170	510	7.5	32
Japan	..*	0.38	1.90	0.42	0.20	502	556	5.0	28
Thailand	2.38	0.25	1.25	0.10	0.17	648	522	7.2	35
India	1.77	0.20	2.28	0.55	0.51	988	219	7.0	17

APPENDIX IV

EFFECT OF Zn ON DRY MATTER AND Zn CONTENT IN RICE

Particulars	Phillipines		India		Pakistan	
	0 ppm	40 ppm	0 ppm	40 ppm	0 ppm	40 ppm
Dry weight (g)	0.53	1.73	1.78	5.71	1.02	2.87
Zinc content (ppm)	19	33	8	151	9	23

APPENDIX V

EFFECT OF MICRONUTRIENT DEFICIENCIES ON RICE

Particulars	Average No. of tillers	Weight of shoot (cm)	Length of root (cm)	No. of leaves per plant	Colour	
					Leaf	Root
Complete	19	36	..	Many	Light green	Light brown
- Boron	17	21	14.0	Many	Dark green	Brown
- Manganese	1	10	2.5	5 - 6	Light green	Brown
- Zinc	1	16	6.5	6 - 7	Light green	Brown
- Chlorine	17	28	..	Many	Dark green	Fibrous
- Copper	14	33	..	Many	Blue green	Soft
- Molybdenum	13	34	..	Many	Light yellow	Brown

APPENDIX VI

CONCENTRATION OF NUTRIENT ELEMENTS IN RICE

	N %	P %	K %	Ca %	Mg %	Fe ppm	Mn ppm	SiO_2 %	Zn ppm
Normal plant	1.77	0.20	2.28	0.55	0.51	988	219	7.0	17
Zinc deficient plant	0.26	0.06	3.32	0.48	0.31	735	138	12.8	8

ENDIX VII

PARTICULARS OF DA ANSPLANTING AND HARVEST

Experiment No.	Variety	I ting	Date of collection of tillering stage samples	Date of harvest
	CO 39	2	-	17-5-76
	CO 37		-	7-6-76
	TNAU 658		-	7-6-76
	IR 20		-	24-6-76
	RP 4-14		-	24-6-76
	Ponni		-	30-6-76
	Bhavani		-	30-6-76
	IR 8		-	6-7-76
	CO 38		-	8-7-76
	TNAU 13493		-	4-8-76
II	RP4-14	20	15-12-76	9-3-77
III	IR 8	31	22-11-77	24-2-78
IV	Bhavani	1	1- 6-78	23-8-78