

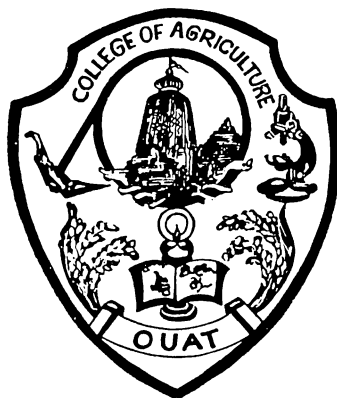
ZINC UPTAKE OF RICE (*Oryza sativa* L.) FROM DIFFERENT SOURCES OF ZINC CONTAINING FERTILISERS

A THESIS SUBMITTED TO
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, BHUBANESWAR
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE
(AGRICULTURAL CHEMISTRY, SOIL SCIENCE AND BIOCHEMISTRY)

BY

Subas Chandra Pani



DEPARTMENT OF AGRICULTURAL CHEMISTRY, SOIL SCIENCE AND BIOCHEMISTRY
COLLEGE OF AGRICULTURE
Orissa University of Agriculture and Technology
BHUBANESWAR-751003
1991

THESIS ADVISOR

Dr. G. N. MITRA

DEDICATED TO
MY BELOVED PARENTS

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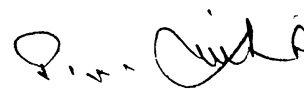
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Bhubaneswar,
Dated, the th May, 1992

C E R T I F I C A T E

I certify that the thesis entitled " ZINC UPTAKE OF RICE (Oryza sativa L.) FROM DIFFERENT SOURCES OF ZINC CONTAINING FERTILISERS " submitted in partial fulfilment of the requirements for the award of the degree of MASTER OF SCIENCE IN AGRICULTURE (AGRICULTURAL CHEMISTRY, SOIL SCIENCE AND BIOCHEMISTRY) of Orissa University of Agriculture and Technology, Bhubaneswar, is a record of bona fide research work carried out by Sri Subas Chandra Pani, under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma or published in any other form.

The assistance and help received during the course of this investigation have been duly acknowledged.


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(G. N. MITRA)
CHAIRMAN
ADVISORY COMMITTEE

A C K N O W L E D G E M E N T

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(Subas Chandra Pani)

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CHAPTER I

INTRODUCTION

CHAPTER-I

INTRODUCTION

Occurrence of Zinc deficiency in the soils of Orissa is a recent phenomenon. Sahu et al. (1990) for the first time estimated available zinc status of the soils of Orissa and reported that in different soil groups available zinc content varied between 0.26 to 4.6 ppm. Zinc deficiency was observed in 12.5% of the soil samples collected from the red soils, 44% from the lateritic soils, 33% from mixed red and yellow soils, 40% from mixed red and black soils, 17% from alluvial soils, 33.5% from saline soils and all the samples collected from black soil regions. Response to Zinc application has been reported by the field officers of the State Department of Agriculture from various locations of the State. The pockets of zinc deficiency in the State are however yet to be delineated.

The different sources of zinc now available in the State are $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, ZnO and Zn-EDTA complexes marketed under different trade names. The correct evaluation of these sources and their methods of applications are yet to be worked out in the State. It is however known from trials conducted elsewhere in India that $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ should preferably be applied to the soil at the time of transplanting of rice.

Seedling root dip in a suspension of ZnO for four hours is the preferred method for the source of Zinc, while Zn-EDTA chelates have been reported quite effective as soil applications. Its use is restricted due to its prohibitive cost. This source can be applied however as foliar sprays to the rice crop at much lower concentration and hence might be economic. There are other sources and methods of zinc application such as application of zinc frits, seed coating of rice seeds with ZnO as well as some unconventional sources such as : Zinc ligno-sulphonate, Zinc fulvate, Zinc citrate etc. used by different workers.

In the absence of proper delineation of Zinc deficient areas in Orissa, some of the predisposing factors which might cause Zinc deficiency, have to be taken while selecting sites to study zinc response. Hogland (1948) reported number of instances of Zinc deficiency in upland rice. According to Patrick and Reddy (1977) Zinc deficiency in low land rice may be due to (1) precipitation of $Zn(OH)_2$ as a result of increased pH after flooding, (2) precipitation of $ZnCO_3$ due to CO_2 accumulation resulting from organic matter decomposition and (3) precipitation of ZnS under very reduced soil condition. According to Mikkelsen and Kuo (1976), (1977) the reversible pH change, oxidation-reduction potential and CO_2 partial pressures may play an important role in regulating Zn uptake by rice. The reversible pH change of the flooded soil where pH

tends to increase in acid soil and decrease in alkaline soil, alters the Zinc equilibrium concentration in the soil solution. Since the solubility of Zinc minerals and Zinc sorbed by soil colloids are pH dependent, an increase in the pH of acid soil when flooded will tend to decrease the zinc concentration in the soil solution (after a very temporary increase). Therefore, the uptake of zinc by rice will decrease. In alkaline soil zinc uptake increases due to submergence since there is a decrease in pH. This reversible pH change explains why zinc uptake is lower in acid and higher in alkaline soil after flooding. In addition to these soil related factors zinc deficiency is likely to occur in areas with high cropping intensity and growing HYV paddy with adequate NPK doses. Taking the all above factors into considering zinc deficiency is likely to occur (1) in most of the alluvial soils of coastal districts with high cropping intensity and growing HYV paddy, (2) in the upland red and lateritic soils under continuous cropping and (3) most of the areas under black soils. Lowland situations with near neutral pH are also vulnerable to Zinc deficiency.

As stated earlier the three sources of Zinc containing materials available in the State are $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, Zn-EDTA and ZnO. It is necessary to evaluate these three sources with respect to response to rice crop. While field experiments are necessary for such evaluation, some fundamental

informations with regard to Zinc absorption and uptake is required when different methods of application are adopted while using these sources.

A study was therefore undertaken

- i) to find out rate of absorption of zinc when rice seedlings are dipped in suspensions or solutions of ZnO , $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ and Zn-EDTA over a period of time and
- ii) the effect of the three sources and their methods of application on zinc uptake and growth when rice was grown on a zinc deficient vertisol. The effects of Zinc uptake on uptake of other macro nutrients such as N, P and K also were studied.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER - II

REVIEW OF LITERATURE

I. SYMPTOMS OF ZINC DEFICIENCY IN RICE

Zinc deficiency in rice has been observed in many parts of our country and outside the country.

Solution culture study of Sommer and Lipman (1926) first established Zn to be an essential nutrient for green plants.

In India Nene (1966) was the first to identify khaira disease in low land rice to be due to Zn deficiency.

Under field conditions Yoshida (1968) made four observations on Zn-deficient rice plants in Pakistan. The observations recorded were (i) Brown streaks and blotches on lower leaves appear 2 to 3 weeks after transplanting and severely affected plants were usually found in low lying patches, (ii) most of the affected plants recover, but those severely affected die (iii) the disorder usually appears in first year of rice cultivation following reclamation and (iv) high rates of fertiliser aggravates the disorder and drainage alleviates it. The symptoms observed by Yoshida (1968) were similar to those observed by Karim and Vlamis (1962).

Tanaka and Yoshida (1970) made a general description of visible symptoms of Zn-deficiency in rice. According to them the mid-rib of the younger leaves, especially the base becomes chlorotic. The more general symptoms are the appearance of brown blotches and streaks in lower leaves followed by stunted growth. Tillering may continue. The size of the leaf blade is reduced, but that of the leaf sheath is little affected. Uneven growth and delayed maturity are the common characteristics of Zn deficiency in the field.

In addition to these Yoshida et al. (1973) observed brown blotches in lower leaves. The leaf blades became smaller although leaf sheaths were less affected.

Scientists from IRRI (1977) described the Zinc deficiency symptoms of Rice as appearance of brown lesions at the 4 to 5 leaf stage. If deficiency was severe the plants died.

Sakal and Singh (1979) conducted field trials in Bihar and found that Zinc deficiency symptoms first appeared about two weeks after transplanting on third leaf which showed light yellow colour at the leaf blade which was quickly followed by the appearance of scattered reddish brown spots which coalesced together and formed reddish brown patches. Later on, the entire leaf became rusty brown, dried and abscised.

Under sand culture study Agarwal and Sharma (1979) described the symptoms of Zn-deficiency in rice. According to

them Zn-deficiency first appears in 3 to 4 week old seedlings, at the time of commencement of tillering. Reddish brown pigments develop in central part of the middle leaves.

Gradually these Pigments intensify and spread all over the lamina and on leaf sheaths. Severely pigmented leaves turn necrotic and papery and leaf tips wither. Within 2 to 3 weeks from the appearance of the deficiency the entire foliage withers and plant growth is restricted. In addition Zn-deficient plants exhibit bleaching of Lamina of young leaves following apical necrosis. Feeding of the apical part of the leaves occur with development of dark brown streaks. The deficient plants have short internodes with leaves appearing to emerge close to each other. Tillers are weak and fail to develop panicles. Setting of grains and their development are very poor resulting in loss of grain yield.

Bhandari et al. (1987) reported visual symptoms of Zinc deficiency appear first in 3 to 4 week old seedlings at the time of commencement of tillering. Most characteristics feature of Zn-deficiency is the development of reddish-brown or chocolate-brown pigmentation (khaira type symptoms commonly known as khaira disease in paddy) in the central part (Lamina) of the middle (third and fourth) leaves. Leaf top remains green for sometime. Gradually, the pigmentation intensifies and spread almost all over the Lamina and also on leaf sheaths. Severely pigmented leaves turn necrotic and papery and the leaf tips wither. Within 2 to 3 weeks from appearance of Zn

deficiency, the entire foliage wither and further growth of Zn deficient plant is arrested. Zinc deficient plants also exhibit discolouration or bleaching of the lamina of the apical part of the leaves, followed by the development of orange yellow to golden colouration with dark brown streaks (or stripes) on the leaves and rolling or curling of lamina. In some cases yellowing or discolouration of young leaves start from the tip to the base followed by bronzing or reddish brown patches on the lamina and marginal (apical) necrosis. Leaf looks like rusted. Growth of the deficient plant is severely stunted and roots look brown in shade. Such plants have short internodes with leaves appearing to arise from part of the leaves, followed by the development of orange yellow to golden colouration with dark brown streaks (or stripes). Rolling or curling of leaf lamina occurs. Tillers are very weak and most of these fail to develop panicles. Setting of grains and their development is very poor resulting in loss of grain yield.

II. RESPONSE OF RICE TO DIFFERENT SOURCES OF ZINC FERTILISERS :

Response of Rice to Zinc application is wide spread in different parts of the country as well as outside the country.

IRRI (1968) reported that application of 10 or 100 ppm Zn to rice either through nursery application or

dipping the root of the seedlings in ZnO (4%) suspension for four hours increased grain yield by 1 to 2.5 t/ha. The maximum grain yields of 6.9 t/ha was recorded through soil incorporation of 100 ppm Zn following 6.68 t/ha through top dressing of same amount of Zn. Symptoms of Zn deficiency in rice were cured through foliar application or top dressing of ZnSO_4 after a week following application.

Pot culture experiment on calcareous soils of Pakistan at IRRI (1968) showed that application of Zinc at 100 ppm increased the drymatter yield from 2.2 g/pot to 5.9 g/pot.

Panda and Nayak (1974) reported that soil application of Zinc sulphate at 60 kg/ha produced more grain yields than foliar spray of zinc sulphate at 0.75% at boot leaf stage.

Mikkelson and Brandon (1975) ameliorated Zn deficiency in rice through application of sulphate, chloride and nitrate of Zn. They also reported Zn-EDTA can also overcome Zn deficiency in Rice.

Ray Choudhury (1977) reported that application of 50 kg ZnSO_4 /ha at transplanting to a lateritic soil of West Bengal alone or in combination with foliar spray of 5 kg ZnSO_4 /ha at early flowering stage increased the grain yields of rice varieties IR-8, Jayanti and Vidyasagar.

Field experiments of Mawardi et al. (1977) in Nile Delta showed that soil application of 25 kg ZnSO_4 /ha

to the main field increased the rice yield of paddy cv. IR-579 by 4.3 t/ha and nursery application of 50 kg ZnSO_4 increased the grain yield of same rice variety by 3.2 t/ha. They also reported that nursery treatment of 50 kg ZnSO_4 /ha and 2.5 kg Zn-EDTA increased the grain yield of variety IR-579 by 4.6 and 5.6 t/ha respectively and by 5.0 and 5.2 t/ha respectively for rice cv. Giza-172.

Trials conducted on calcareous soil taking rice cv. IR-23 at IRRI (1977) under transplanted situation in dry season indicated that rice plants in no Zn plot did not survive to produce yield, where as application of 50 kg ZnSO_4 /ha, 2% seedling root dip of ZnO suspension and 2% ZnO suspension seedling root dip followed by 0.5% ZnSO_4 foliar spray 5 days before panicle initiation produced grain yields of 4.9, 5.5 and 5.4 t/ha respectively. These treatments in wet season produced grain yield of 3.5, 4.1 and 4.3 t/ha respectively. However no Zn treatment produced 0.5 t/ha under direct sown condition in dry season the same variety produced 0.7 t in no Zn treatment and 0.3 t/ha in wet season, however foliar sprays of 0.5% ZnSO_4 solution did not increase grain yield significantly over control in dry season. In wet season coating of pre-germinated seeds with 2 kg ZnO/ha followed by foliar spray of 0.5% ZnSO_4 solution produced grain yields of 3.4 t/ha against ZnO alone of 3.1 t/ha.

Balal (1978) reported that seedling root dip with 2% ZnO suspension or soil application of 24 to 48 kg ZnSO_4 /ha to rice cv. Nahda in Egypt produced 10 to 20% higher rice yield over control.

Field trials were conducted at IRRI(1978) in a soil having pH 8.4, organic matter 9.6% and available Zn 0.04 ppm with rice cv. of IR-26, IR-34 and IR-36. When seeds of these rice varieties were coated with ZnO at 1.6 kg/ha, an average grain yields of 3.2 - 3.7 t/ha were produced soil application of 4.5 kg Zn/ha in form of ZnSO_4 produced 3.7 - 3.3 t/ha grain. Seedling root dip of ZnO at 1.6, 2.2 and 3.2 kg Zn/ha produced an average yield of 3.1 - 3.3, 3.6 and 3.2 - 4.2 t grains/ha respectively.

Ghobrial (1979) grew rice cv. IR-298 on a heavy soil and applied 0, 2, 4, 6 and 8 kg Zn/ha as soil application at sowing. Paddy and straw yield increased with increasing levels of Zn application from 4.14 and 6.69 t/ha respectively with no Zn application to 4.66 and 7.63 t/ha with application of 8 kg Zn/ha .

Amer et al. (1979) reported that application of 5 kg Zn/ha as Zinc sulphate mixed with soil or applied to the soil surface at or two weeks after transplanting increased grain yields upto 9.05, 8.95 and 9.37 t/ha in rice cv. Giza, 3.77 t/ha when dipped in 2% ZnO suspension at transplanting

and 9.51 t when 5 kg Zn/ha as ZnO was applied to soil as to 7.93 t in the untreated control.

Field experiments of Kumar et al. (1979) in Gangetic alluvial soils in wet season showed that soil application of 16 kg Zn/ha or foliar spray of 5 kg Zn/ha significantly increased the grain yield as well as straw yield by 1.7% over control.

Mengel and Wilson (1979) grew rice cv. Saturn in a severely Zn deficient silty loam soil at Crowley, Louisiana and applied Zn as seed dressing or as soil or foliar application. They found that the most effective treatments were soil application of 0.95 kg Zn/ha as Zn-EDTA, seed dressing with 0.5% kg Zn/ha as ZnO or Zinc lignosulphonate. All these treatments produced higher yields.

Pot culture trials of Maskina et al. (1979) in Haplustults soil from Hoshiarpur taking rice cv. Jaya showed that application of 5 ppm Zn in the form of DTPA, EDTA, fulvate, citrate or sulphate increased drymatter yield by 73, 41, 51, 40 and 32% respectively over control. The EDTA form was most effective in increasing plant Zn content.

Singh (1979) reported that rice grown under submerged conditions in calcareous and non-calcareous soil Zn-EDTA was superior to ZnSO_4 and ZnO in increasing grain yield.

Agarwal et al. (1980) reported in 18 field trials at 15 locations in alluvial soils of Uttar Pradesh, rice grown with 0.39 ppm dithiazone extractable Zn soil showed foliar symptoms of Zn deficiency and responded to Zn application and paddy yields were increased by 0.94 - 1.45 t/ha.

Hoque et al. (1980) in Balgladesh showed that Zinc application increased rice yield of four varieties such as IR-8, Payam, Nizersail and Pago from 2.7, 2.9, 3.3 and 3.1 t/ha in control to 3.8 , 3.0, 3.4 and 3.2 t/ha respectively in Zn treated plots.

Mawardi et al. (1980) reported that the dry weight and yield of rice plant were increased significantly through soil application of Zn at 25 to 75 kg ZnSO_4 /ha, following foliar spray of 2 to 10 g ZnSO_4 /litre at 40 days after transplanting.

Field trials of Hoque and Khan (1981) in Bangladesh showed that in spring rice cv. BR₃ increased grain yield of 0.31 t/ha was obtained with application of ZnSO_4 .

Ahmed et al. (1981) grew rice cv. Chandramukhi in pots in Zn deficient soils collected from different locations of Bangladesh and observed that application of 5 kg Zn/ha increased the tiller number, plant height and drymatter yield as compared to no Zn treatment.

Report of Sarkar and Deb (1981) indicated that application of 5 to 10 kg Zn/ha as tracer ZnSO_4 was slightly superior to Zincated urea in increasing paddy yield.

Field trials of Bhuiya et al. (1981) in dark grey flood plain soils of Bangladesh having an average Zn 0.11 ppm showed that application of 10 kg ZnSO_4 /ha increased the grain yield from 0.89 t to 2.04 t/ha and straw yield from 1.44 to 3.04 t/ha. Seedling root dip with 2% ZnO suspension increased the grain yield to 1.94 t/ha and straw yield 2.74 t/ha.

Uddin et al. (1981) reported that in an acid clay soil having 0.45 ppm average Zn, soil application of 20 to 40 kg Zn/ha, seedling root dip with 1.6% ZnSO_4 or foliar spray of 1 kg Zn/ha significantly increased the paddy yield.

Pot culture study of Dubey et al. (1981) showed that application of 5 to 10 ppm Zn in 19 soil types (alfisols and ultisols) and red yellow soils increased the grain and straw yield of rice.

Ponnamperuma and Orticio (1981) reported that application of Zn in a Zn deficient peat soil increased the yield of rice from 0.5 to 5 t/ha.

Report of Rabindra (1981) indicated that soil application of 50 kg Zn/ha at planting and seedling root dip of 1% ZnO or ZnSO_4 and foliar spray of 0.5% ZnSO_4 produced higher grain yield of paddy over control. Soil application of

50 kg Zn/ha gave highest yield. In case of seedling root dip treatments ZnO was superior to ZnSO_4 .

Field trials of Bhardwaj and Prasad (1981) in Doon valley region at different levels of ZnSO_4 (0, 10, 20, 40 kg/ha) application showed that application of 20 kg ZnSO_4 /ha produced highest grain yield.

Experiments of Xie et al. (1982) in China showed that application of 15 kg ZnSO_4 /ha produced grain yield of 5.73 t/ha, seedling root dip with ZnO suspension gave 5.74 t/ha. While foliar spray of Zn produced 5.24 t/ha, in comparison control plot gave only 4.91 t/ha. Findings of Wang et al. (1982) indicated that application of various forms of Zinc fertilisers increased the yield of rice ranging from 0.96 to 1.23 t/ha.

Pot culture study of Rathore et al. (1982) on alluvial soils of Gwalior district revealed that with application of Zn, grain yield of rice increased ranging from 21.8 to 247.1% and straw yield increased from 3.6 to 505.5%.

Rai et al. (1982) reported that application of Zn to six high yielding rice varieties in calcareous soil produced significantly higher grain yield.

Field trials of Nampoodiri and Ramasubramonian (1982) showed that foliar application of 0.5% ZnSO_4 , soil application of 20 kg ZnSO_4 /ha, seedling root dip with 2% ZnO suspension produced 6.8, 6.71 and 6.38 t/ha respectively as compared to 5.91 t/ha in no Zn treatment.

Prasad et al. (1982) observed that application of 5 kg Zn/ha to Zn deficient calcareous soil was optimum for adequate yield.

Experiments of Singh et al. (1982) in sandy loam calcareous soil showed that application of Zn to rice cv. Sita in form of soil application of ZnSO_4 , foliar spray of 0.5% or 1% ZnSO_4 or seedling root dip with 3% ZnO suspension significantly increased the grain yield. His findings revealed that seedling root dip with 3% ZnO suspension gave similar yield to ZnSO_4 applied at the rate of 25 kg/ha.

Srivastava et al. (1982) in pot culture experiment using silty clay loam soil and rice cv. Jaya showed foliar spray of 100 ppm Zn-EDTA and 1130 ppm ZnSO_4 along with lime increased the drymatter yield in similar form.

Sharma et al. (1982) showed that soil application of ZnSO_4 , foliar spray of 1 or 2% ZnSO_4 , seedling root dip of 2 or 4% ZnO suspension increased the rice yield significantly over control in a moderately Zn deficient sodic soil. Their observations indicated that the yield increases due to various Zn application ranged from 3.21 t/ha to 5.78 t/ha. Dipping of roots in 2% or 4% ZnO suspension was as effective as applying 5.6 or 11.2 kg Zn/ha and was more economical.

Studies of Reyes and Brinkman (1982) showed that soil application of ZnO significantly increased the dry-matter yield and grain yield.

Findings of Sadana and Takkar (1983) showed that application of 0 to 10 ppm Zn as ZnSO_4 to rice cv PR 106 grown in Rohi sandy loam soils increased drymatter yield of Rice.

Kulkarni et al. (1983) mentioned that application of 50 kg ZnSO_4 /ha produced significant yield both in Kharif and Summer rice.

Field trials of Sanchez (1983) at Granada in Columbia showed that broadcast or shallow placement of 3 to 24 kg Zn as ZnSO_4 or 1.5 to 12 kg Zn/ha as chelated Zn increased the paddy yield of rice cv. IR-22 grown in an Entisol with available Zn of 0.7 ppm and pH of 6.6 to 7.2. Their trials also showed that foliar application of phenol chelate (7% Zn) at 630 to 2320 g Zn/ha and seed treatment with ZnSO_4 at 10 g/100g seed produced significantly higher rice yield over control. Broadcast application of 6 kg Zn/ha as ZnSO_4 , 4 and 3 kg as chelated Zn (14% Zn) increased paddy yield by 87 and 92% respectively. Foliar application of 630 g Zn/ha. as phenol chelate (7% Zn) increased yield by 51% and seed treatment by 67%.

Studies of Nagarajah et al. (1983) showed that application of Zn at 10, 20 and 30 kg/ha or seedling root dip with 2% ZnO suspension before transplanting, in Srilanka increased the grain yield significantly.

Singh (1983) compared the relative efficiency of different Zinc sources like Zn-EDTA, Zn-Rayplex, ZnSO_4 and Zinc phosphate in rice in a Zn deficient soil. His findings revealed that Zn-EDTA was superior to Zinc sulphate with respect to grain and straw yield.

Findings of Sinha and Sakal (1983) showed that rice cv. IR-20 significantly produced higher yield with Zn application at 2.5 and 5 ppm as ZnSO_4 . Maximum response of rice to Zn was observed at tillering probably due to the fact that nutrient requirement of rice is highest at this stage.

Report of Singh et al. (1983) showed that application of Zn as ZnSO_4 and seedling Root dip of ZnO at two locations in Bihar produced significantly higher grain yield of rice.

Field experiments of Sarkar et al. (1983) showed that application of Zn at 5 kg/ha to rice in vertisol increased the paddy yield.

Experiments of Verma and Neuce (1984) showed that application of Zn to saline soil increased yield and yield attributing character of rice cv. IR 28. Maximum response was obtained at 10 ppm Zn.

Singh and Abrol (1984) conducted field trials in alkali soil with application of 0, 10, 20, 40, 80 or 120 kg ZnSO_4 /ha along with 4 t gypsum/ha. They recorded significant grain yield of 6 t/ha with 10 kg ZnSO_4 /ha only. Rice plants in control were stunted and had visible Zn deficiency symptoms.

Sand culture trials of Ram and Raman (1984) showed that Zn fulvate or Zn humate increased the drymatter yield of rice plant as compared to ZnSO_4 at 2.5 ppm level Zn.

Mukherji (1985) reported that 1% ZnSO_4 foliar spray at 30 and 45 days after sowing increased the yield of modern cultivars than local cultivars of rice.

Trials of Sakal et al. (1985) in silty loam calcareous soil revealed that application of Zn to rice increased significantly the crop yield. The magnitude of yield response was intensified when Zn was applied along with organic manures.

Experiments of Katyal (1985) showed that seedling root dip with 2 to 4% ZnO suspension effectively corrected Zn deficiency and increased the yield of rice which was equal to yield on application of 10 kg Zn/ha as ZnSO_4 .

Pot culture study of Prasad and Singh (1985) in clay soil showed that the application of Zn to Rice cv. Jaya increased the yield. The grain yield of 37.6 to 39.7 g/pot were recorded at 10 and 20 ppm Zn respectively and control pot gave only 34.3 g/pot.

Field experiments of Saravanan and Ramanathan (1986) in alluvial clay loam soil showed that application of 0 to 16.5 kg Zn/ha increased grain yields from 3.1 to 4.7 t/ha.

Chavan and Gupta (1986) reported that seedling root dip with 1% ZnO suspension for 1 hour or soil application of 5 ppm Zn to a lateritic Zn deficient soil significantly increased the grain yield.

Findings of Zia and Yousaf (1986) showed that dipping sprouted seeds and seedling in 1% ZnO suspension before sowing or transplanting and broadcasting 10 kg ZnSO_4 /ha to nursery bed effectively cured Zn deficiency in rice.

Findings of Karacal and Taceren (1986) in Turkey showed that application of foliar spray of 1% ZnSO_4 solution or 1% Zn-EDTA and ZnO seed coating to rice cv Ribe increased the yield over control.

Pot culture study of Sharma et al. (1986) showed that application of ZnSO_4 increased the grain yield by 16.2% and straw yield by 19.2%.

Field trials of Das (1986) during kharif season showed that application of Zn at 0, 15, 20 or 25 kg Zn/ha as ZnSO_4 to rice cv. Pankaj produced the grain yields of 3.28, 3.65, 4.12 and 3.94 t/ha respectively. Plant height was greater and number of tillers were highest at 70 days after transplanting at 20 kg Zn/ha.

Saravanan and Ramanathan (1988) grew rice in a Zinc deficient soil of 0.9 ppm DTPA Zn, with application of 12.5 to 75 kg ZnSO_4 /ha and observed that 25 kg ZnSO_4 /ha gave highest yield of 5.2 t/ha compared with 4.6 t/ha with control.

Machhi et al. (1988) conducted field trials at Danti in a partially reclaimed saline sodic soil taking rice cv. Jaya and Masuri and applied 0, 15, 30, 45 or 60 kg ZnSO_4 /ha. Paddy

yields of 4.45 to 5.22 t/ha was recorded with increases in Zn doses.

Zinc trials of Saborit et al. (1988) in Cuba showed that application of 16.3 kg Zn/ha as ZnSO_4 produced higher yield than no Zinc treatments both in dry and wet season.

Chhibba et al. (1989) conducted field trials on a Zn deficient soil of 0.5 ppm DTPA Zn in Punjab taking 0, 5 or 10 kg Zn/ha as ZnSO_4 , ZnO and Zinc frits as soil application to the rice cv. Jaya. Grain yield increase significantly over control by Zn application irrespective of rate and source. Highest grain yield was produced by ZnSO_4 and Zn frits. ZnO was least effective.

Sahu et al. (1989) conducted field trials on response of rice to Zn on alluvial soils of Regional Research Station (RRS) Ranital and Black soil of RRS of Bhawanipatna in Orissa. The alluvial soil (Haplaquept) of Ranital had a pH of 7.5 (1:1 soil water ratio) and DTPA extractable Zn 0.58 ppm. The Black soil of Bhawanipatna (Chromusterts) had a pH of 7.8 and DTPA extractable Zn 0.53 ppm. The data showed that rice cv. CR-1018 at Ranital and rice cv. Jajati at Bhawanipatna produced maximum grain yield when their seedlings were dipped in 4% ZnO for four hours. These yields were at par with two foliar sprays of ZnSO_4 at 0.5% concentration.

Field experiments of Jayaraman and Ramiah (1989) showed that application of 6 kg Zn as ZnSO_4 improved the rice yield from 3.8 to 6.22 t/ha in Rabi season. Application of 6% ZnO seedling root dip was most effective in decreasing spikelet sterility.

Sarkar et al. (1989) conducted field trials in Zn deficient soils of Tripura applying 20 kg ZnSO_4 /ha to the nursery bed or foliar spray of 0.5% ZnSO_4 with 0.25% lime at 10 days interval beginning 10 days after transplanting. Paddy yield of 7.4 t/ha was obtained with Zn treatment as compared to 5.6 t/ha without Zn.

Vyas et al. (1990) reported that application of Zn at 2.5 to 20 kg per ha significantly increased grain yield as well as straw yield of rice cv. Sanradhi. The maximum grain and straw yield were recorded at 5 kg Zn/ha.

Pot culture experiment of Singh et al. (1990) on high altitude haplaquent of iron rich soils of Meghalaya showed that application of Zn at 7.5 ppm increased the shoot weight of rice variety CR-1009 from minimum 30% to maximum 100.6% over control.

Rattan and Shukla (1991) conducted pot culture experiments to study the response of rice cv. Pusa-33 to various sources of Zn on a soil of Typic Ustipsamment having pH 8.4, DTPA extractable Zn 0.36 ppm. The results indicated

that application of 5 ppm Zn as ZnSO_4 produced the maximum shoot dry matter yield (9.26 g/pot) over other Zinc sources such as Zn-EDTA and Zn-DTPA.

Maharana (1992) conducted 119 field experiments in farmers field to study the response of rice to application of ZnSO_4 in deltaic alluvial soils of Puri and Cuttack district, Brown forest soils of Ganjam district and red and yellow soils of Mayurbhanj district of Orissa. He recorded that application of ZnSO_4 to rice both in Kharif and Rabi season significantly increased grain and straw yield in 86 trials out of total 119 trials.

Sahay (1992) conducted 30 field trials on response of rice to Zn application in soils of Bihar. He reported that application of ZnSO_4 at 25 kg/ha produced the grain yield of 10.93 to 11.11 q/ha over no Zn application.

Sur (1992) conducted 71 trials on response of rice to Zn in West Bengal. He reported that application of Zn at 25 to 37.5 kg ZnSO_4 /ha produced maximum grain and straw yield.

III. ZINC UPTAKE BY RICE FROM DIFFERENT ZINC SOURCES :

Pot culture study of Maskina et al (1979) on Haplustults soil from Punjab showed that Zn uptake by rice cv. Jaya at 5 ppm level through different sources was maximum by application of Zn-DTPA followed by Zn-EDTA.

Pot culture experiment of Singh (1979) in calcareous and non-calcareous soils under submerged conditions indicated that maximum Zn-uptake by rice was recorded through application of Zn-EDTA followed by ZnSO_4 and ZnO. Zn uptake increased with increased levels of Zn application. The interaction between Zn uptake and N uptake was found to be positive and uptake of Zn and P was negative.

Mawardi et al. (1980) reported that soil application of ZnSO_4 at 75 kg/ha and chelated Zn at 5 kg/ha significantly increased the Zn content of rice leaf and rice root at PI stage.

Chand et al. (1981) reported that Zn uptake and Zn utilisation by rice in a Zn deficient saline sodic soil decreased in order of $\text{Zn-DTPA} > \text{Zn-fulvate} > \text{Zn-EDTA} > \text{ZnSO}_4$.

Sarkar and Deb (1981) conducted pot experiments in flooded rice taking 5 to 10 kg Zn/ha in different forms of Zn such as ZnSO_4 , Zincated urea and ZnO using Zn-65 as a tracer. ZnSO_4 was similar or slightly superior to Zincated urea and both were superior to ZnO seedling root dip with respect to Zn uptake by rice. Application of Zn on soil surface or mixing with soil has no effect on Zn uptake. Dipping the roots in 1% ZnO or applying Zn through irrigation water also increased the Zn uptake by rice over control.

Rabindra (1981) indicated that soil application of 50 kg Zn/ha before sowing or before transplanting, foliar spray of 0.5% ZnSO_4 or dipping seedling roots with 1% ZnO or

ZnSO₄ at transplanting increased the Zn content of rice leaves of cultivars Prakash, Vikram and Mangala grown on a soil with pH of 6.5, 4.9 and 8.9 respectively.

Bhardwaj and Prasad (1981) found that application of ZnSO₄ at 0, 10, 20, 40 kg/ha increased the Zinc concentration of rice leaves.

Findings of Sharma et al. (1982) on application of Zn at 0, 5.6, 11.2, 22.4 kg/ha in form of ZnSO₄ to a Zn deficient sodic soil indicated that Zn content of rice leaf and its uptake by rice increased with increasing Zn levels upto 22.4 kg/ha as ZnSO₄.

Field experiments of Singh et al. (1982) on calcareous sandy loam soil indicated that Zinc uptake by grain of rice cv. Sita were 39.7, 99.2, 146.2, 137.8, 102.8 147.4 and 137.7 g/ha through application of no Zn, 12.5 kg ZnSO₄/ha, 25 kg ZnSO₄/ha, 50 kg ZnSO₄/ha, 0.5 ZnSO₄ foliar spray, 1% ZnSO₄ foliar spray, seedling root dip of 3% ZnO respectively. The same uptake by straw were 43.4, 104.7, 166.7, 176.4, 121.8, 155.5 and 163.4 g/ha respectively.

Srivastava et al. (1982) compared the foliar spray of Zn-EDTA at 100 ppm and ZnSO₄ at 1130 ppm along with lime in pot culture experiment of silty clay loam soil on 20 days old seedlings of rice cv. Jaya. They observed that the Zn uptake by rice plant for both the sources were similar.

Field study of Sadana and Takkar (1983) on rice cv. PR-106 showed that Zn application through either seedling root dip at 2 or 4% ZnO suspension foliar spray of 1 or 2% ZnSO_4 or seedling root dip along with foliar spray of both or 50 kg soil application of ZnSO_4 /ha increased the Zn concentration of rice leaves.

Nagarajah et al. (1983) conducted field experiment at two sites of Srilanka at 0, 10, 20 and 30 kg Zn/ha as ZnSO_4 . They reported that Zn concentration in leaves and straw varied between 40 to 59 ppm in leaves and 90 to 100 ppm in straw at one place and 16 to 38 ppm in leaves and 24 to 35 ppm in straw in the second location.

Singh et al. (1983) conducted field experiment on rice cv. Sita at 0, 2.5, 5 and 10 kg Zn/ha as ZnSO_4 . They reported that Zn uptake by grain at 0, 2.5, 5 and 10 kg/ha were 41.4, 43.9, 46.7 and 43.8 g/ha respectively and Zn uptake by straw at the same level of Zn were 19.9, 23.5, 29.6 and 31.8 g/ha.

Findings of Singh (1983) indicated that Zn concentration of rice leaves increased through Zn-application from 0 to 10 ppm. The Zn concentration was higher in straw than grain. Zn uptake from Zn-EDTA was higher than ZnSO_4 .

Pot culture experiment of Sinha and Sakal (1983) indicated that application of Zn at 0, 2.5 and 5.0 ppm level

as ZnSO_4 increased the Zinc concentration of rice root, leaf sheath, leaf blade at tillering, panicle initiation and maturity. Maximum Zn content was observed in roots at all the stages followed by leaf sheath and leaf blade. Maximum Zn concentration was recorded at 5 ppm level of Zn in all the plant parts at all the three growth stages.

Field trials of Singh et al. (1983) at two different locations in Bihar taking rice cv. Sita as test crop indicated that application of 5 kg Zn/ha as ZnSO_4 or seed coating of ZnO or Zinc phosphate or Zinc oxysulphate increased the Zn concentration and uptake by rice plant. Maximum uptake was recorded by ZnSO_4 followed by Zinc oxysulphate, ZnO and Zinc phosphate.

Sarkar et al. (1983) conducted field trials in vertisols of Hyderabad to study the Zn use efficiency of different Zn sources such as soil application of ZnSO_4 foliar spray of ZnSO_4 , seedling root dip and application of Zincated urea in rice-rice sequence. According to them Zincated urea had greater Zn use efficiency of 0.7 to 2.7% for first rice crop, 0.27 to 0.53% for second rice crop.

According to Singh and Abrol (1984) Zn uptake by rice increased with increasing rates of Zn application from 0 to 120 kg ZnSO_4 application. Maximum uptake was observed at 120 kg ZnSO_4 per ha.

According to Ram and Raman (1984) Zn uptake by rice plant in sand culture experiment was not affected due to application of Zn-fulvate, Zn-humate and ZnSO_4 at 2.5 and 5 ppm Zn.

Field experiments of Sakal et al. (1985) in silty loam calcareous soil indicated that application of Zn at 5 and 10 kg/ha as ZnSO_4 , ZnO and Zn frits increased the Zn concentration and uptake by rice plant. Zn uptake considerably increased due to Zn frits over other two sources.

Field trials of Sakal et al. (1985) in silty loam calcareous soil indicated that application of Zn at 2.5 and 5 kg/ha as ZnSO_4 increased the Zn uptake by rice grain and straw. Maximum Zn uptake was recorded in straw than grain at 2.5 ppm level of Zn.

Pot experiment of Rajendraprasad and Singh (1985) showed that application of Zn at 0, 10, 20 ppm as Zn-EDTA increased Zn uptake by rice cv. Jaya. Maximum uptake of 5.10 mg/pot was recorded at 20 ppm level and minimum of 2.68 mg/pot at no Zn level.

Green house experiment of Chatterjee and Mandal (1985) showed that Zn uptake and concentration in rice roots were higher for Zn EDTA than ZnSO_4 application at same dose of Zn.

Sharma et al. (1986) conducted pot trials in seven soils taking two levels of Zn at 0 and 10 ppm as ZnSO_4 to study the Zn uptake from different soils. They reported that Zn uptake by rice shoot from these soils varied from 11.96 to 27.20 ppm in no Zn treatment and 23.9 to 43.5 at 10 ppm Zn level.

Field trials of Das (1986) at 0, 15, 20 or 25 kg Zn/ha as ZnSO_4 to rice cv. Pankaj showed a highly significant correlation between the grain yield and Zn content of the plant.

Shukla (1987) conducted pot culture experiments taking rice cv. Pusa-33 in a Typic Ustipsamment of pH 8.4 at four levels of Zn (0, 2.5, 5, 10 ppm) as ZnSO_4 and three levels of Iron (0, 10, 20 ppm) as FeSO_4 . He concluded that both Zn uptake increased with increasing levels of Zn alone, but Zn uptake decreased with increase in levels of Iron.

Sakal et al. (1988) reported that Zn concentration varied widely in different parts of rice plant, highest being in roots followed by shoot and leaf blade. They concluded that the mobility of Zn from root to shoot was relatively slower. The Zn concentration at 0, 5 and 10 ppm level were 50, 65 and 75 ppm respectively in roots, 35, 46 and 52 ppm in shoot and 27, 42 and 47 ppm in leaf blades. Zn uptake by shoot was higher than root because of high drymatter yield.

Field trials of Bansal and Nayyar (1989) on a loamy sand soil at Ludhiana showed that application of Zn at 2.3, 5.6 or 11.2 kg/ha either through ZnSO_4 or Zn-EDTA to rice cv. PR-106 increased Zn uptake by rice plant and maximum uptake of Zn was recorded at 5.6 kg Zn/ha as Zn-EDTA.

Chhibba et al. (1989) conducted field trials in a Zn deficient (0.55 ppm DTPA extractable Zn) soil of Punjab at 0, 5, 10 kg Zn/ha as ZnSO_4 , ZnO and Zinc frits to rice variety Jaya. According to them Zn uptake by rice grains significantly increased with Zinc application over control irrespective of Zinc sources.

Pot culture experiment of Rattan and Shukla (1991) in Typic ustipsamment soil indicated that Zn content and uptake by rice cv. Pusa-33 were in the order of Zn-EDTA > Zn-DTPA > ZnSO_4 .

Field trials of Maharana (1992) in alluvial soils of Puri and Cuttack district, black and mixed red and black soils of Kalahandi district, brown forest soils of Ganjam district and red and yellow soils of Mayurbhanj district showed that application of Zn as ZnSO_4 increased the Zn uptake by rice. Uptake of Zn was more by straw than by grains.

Field trials of Sahay (1992) in different districts of Bihar showed that Zn uptake by grain and straw of rice significantly increased due to Zn application. He reported

Zn uptake of grain varied from 13.24 to 24.75 ppm and that in straw varied from 13.33 to 23.36 ppm.

IV. EFFECTS OF ZINC ON N-UPTAKE BY RICE :

Enyi (1966) recorded a significant and positive correlation between nitrogen and Zinc content of Rice plant. His findings (1967) further, showed that with increased level of N the contents of K, Ca, Mn, Zn and Mo became higher in rice plant.

Report of Jain and Singh (1967) showed that soil application of Zn at 2.53 kg/ha or foliar spray with Fe at 2.23 kg/ha significantly increased uptake of N and Ca by rice plants.

Kang (1967) reported addition of Zn and Mo increased the assimilation of inorganic N and increased the protein and non-protein organic N levels to 1.2 to 1.3 fold.

Bandopadhyay and Adhikari (1968) reported that application of nitrogen as $(\text{NH}_4)_2\text{SO}_4$ increased the uptake of Zn by rice.

Venkatasubramanyam and Meheta (1974) reported increased uptake of nitrogen by upland rice with increased concentration of Zn at the rhizosphere.

Study of Mawardi et al. (1977) showed that application of Zn to rice increased the N content of rice leaves.

Study of Chaudhry et al. (1977) indicated that application of N and Zn at 25 and 15 ppm each stimulated increased uptake of Zn through formation of Zinc nitrate complex.

Singh (1979) reported that application of Zn to low land rice stimulated higher N uptake.

According to Marian and Kosy (1979) application of Zn significantly increased the N content of grain and decreased the same in straw.

Pavansesivam (1980) reported that application of N and K at 40 and 11 ppm each increased the Zn content in rice. Application of N beyond 40 ppm decreased the Zn content.

Singh and Singh (1981) recorded increased yield, uptake of N and protein content of grain by application of 10 ppm Zn. At tillering N content of plant increased from 2.37 to 3.92% due to Zn application. Further study of Singh and Singh (1983) confirmed that Zn fertilisation increased the uptake of N by rice in presence or absence of P application. Ahn and Ahn (1975) and Ahn et al. (1976), however reported decreased uptake of Zn by local cultivars of rice with nitrogen application.

Pot culture experiment conducted by Sahu (1989) in Zn deficient alluvial soil (0.52 ppm DTPA-Zn) showed

that maximum uptake of N by rice plant occurred at 5 ppm level of Zinc application. Serious disturbance in N uptake was observed when the above mentioned level of Zn application were exceeded either on the lower or upper side.

V. EFFECTS OF ZINC ON P UPTAKE BY RICE :

Singh and Jain (1964) reported soil application of 2.53 kg Zn/ha increased the crude protein, P and Ca content of grain.

Report of Enyi (1967) revealed that higher level of P application increased the accumulation of Zn in plant.

Jain and Singh (1967) reported P uptake was markedly increased by foliar spray with Zn alone or in combination with iron.

Sharma et al. (1968) reported that application of P to both upland and low land rice reduced Zn uptake.

Coronell and Wallihem (1971) noted that Zn application reduced the P uptake and content of young leaves of rice from 0.30 to 0.14%.

Aymond (1973) recorded Zn induced P and Mn deficiency in rice.

Subramanyam and Meheta (1974) observed Zn deficiency in Rice through application of 200 ppm P. This Zn deficiency was corrected through application of ZnSO_4 that

caused reduced uptake of P, Ca, Mg, Fe and Mn by rice.

Hulagar et al. (1975) observed little effect of P on Zn or of Zn on P.

Gangwar (1976) recorded significant negative correlation between Zn and P in rice.

Study of Mawardi et al. (1977) showed that application of Zn to rice decreased the P content in leaves.

Singh (1979) reported that application of Zn to low land rice depressed the uptake of P.

According to Marian and Kosy (1979) Zinc application decreased the P content of both grain and straw.

Urs (1980) recorded higher uptake of N,P,K, Ca and Mg in both grain and straw by application of 2.5 ppm Zn than no Zinc application.

Halдар and Mandal (1931) reported decreased concentration of Zn in both shoot and root parts of rice by application of P. According to these authors the decreased concentration of Zn in plant was not due to dilution effect or due to reduced translocation of Zn from root to shoot but was due to the changes in availability of Zn in soil solution. In contrast Dwivedi et al. (1975) and Takkar et al. (1976) reported that depressing effect of P on Zinc uptake was not in the soil but was either at the root surface or within the plant.

Sedberry et al. (1932) reported that application of P increased the P content with decreasing concentration of Zn in rice leaves. According to them, grain yield was positively correlated with leaf P and negatively correlated with leaf Zn. These authors compared different P sources on uptake of Zn but found no significant effect. Orabi and Abuleenane (1980), however reported increased drymatter yield and higher uptake of P by application of either ZnSO_4 or Zn-EDTA.

Findings of Gupta et al. (1984) showed that in lime treated soils, application of normal levels of P (40 kg/ha) reduced the uptake of Zn by rice.

Kulkarni and Chavan (1985) reported that application of Zn significantly decreased the uptake of P by rice in laterite soils.

Mittal and Meheta (1987) reported that application of P formed insoluble Zinc phosphate in soil solution and hence reduced Zn uptake by rice.

Gangwar et al. (1989) reported that application of Zn at 5 to 20 ppm decreased the P content of shoot and root of rice.

Pot culture experiment conducted by Sahu (1989) in Zn deficient alluvial soil (0.52 ppm DTPA-Zn) showed that maximum uptake of P by rice plant occurred at 2.5 and 5 ppm

levels of Zn application. Significant decrease in P uptake was observed when the above mentioned level of Zn application were exceeded either on the lower or upper side.

VI. EFFECTS OF ZINC ON K-UP TAKE BY RICE :

Quayyum and Athar (1981) reported that application of graded levels of K to rice in clay loam soil enhanced Zn uptake by grain and straw, but combined application of N, P and K decreased the uptake of Zn.

Pot culture study of Sahu (1989) in a Zn deficient alluvial soil (0.52 ppm DTPA-Zn) showed that highest uptake of K by rice plant occurred at 2.5 and 5 ppm levels of Zinc application. Significant decrease in drymatter yields with serious disturbances in nutrient uptake was observed when the above mentioned level of Zn application were exceeded either on the lower or upper side.

CHAPTER III

MATERIALS AND METHODS

CHAPTER - III

MATERIALS AND METHODS

I. ZINC UPTAKE BY SEEDLING ROOT DIP :

A Zinc deficient black soil (0.55 ppm DTPA extractable Zinc) from RRS, Bhawanipatna was taken for growing rice seedlings in plastic pots of 4.5 kg capacity. Three numbers of such pots were filled with finely ground unsieved soils. The soils in pots received N and P at 40 and 20 ppm each in form of GR Grade DAP and NH_4Cl . K at 20 ppm was added in form of AR grade KCl. These nutrients were added in form of solution. Seeds of Rice variety ' LALAT ' were soaked with deionised water for 24 hours in plastic beakers. Then the excess water was drained out, seeds were tied with a clean cloth and allowed for germination for another 24 hours. The germinated seeds were sown in the pots. The pots were kept under sun. The pots were irrigated with deionised water to maintain standing water of 1 cm depth. Twentyone days old seedlings were carefully uprooted without injuring the roots. The roots were washed carefully by deionised water.

ZnO 4% suspension, Zn-EDTA 0.05% solution and ZnSO_4 0.5% solution neutralised with 0.25% lime water (pH 7.2) were

prepared and preserved in separate plastic beakers. Roots of hundred number of seedlings were dipped in these three different Zn sources. Twenty number of seedlings were drawn out of the beakers at interval of 1 hr, 2 hrs, 4 hrs, 6 hrs, 8 hrs each. The roots were washed three times with deionised water and the plants were dried in oven at 70°C for 48 hours. The dried samples were finely ground. The diacid ($\text{HNO}_3 : \text{HClO}_4$) digested plant samples were used for Zinc analysis.

II. POT CULTURE :

A pot culture study was conducted to study the response of rice to different Zinc sources and doses in the zinc deficient black soil.

4.5 kg of this soil was weighed into 24 number of plastic pots closing the bottom hole with polythene sheets. Eight treatments of Zinc such as no Zn (control), 2.5 ppm and 5 ppm Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, 0.6 ppm, 0.3 ppm and 0.03 ppm Zn as Zn-EDTA, ZnO (4%) seedling root dip and Zn-EDTA(0.05%) seedling root dip were replicated thrice in CRD. All the pots received a uniform basal dose of N , P , K at 40, 20 , 20 ppm respectively. Source of N and P was DAP and NH_4Cl of chemical grade and the soil was saturated with deionised water. Twentyone day old seedlings of rice variety 'LALAT' which were raised previously in the same soil in a plastic

pot were transplanted directly after washing the roots with deionised water. Ten seedlings were uprooted carefully with no damage to roots, washed with deionised water and dipped in 4% ZnO suspension and 0.05% Zn-EDTA solution each for four hours and then transplanted in pots. A standing water of 3 cm was maintained throughout the growth period by adding deionised water.

At 45 days after transplanting plant height and tiller numbers were measured. Plants were harvested from above ground using a stainless steel blade. The plant samples were washed with deionised water followed by 0.1 N HCl and double distilled water. The samples were dried in oven at 70°C temperature for constant weight, ground and used for chemical analysis.

III. METHODS OF ANALYSIS :

I) SOIL ANALYSIS :

1. MECHANICAL ANALYSIS : The mechanical analysis of 2 mm sieved soils was done by hydrometer method as described by Piper (1950).
2. SOIL REACTION : The pH of 1:2 soil : water suspension was determined by ELICO digital pH meter Model-LI 10 using glass and calomel electrodes.
3. ORGANIC CARBON : Organic carbon was determined by Walkley and Black method as described by Jackson (1967).

4. CATION EXCHANGE CAPACITY : Cation exchange capacity was determined by successive extraction with neutral 1N NH_4OAc as described by Jackson (1967).
5. AVAILABLE NITROGEN : Available Nitrogen was determined by alkaline permanganate method as described by Subbiah and Ashija (1956).
6. AVAILABLE PHOSPHORUS : Available phosphorus was estimated by Olsen's method as described by Jackson (1967).
7. AVAILABLE POTASSIUM : Available potassium was determined by extraction with 1N NH_4OAc (pH 7.0) and estimated by Flame photometer, ELICO Model LI 10.
8. AVAILABLE ZINC : Available Zn was estimated by extracting with DTPA-Triethanolamine as described by Lindsay and Norvel (1978).

The solution containing 0.005M diethylenetriamine penta-acetic acid (DTPA), 0.1M triethanolamine (TEA) and 0.01M calcium chloride adjusted to pH 7.3 with HCl was used with a soil to solution ratio of 1:2. The reagent was added directly to the centrifuge tube with soil. The tubes were shaken for two hours, centrifuged at 3000 rpm and clear supernatant was used for determination of Zn by Atomic Absorption Spectrophotometer, Varian Model 1475 using hollow cathode lamp of Zn.

II) PLANT ANALYSIS :

1. NITROGEN : Nitrogen in plant sample was determined by microkjeldahl method as described in A.O.A.C. (1965).
2. DIACID DIGESTION : 0.5 g of powdered plant samples were pre-digested with 10 ml concentrated HNO_3 for 12 hours followed by digestion with 5 ml diacid mixture ($\text{HNO}_3:\text{HClO}_4$, 3:2). The volume was made upto 50 ml with double distilled water. Suitable amounts of aliquots were taken for analysis of P, K and Zn.
 - i) Determination of P : Phosphorus was determined by vanadomolybdate yellow colour method as described by Jackson (1967).
 - ii) Determination of Potassium : Potassium was determined by Flame photometer model ELICO LI-10.
 - iii) Determination of Zn : Zn from the aliquots after suitable dilution were determined by Atomic Absorption Spectrophotometer using hollow cathode lamp for Zn.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER-IV

RESULTS AND DISCUSSION

Two types of experiments were conducted for this study (I) Zinc uptake by rice seedlings when they were dipped in different zinc solutions or suspensions of zinc containing fertilisers for various periods of time and (II) Zinc uptake by rice plant from different sources when grown in pots containing a zinc deficient soil.

The first study consisted of three sources of Zinc such as :

- (a) 4% ZnO suspension
- (b) 0.5% solution of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$
- (c) 0.05% solution of Zn-EDTA

The absorption from these three sources at time intervals of 1, 2, 4, 6 and 8 hours were studied.

The second study which involved a pot culture experiment consisted of three sources of zinc such as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, Zn-EDTA and ZnO and two methods of application such as soil application and seedling root dip. Details of the treatments have been given in Materials and Methods.

I) ABSORPTION OF ZINC BY RICE SEEDLINGS FROM DIFFERENT SOURCES :

Twentyone day old rice seedlings were dipped in 4% suspension of ZnO, 0.5% solution of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ or 0.05% solution of Zn-EDTA for 1 , 2 , 4 , 6 and 8 hours and the zinc content of rice seedlings were determined. The results are given in table 1 and fig.1.

It is observed from table 1 that zinc content of the rice seedlings increased with time for ZnO and Zn-EDTA upto 8 hours. In case of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ the maximum was reached at 6 hours beyond which there was a significant decrease. Zinc absorption from different sources can be observed better from figure 1. It is seen from this figure that maximum zinc absorption took place during the first hour from all the sources. It was as high as 781% in case of ZnSO_4 and 583% in case of ZnO. The rate of absorption per hour was relatively slower for Zn-EDTA and the increase was only 65.6% during the first hour (table 1). In case of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ a plateau was reached between first and second hour beyond which there was again a sharp increase in zinc absorption upto 6th hour. In case of ZnO there was a relatively slower rate of increase beyond first hour upto eighth hour. Absorption from Zn-EDTA was much slower beyond the 1st hour and appeared to reach a constant maxima beyond four hours.

Table 1. EFFECT OF SEEDLING ROOT DIP OF VARIOUS ZINC TREATMENTS ON ZINC CONCENTRATION OF RICE SEEDLINGS

Time (hour)	ZnO (4% suspension)		ZnSO ₄ ·7H ₂ O (0.5% solution)		Zn-EDTA (0.05% solution)	
	Conc. of Zn(ppm)	% increase in Zn content per hour	Conc. of Zn(ppm)	% increase in Zn content per hour	Conc. of Zn(ppm)	% increase in Zn content per hour
0	90	-	90	-	90	-
1	615	583.3	793	781.0	149	65.6
2	720	17.0	841	6.1	174	16.8
4	770	3.5	1338	29.6	201	7.7
6	871	6.6	2201	32.2	209	2.0
8	889	1.0	1522	-15.4	213	1.0
SE(m) ±	3.27	-	22.87	-	3.30	-
C.D. (0.05)	10.08	-	70.48	-	9.79	-

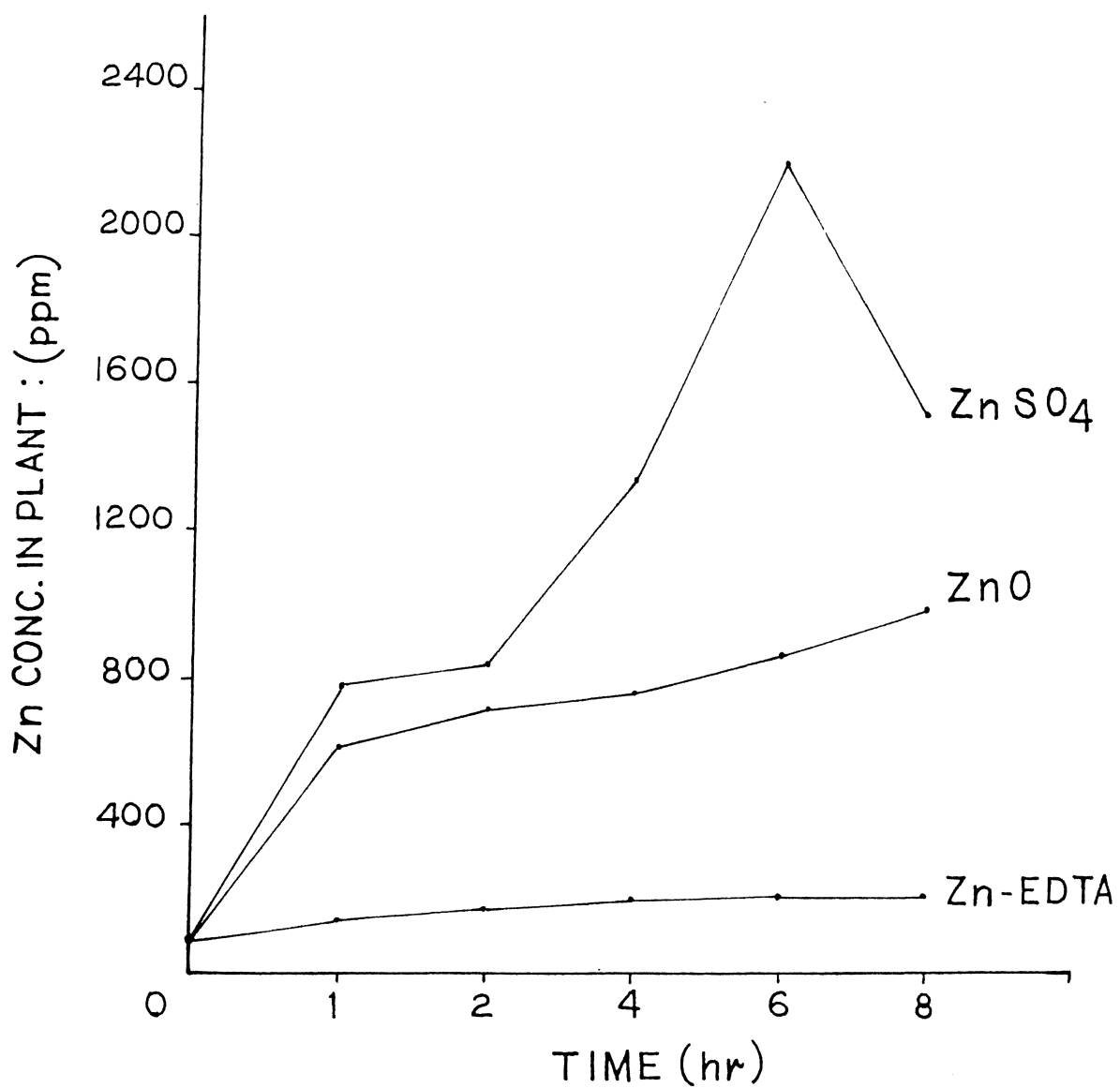


Fig.1. EFFECT OF SEEDLING ROOT DIP ON ZINC ABSORPTION BY RICE SEEDLING WITH TIME

This study indicates the different pattern of zinc absorption from the three different sources. The concentration of the three sources of course were different from one another. This was done intentionally taking into account the prevalent practices adopted for zinc application to rice and the possibility of toxicity if higher concentrations of a particular source were taken. It has to be taken into account that the rice seedlings were more or less in a stationary state of their growth during the short time interval of the experiment and hence had no additional nutrient requirement to support growth. The critical zinc requirement was met during the first hour, after which there was relatively slower rate of increase in zinc content of plants per hour as given in table 1. Among the three sources the most readily available source was $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ from which zinc was absorbed as Zn^{++} ion. ZnO was an insoluble source and zinc uptake from this source was probably through solubilisation of ZnO by organic acids released by rice roots and consequent uptake as Zn^{++} ion. However this mechanism cannot alone explain the high rate of zinc uptake during the first hour for this source. There was probably a strong adsorption of the fine particles of ZnO on the root surface and possibly complex formation so that these particles could not be washed from root surface by 0.1N HCl and distilled water, a treatment given to the roots of all the rice seedlings before

they were dried for chemical analysis. Since the entire rice seedlings including the roots were analysed, any Zn adsorbed or absorbed by the roots was also included in the reported figures.

Zn-EDTA was probably absorbed as the entire chelated molecule and hence the rate of absorption was slow.

For all the three sources it probably took some time for equilibrium to establish after the initial high rate of absorption during the first hour. In case of ZnO and Zn-EDTA there was a gradual decrease in rate of absorption from second to eighth hour, but in case of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ there were further increases from second to sixth hour probably due to readily available form of Zinc. The decrease in zinc content from sixth to eighth hour was probably caused by Zn toxicity.

According to Mengel and Kirkby (1978) there is considerable disagreement in the literature as to whether zinc uptake is passive or active. In plant roots 90% of the total zinc may occur in exchange site or adsorbed to surfaces of the cell wall of the cortex. Confusion may arise about the manner of zinc uptake for short term experiments.

II) POT CULTURE STUDY :

A pot culture experiment was conducted with a zinc deficient vertisol. The physico-chemical properties of the soil are given in table 2. It is observed from table 2

Table 2. SOIL ANALYSIS RESULTS

 Physico-Chemical Properties of the Soil :

I. Physical properties :

Mechanical Composition :

Sand (%) : 55.04

Silt (%) : 14

Clay (%) : 30.96

Textural class : SANDY CLAY LOAM

II. Chemical properties :

i) pH (1:2) = 6.85

ii) CEC = 9.79 [c mol (P⁺) kg⁻¹]iii) EC = 0.8925 dS M⁻¹

iv) Organic carbon : Walkley- Black Method) = 0.724%

v) Nitrogen (Alkaline Permanganate Method)= 370 kg ha⁻¹vi) Available P : (Olsen's Method) = 6.8 kg ha⁻¹vii) Available K : (Ammonium acetate method) = 293 kg ha⁻¹

viii) Zn(DTPA-extractable) : 0.55 ppm

that the soil used was a sandy clay loam with low available P (6.3 kg/ha) and zinc (0.55 ppm, DTPA extractable). The soil had a pH of 6.85 .

1) EFFECT OF ZINC APPLICATION ON GROWTH AND YIELD OF RICE PLANT

Height of the plant, number of tillers per plant and drymatter yield were recorded at 45 days after transplanting. Each pot had two plants. The results are given in table 3 and drymatter yield in figure 2. It is observed from this table that height of the plants, number of tillers per plant and drymatter yield increased significantly over the control for all the zinc treatments except the two treatments consisting of seedling root dips in ZnO and Zn-EDTA. The amount of zinc absorbed by seedlings within a period of four hours (Table 1) from these two sources was probably not enough to sustain the plant for 45 days. The lower values obtained for ZnO seedling root dip were probably due to washing of the roots of the rice seedlings with deionised water before transplanting. The benefit obtained from this source is probably more for ZnO particles adsorbed on the root surface rather than absorption of zinc by the roots.

Maximum increase in drymatter yield was recorded with 5 ppm Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ soil treatment. This was statistically at par with the treatments consisting of

Table 3. EFFECT OF ZINC APPLICATION ON GROWTH AND YIELD OF RICE PLANT.

Tr No.	Treatments	Height (cm)	No. of tillers per plant	Dry matter yield (g/pot)	% Increase over control
T ₁	Control	23.35	4	0.483	-
T ₂	Zn 2.5 ppm as ZnSO ₄	32.867	12	3.15	652.2
T ₃	Zn 5 ppm as ZnSO ₄	32.767	12	3.917	810.97
T ₄	Zn 0.6 ppm as Zn-EDTA	30.85	9	3.60	745.34
T ₅	Zn 0.3 ppm as Zn-EDTA	32.38	12	3.35	797.1
T ₆	Zn 0.03 ppm as Zn-EDTA	34.283	9	3.533	731.47
T ₇	ZnO (4%) Seedling root dip	24.883	6	1.20	248.45
T ₈	Zn-EDTA (0.05%) Seedling root dip	25.95	4	0.767	158.30
S. E. (m) ±		1.91	0.8	0.28	-
C. D. (0.05)		5.73	2.4	0.84	-

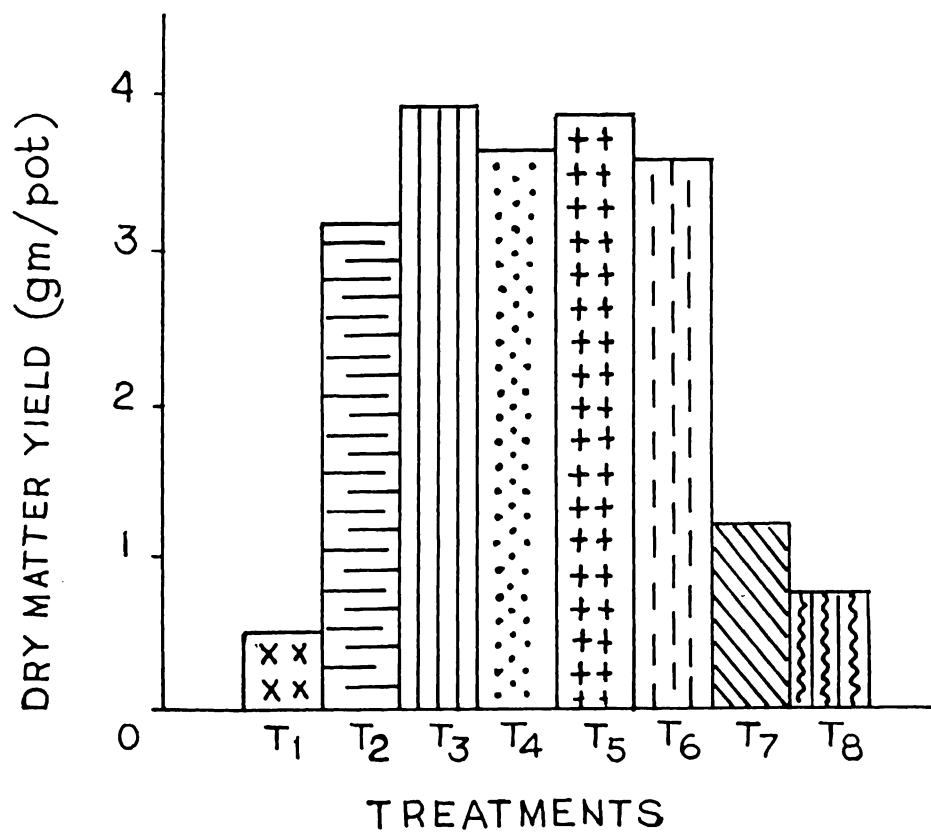


Fig.2 .EFFECT OF ZINC APPLICATION ON DRY MATTER
YIELD OF RICE PLANT

2.5 ppm Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ and 0.6, 0.3 and 0.03 ppm Zn as Zn-EDTA. The beneficial effect observed for the treatment with 0.03 ppm Zn as Zn-EDTA as soil application is surprising. The probable reasons for getting such a result has been discussed in subsequent pages.

The plants growing under treatment 'control' showed characteristic Zinc deficiency symptoms (Photograph-1). This consisted of reddish brown pigments on the central part of the leaves, bleaching of lamina of young leaves followed by apical necrosis, short internodes, weak and less number of tillers and reduced plant height and growth.

2051 The relative performance of every treatment as compared to control along with general view of the entire experiment are shown in Photographs 2 to 9. The growth pattern substantiates the data presented in table 3.

ii) EFFECT OF ZINC APPLICATION ON ZINC CONTENT AND UPTAKE BY RICE PLANT :

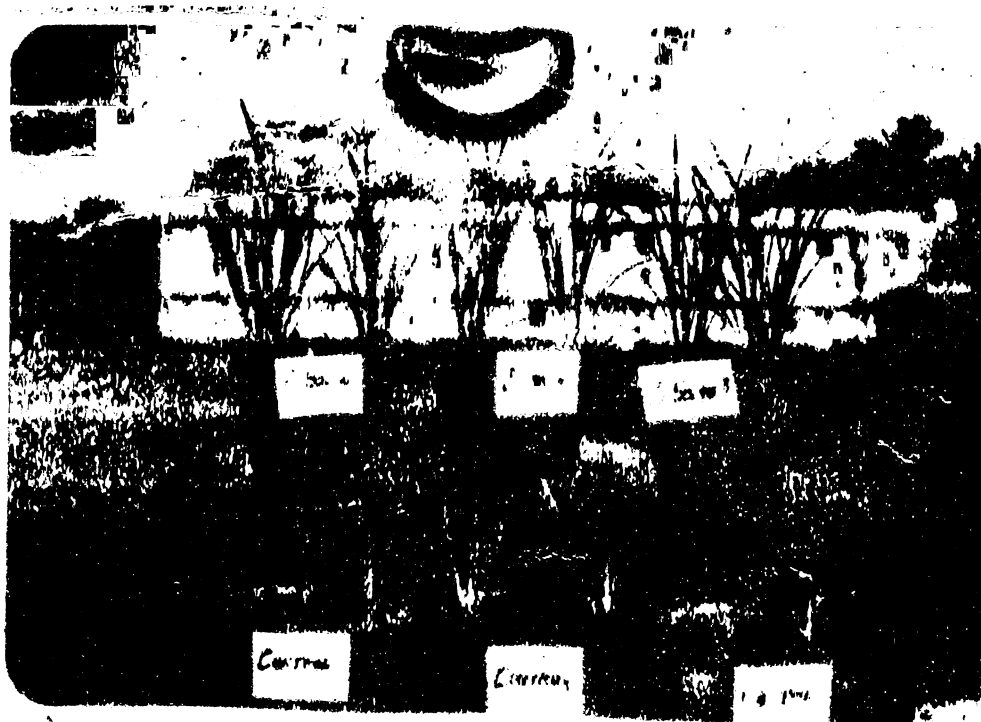
The zinc content and zinc uptake per pot determined for each treatment are given in table 4 and figures 3 and 4. It is observed from this table that zinc content for all the treatments were significantly higher than the control including the two seedlings root dip treatments whose drymatter yield were not significantly



PHOTOGRAPH-1 : ZINC DEFICIENCY SYMPTOMS
IN RICE



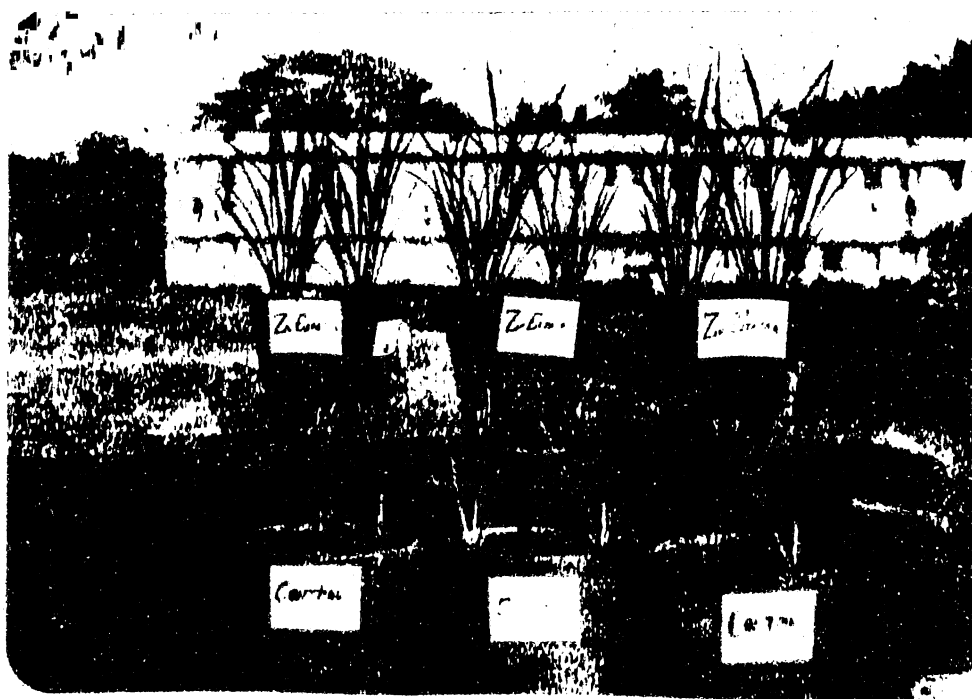
PHOTOGRAPH -2: CONTROL VS. SOIL APPLICATION
OF 2.5 ppm ZINC AS $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$



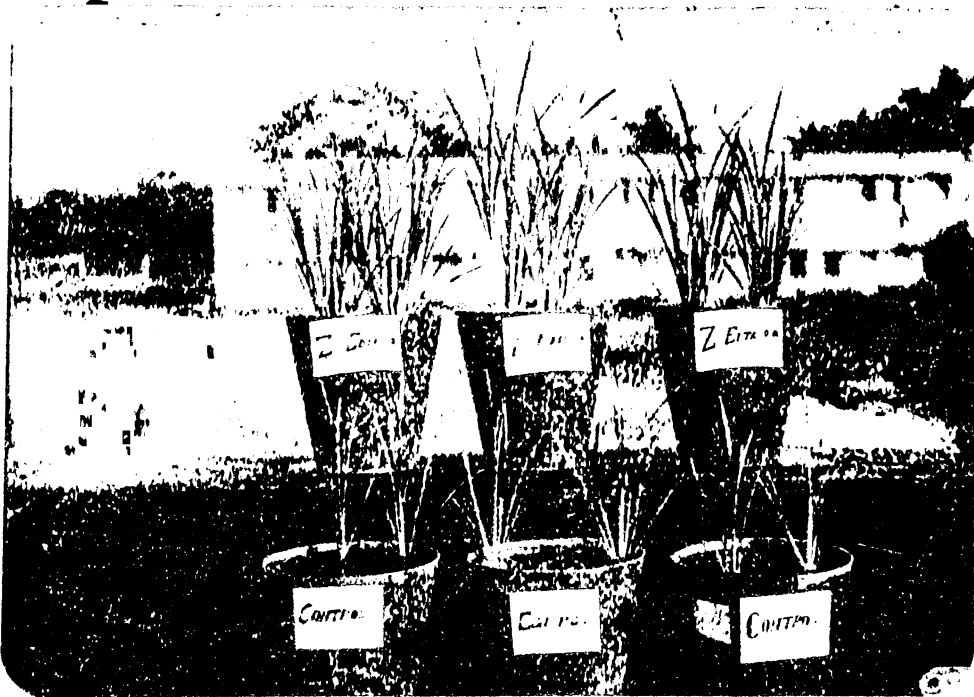
PHOTOGRAPH-3: CONTROL VS. SOIL APPLICATION
OF 5.0 ppm ZINC AS $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$



PHOTOGRAPH-4 : CONTROL Vs. SOIL APPLICATION
OF 0.6 ppm ZINC AS Zn-EDTA



PHOTOGRAPH-5: CONTROL Vs. SOIL APPLICATION
OF 0.3 ppm ZINC AS Zn-EDTA



PHOTOGRAPH-6 : CONTROL Vs. SOIL APPLICATION
OF 0.03 ppm ZINC AS Zn-EDTA



PHOTOGRAPH-7 : CONTROL Vs. SEEDLING ROOT
DIP IN 4% ZnO SUSPENSION



PHOTOGRAPH-3: CONTROL Vs. SEEDLING ROOT
DIP IN 0.05% Zn-EDTA
SOLUTION



PHOTOGRAPH-9 : GENERAL VIEW OF THE ENTIRE
EXPERIMENT

Table 4. EFFECT OF ZINC APPLICATION ON ZINC CONTENT AND ZINC UPTAKE OF RICE PLANT.

Tr. no.	Treatments	Zn content(ppm)	Zn uptake(mg/pot)
T ₁	Control	18.67	0.009
T ₂	Zn 2.5 ppm as ZnSO ₄	59.67	0.188
T ₃	Zn 5 ppm as ZnSO ₄	60.00	0.240
T ₄	Zn 0.6 ppm as Zn-EDTA	51.00	0.183
T ₅	Zn 0.3 ppm as Zn-EDTA	52.67	0.202
T ₆	Zn 0.03 ppm as Zn-EDTA	38.67	0.130
T ₇	ZnO (4%) Seedling Root dip	56.00	0.069
T ₈	Zn-EDTA (0.05%) Seedling Root dip	93.33	0.070
S.E. (m) ±		5.95	0.024
C.D. (0.05)		17.84	0.071

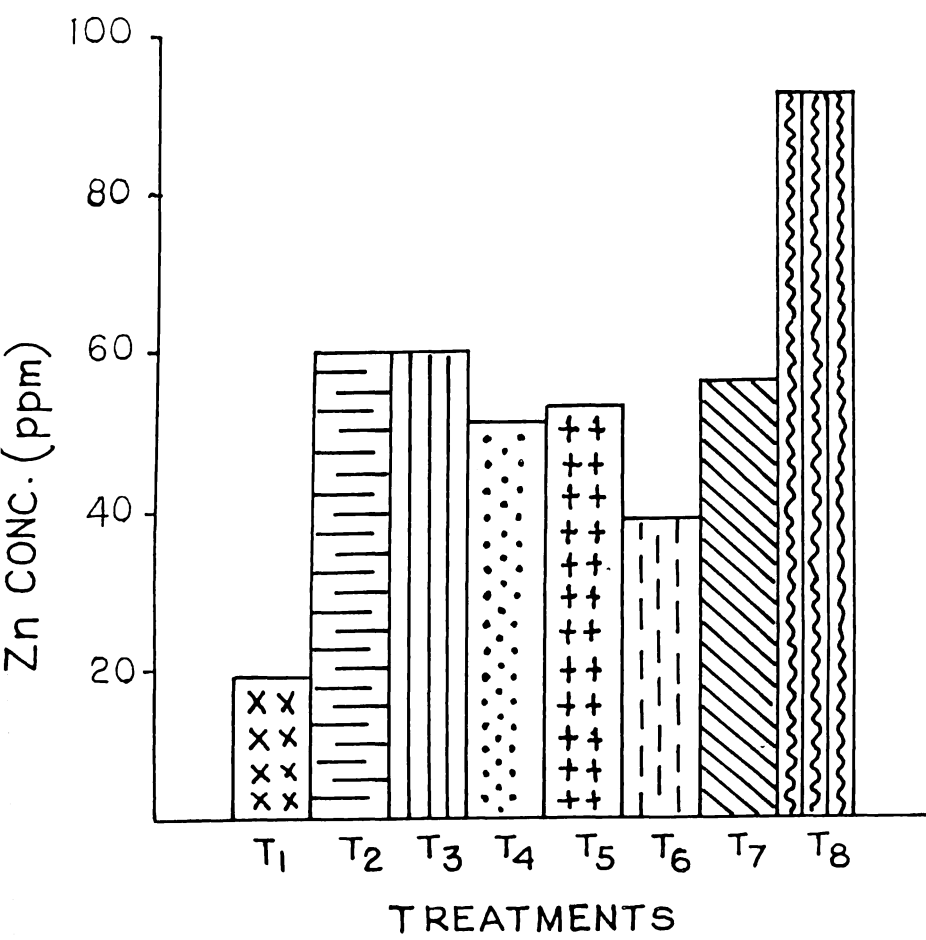


Fig.3. EFFECT OF ZINC APPLICATION ON ZINC CONTENT OF RICE PLANT

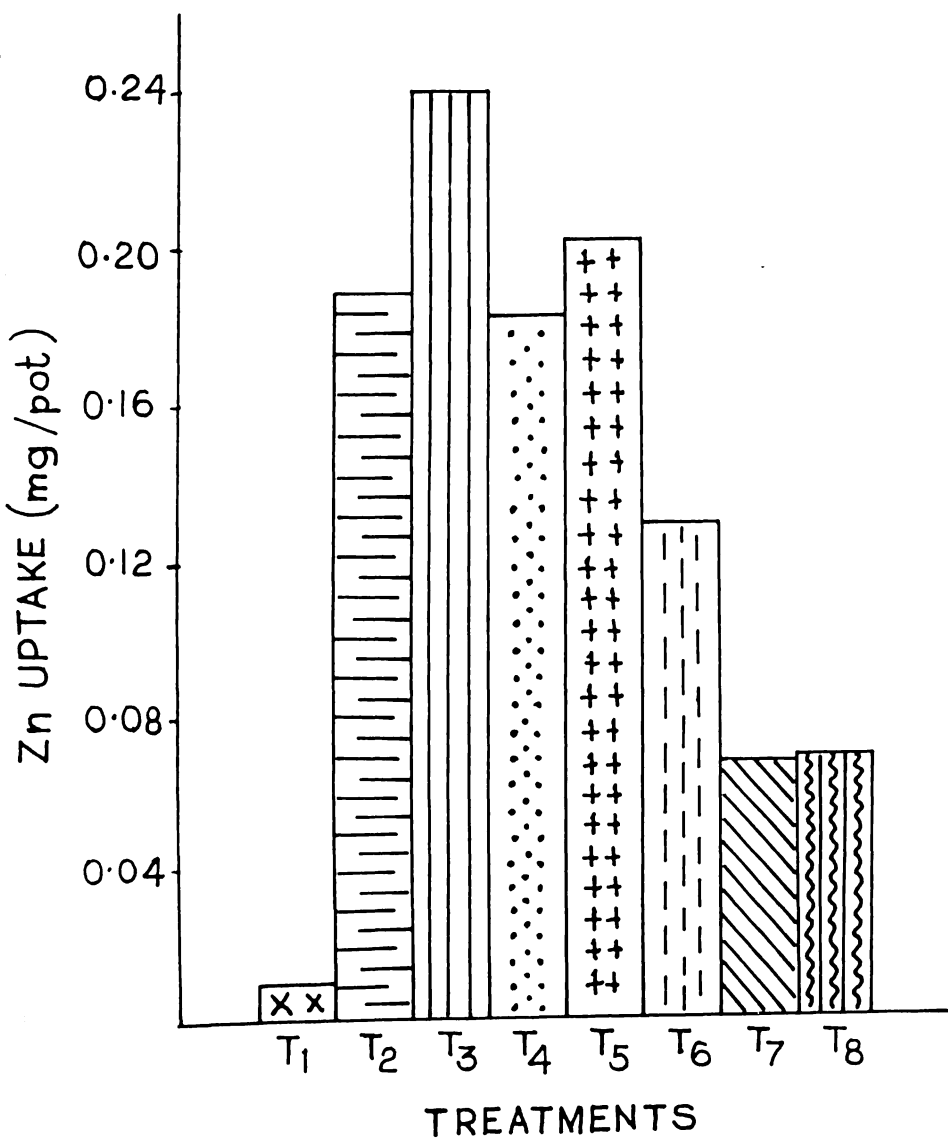


Fig.4 . EFFECT OF ZINC APPLICATION ON ZINC UPTAKE OF RICE PLANT

higher than the control. Zinc uptake for the seedling root dip treatments were not significantly higher than the control due to non-significant increase in the dry-matter yield. However zinc content of the Zn-EDTA seedling root dip was the highest and significantly higher than all the treatments. This observation is again difficult to explain. The reduced growth with such a high zinc content in plant can only be explained due to zinc toxicity. The Zn-EDTA used in this experiment was obtained from a commercial firm marketing this product. The unusual behaviour of this product at relatively lower concentrations points to admixture of some other compounds (possibly a hormone) in the product marketed.

Maximum zinc uptake was obtained for 5 ppm Zn, soil application as zinc sulphate which also gave the highest drymatter yield. Zinc uptake from soil applications of zinc sulphate at 2.5 and 5 ppm and Zn-EDTA at 0.3 and 0.6 ppm Zn were statistically at par.

iii) EFFECT OF ZINC APPLICATION ON NITROGEN CONTENT AND UPTAKE BY RICE PLANT :

Nitrogen content and uptake by the rice plant at harvest were determined for all the treatments and the data are presented in table 5 and figures 5 and 6. It is observed from this table and figures that nitrogen content

Table 5 . EFFECT OF ZINC APPLICATION ON NITROGEN CONTENT
AND UPTAKE OF RICE PLANT .

Tr. no.	Treatments	Nitrogen content (%)	Nitrogen uptake (mg/pot)
T ₁	Control	1.82	8.73
T ₂	Zn 2.5 ppm as ZnSO ₄	2.04	64.28
T ₃	Zn 5 ppm as ZnSO ₄	2.29	88.57
T ₄	Zn 0.6 ppm as Zn-EDTA	2.24	81.09
T ₅	Zn 0.3 ppm as Zn-EDTA	2.79	106.71
T ₆	Zn 0.03 ppm as Zn-EDTA	2.14	75.69
T ₇	ZnO (4%) Seedling Root dip	2.87	34.71
T ₈	Zn-EDTA (0.05%) Seedling Root dip	2.782	21.42

S.E. (m) ±		0.08	6.82
C.D. (0.05)		0.25	20.44

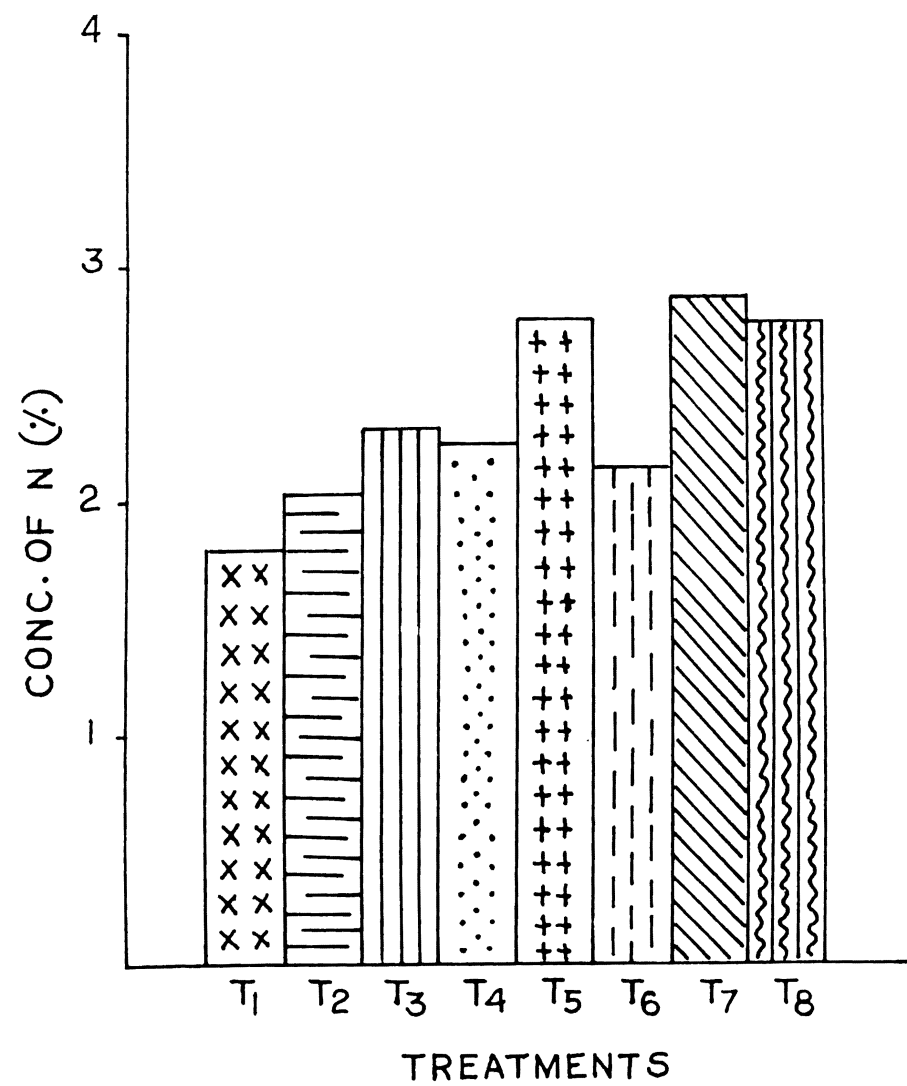


Fig.5. EFFECT OF ZINC APPLICATION ON NITROGEN CONTENT OF RICE PLANT

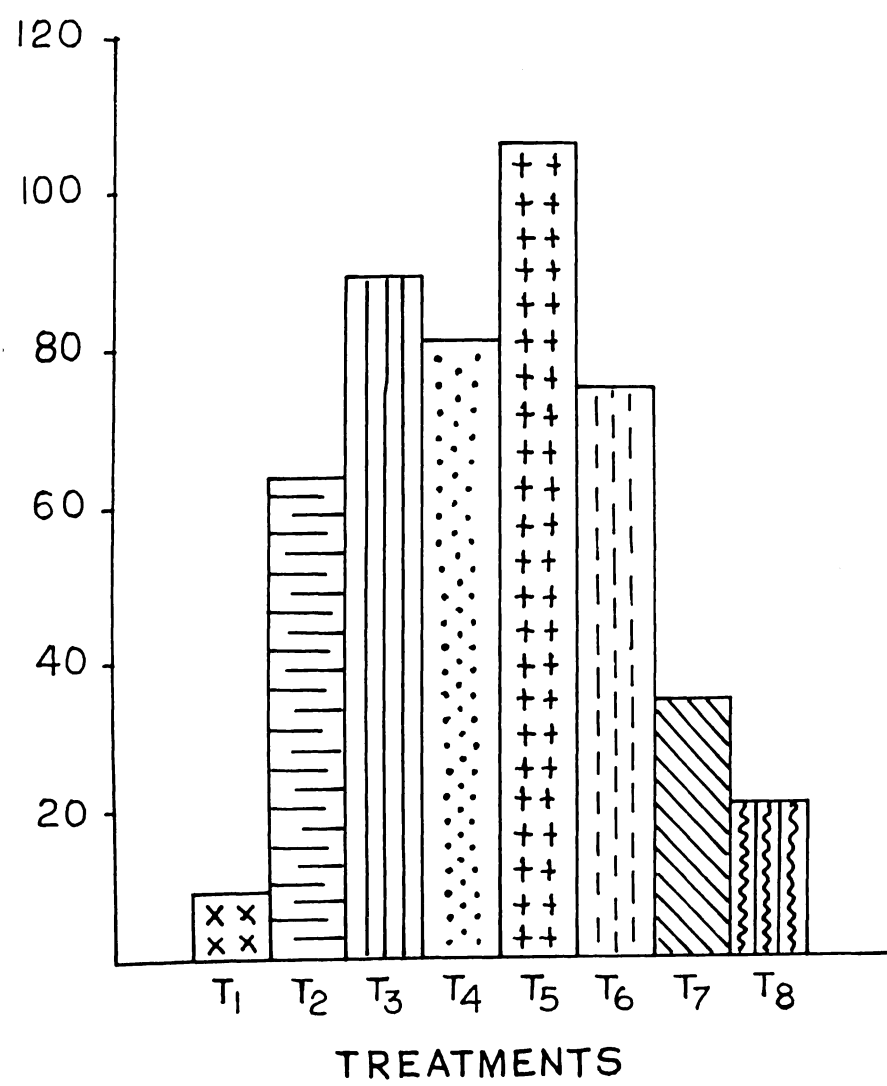


Fig. 6. EFFECT OF ZINC APPLICATION ON
NITROGEN UPTAKE OF RICE PLANT

of the plants increased significantly over the control for all the zinc treatments except 2.5 ppm Zn as zinc sulphate. Nitrogen uptake for all the treatments were significantly higher than the control except Zn-EDTA seedling root dip.

Zinc has been reported to increase the nitrogen content of the rice plant. (Enyi, 1966; Enyi, 1967; Jain and Singh, 1967; Venkatasubramanyam and Meheta, 1974 ; Mawardi et al. , 1977 and Singh and Singh, 1981). Nitrogen content of the Zn-EDTA treatments was probably modulated by the presence of the unknown compound in the commercial product. Among the zinc sulphate treatments application of 5 ppm Zn resulted in highest nitrogen content and nitrogen uptake. Application of 0.3 ppm Zn as Zn-EDTA also gave the highest nitrogen content and nitrogen uptake.

iv) EFFECT OF ZINC APPLICATION ON PHOSPHORUS CONTENT AND UPTAKE BY RICE PLANT :

Phosphorus content of rice plant and phosphorus uptake per pot were determined at harvest for the different zinc treatments. The data are given in table 6 and figures 7 and 8 . It is observed from this table that phosphorus content was highest for control and lowest for Zn-EDTA seedling root dip. Zinc content of the plants of these two treatments were in the reverse order. A negative correlation between zinc content and phosphorus content of the rice plant

Table 6 . EFFECT OF ZINC APPLICATION ON PHOSPHORUS CONTENT
AND UPTAKE OF RICE PLANT

Tr. no.	Treatments	Phosphorus content (%)	Phosphorus uptake (mg/pot)
T ₁	Control	0.212	1.022
T ₂	Zn 2.5 ppm as ZnSO ₄	0.197	6.203
T ₃	Zn 5 ppm as ZnSO ₄	0.142	5.470
T ₄	Zn 0.6 ppm as Zn-EDTA	0.135	4.879
T ₅	Zn 0.3 ppm as Zn-EDTA	0.141	5.410
T ₆	Zn 0.03 ppm as Zn-EDTA	0.145	5.158
T ₇	ZnO (4%) Seedling Root dip	0.150	1.800
T ₈	Zn-EDTA(0.05%) Seedling Root dip	0.125	1.075

S.E. (m) ±		9.613 x 10 ⁻³	0.448
C.D. (0.05)		0.029	1.343

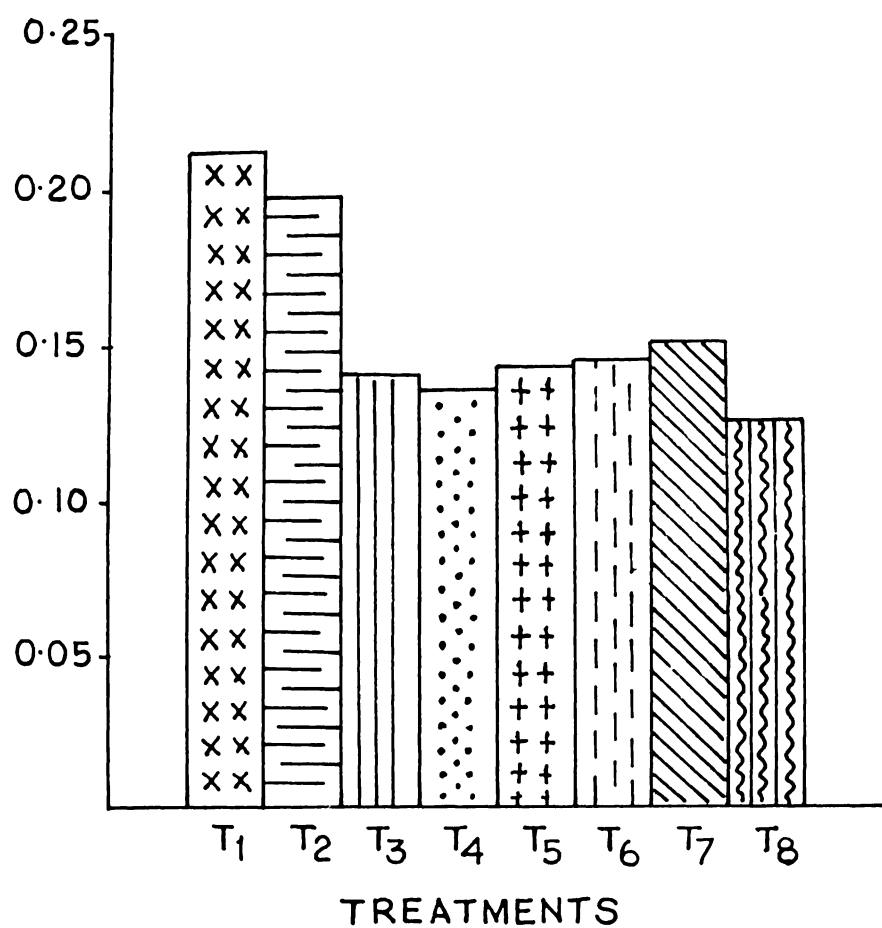


Fig. 7. EFFECT OF ZINC APPLICATION ON PHOSPHORUS CONTENT OF RICE PLANT.

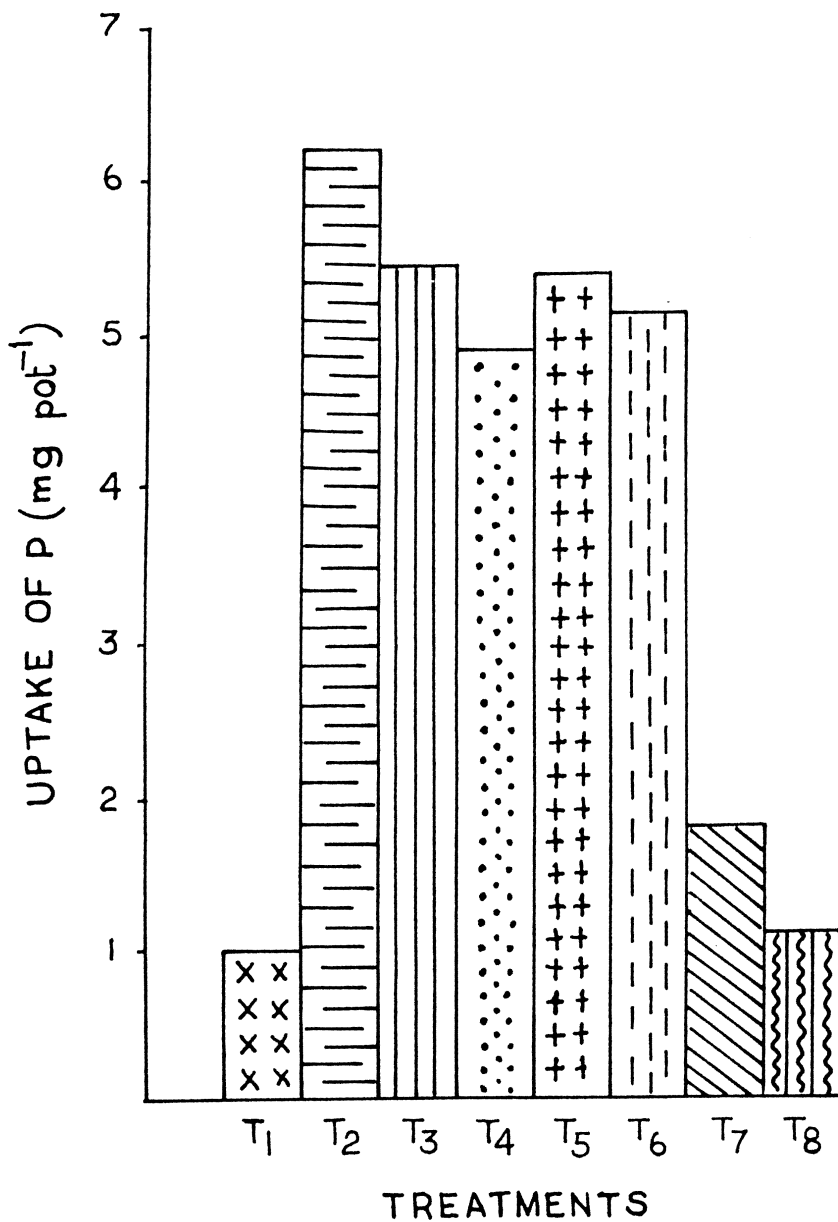


Fig.8.EFFECT OF ZINC APPLICATION ON
PHOSPHORUS UPTAKE OF RICE PLANT

has been reported by many workers. (Sharma et al., 1968; Coronell and Wallihem, 1971 ; Aymond, 1973; Subramanyam and Meheta, 1974; Gangwar, 1976 and Sedberry et al., 1982). Among the two zinc sulphate treatments 2.5 ppm Zn application was found to have significantly higher P content in plants than 5 ppm. The differences in P content of the plants in various Zn-EDTA treatments were however not significantly different from one another.

P uptake which was modulated by yield was found to be significantly higher than the control for all the zinc treatments except the two treatments with seedling root dip. P uptakes were in the reverse order as P content in Zinc sulphate treatments but did not follow this pattern in Zn-EDTA treatments.

v) EFFECT OF ZINC APPLICATION ON POTASSIUM CONTENT AND UPTAKE BY RICE PLANT :

Potassium content in the plants and the uptake of potassium per pot are given in table 7 and figures 9 and 10. It is observed from this table that the potassium content of the plants for the two zinc sulphate treatments increased significantly over control, but the differences with respect to Zn-EDTA treatments were not significant. The potassium uptakes were however significantly higher than the control for all the zinc treatments except the two seedling root dip treatments.

Table 7. EFFECT OF ZINC APPLICATION ON POTASSIUM
CONTENT AND UPTAKE OF RICE PLANT .

Tr. no.	Treatments	Potassium content (%)	Potassium uptake (mg/pot)
T ₁	Control	2.360	11.317
T ₂	2.5 ppm as ZnSO ₄	2.850	89.758
T ₃	Zn 5 ppm as ZnSO ₄	3.080	120.743
T ₄	Zn 0.6 ppm as Zn-EDTA	2.650	95.225
T ₅	Zn 0.3 ppm as Zn-EDTA	2.633	101.033
T ₆	Zn 0.03 ppm as Zn-EDTA	2.423	85.605
T ₇	ZnO(4%) Seedling Root dip	2.517	30.90
T ₈	Zn-EDTA (0.05%) Seedling Root dip	2.717	21.067

S.E. (m) ±		0.111	8.139
C.D. (0.05)		0.332	24.552

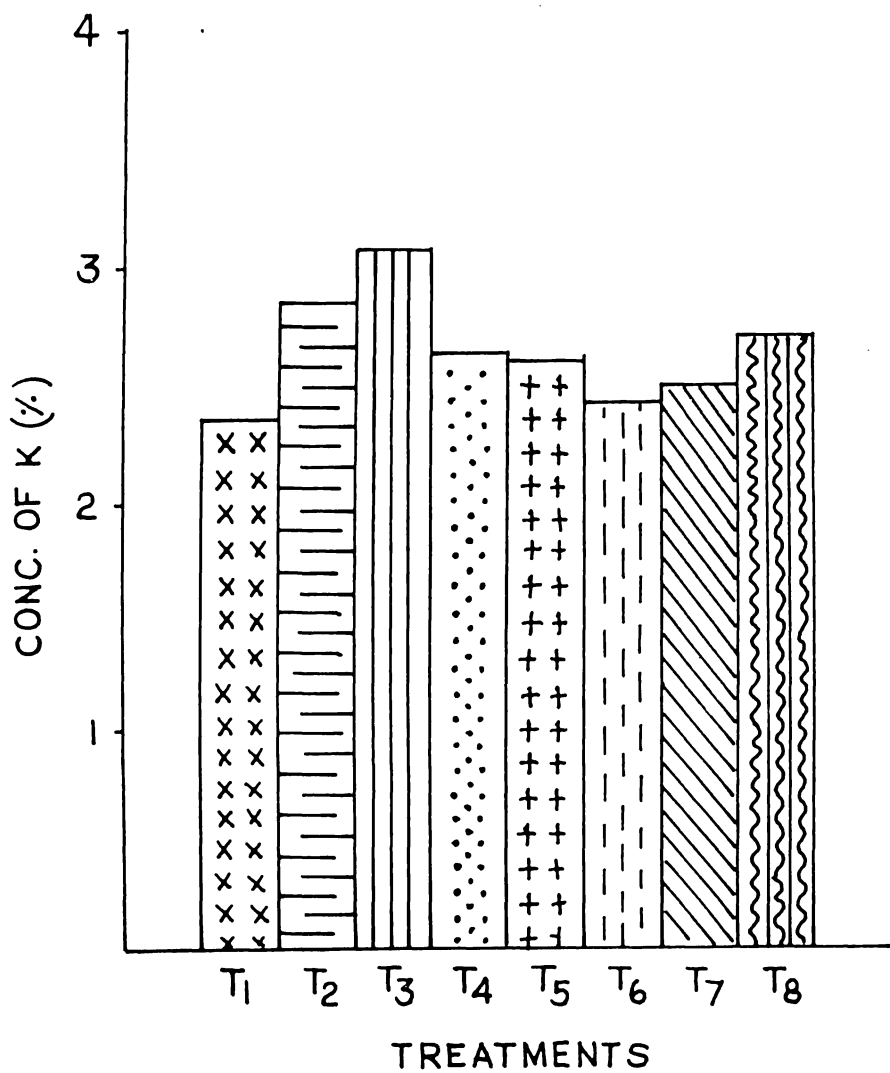


Fig.9. EFFECT OF ZINC APPLICATION ON POTASSIUM CONTENT OF RICE PLANT

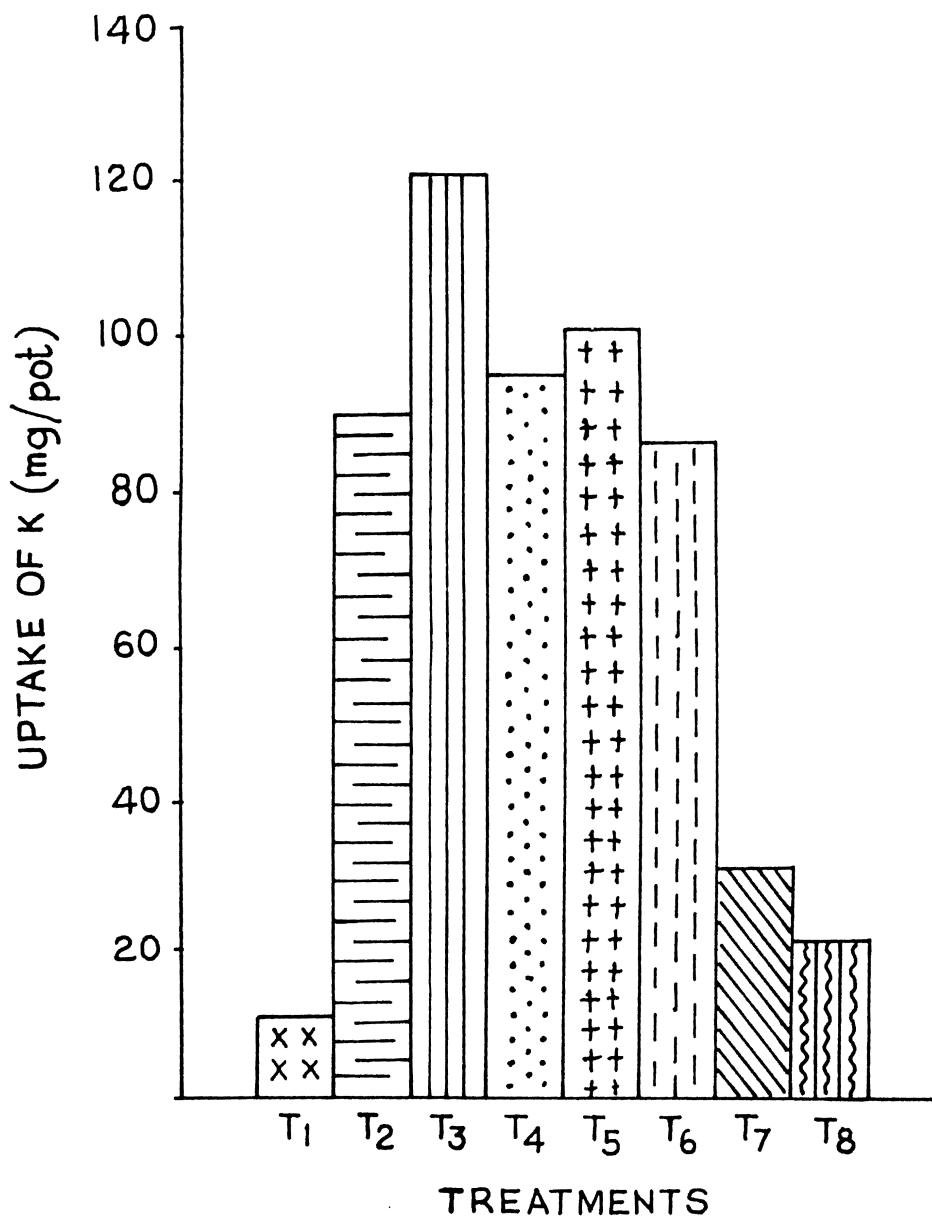


Fig.10. EFFECT OF ZINC APPLICATION ON
POTASSIUM UPTAKE OF RICE PLANT

Effects of zinc application on K content and uptake by rice plant as reported by different workers are contradictory. Urs (1980) recorded higher uptake of N,P,K, Ca and Mg in both grain and straw by application of 2.5 ppm than no zinc application. Quayyum and Ather (1981) reported that application of graded levels of K to rice in clay loam soil enhanced zinc uptake by grain and straw, but combined application of N, P and K decreased the uptake of Zinc.

If the K uptake and K content of the plants are taken together, the highest K content and K uptake was observed in the treatment with the application of 5 ppm zinc as zinc sulphate which incidentally gave the highest dry-matter yield and Zn content among the zinc sulphate treatments. Similarly with respect to Zn-EDTA, the highest K uptake and K content of the plants were observed with 0.3 ppm Zn as Zn-EDTA. This treatment also gave highest drymatter yield, zinc content and zinc uptake among the treatments with soil application of Zn-EDTA. A positive effect of zinc application on K content and uptake is indicated from this study.

CHAPTER V

SUMMARY AND CONCLUSION

CHAPTER - V

SUMMARY AND CONCLUSION

This study consisted of two types of experiment such as (i) zinc absorption from different sources of zinc by rice seedlings subjected to root dips in the suspensions or solutions of these sources for different periods of time and (ii) pot culture experiment with a zinc deficient vertisol to find out response of rice to different sources of zinc and their methods of application.

The first type of study consisted of seedling root dip in solutions of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, Zn-EDTA or suspension of ZnO for a period of 0-8 hours and estimation of Zn absorbed by the rice seedlings. It was observed that the rate of absorption of Zn was maximum during the first hour but slowed down considerably during subsequent hours (Table 1, Figure 1). Maximum absorption of zinc during first hour was observed in 0.5% solution of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (781%) followed by 4% suspension of ZnO (583%). The rate of absorption during first hour was considerably less (65.6%) from 0.05% solution of Zn-EDTA. While the concentration of zinc was different for the three sources, this study indicated that probably different mechanisms were

involved for zinc uptake from the three sources. In case of ZnSO_4 , Zn^{++} ions absorbed on the exchange sites were taken up partly by passive and partly by active uptake. ZnO was probably first converted into some soluble inorganic or organic salt so that Zn^{++} ions could be produced and absorbed by the roots. In case of Zn-EDTA the entire molecule was probably absorbed by roots and hence there was a slower rate of absorption from this source.

The pot culture study showed that soil application of Zinc as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ or Zn-EDTA was better than seedling root dip. Maximum drymatter yield was obtained on application of 5 ppm Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ or 0.3 ppm Zn as Zn-EDTA (Table 3).

When the zinc content of the plants were estimated it was observed that zinc content of the plants for all the Zn treatments were significantly higher than the control including the two seedling root dip treatments (Table 4). Among the zinc sulphate treatments highest zinc content and zinc uptake were observed on application of 5 ppm Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$. Among the Zn-EDTA treatments the highest zinc content was observed in the plants subjected to seedling root dip in 0.05% solution of Zn-EDTA and highest zinc uptake in 0.3 ppm Zn applied to the soil as Zn-EDTA. The higher zinc content of the two seedling root dip treatments was difficult to explain taking into account

the non-significant increase in drymatter yield of these two treatment.

The nitrogen content of the plants increased significantly over control for all the zinc treated plants except 2.5 ppm Zn as soil application in the form of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$. Maximum nitrogen uptake was observed for 5 ppm Zn among the zinc sulphate treatments and 0.3 ppm Zn among Zn-EDTA treatments. Nitrogen content of the plant in general was found to increase with increase in zinc content of the plants.

The phosphorus content of the plants was found to decrease significantly as compared to control for all the zinc treatments except for 2.5 ppm soil application of zinc as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$. The P uptake was highest for 2.5 ppm Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$. In general the increase in zinc content of the plants was found to have reverse relationship with the P content of the plants. The treatments with lowest and highest zinc content had the highest and lowest P content respectively in the plants.

The potassium content was found to increase mostly in a non-significant manner over the control in most of the zinc treatments except the two zinc sulphate treatments where the increase was significant. In general increase in zinc content of plant resulted in increase in K content

as well. K uptake of course was higher where drymatter yield was high.

Taking all the observations discussed in the previous paragraphs into consideration one can conclude that :

- 1) Rice seedlings can absorb considerable amount of zinc when their roots are dipped in solutions of ZnSO_4 , Zn-EDTA or suspension of ZnO. Maximum absorption takes place during the first hour and the rate of absorption decreases substantially in the subsequent hours. Seedling root dip for a maximum period of two hours is enough when such a method is adopted for supplying zinc from zinc sources.
- 2) Soil application of 5 ppm zinc (or 10 kg Zn/ha) as zinc sulphate or 0.3 ppm (0.6 kg Zn/ha) as Zn-EDTA can be applied to zinc deficient soils to get maximum yield.
- 3) Seedling root dip in 4% ZnO suspension or 0.05% Zn-EDTA solution for four hours did not increase drymatter yield significantly over control in the pot culture experiment. (The results of ZnO treatment however is subjected to error committed in the study by washing the roots of the seedlings before transplanting).

- 4) Zinc content of the plants due to various zinc treatments were found to have a positive relationship with nitrogen and potassium content but a negative relationship with the phosphorus content of the plants.
- 5) The relatively higher zinc content of the plants observed under two seedling root dip treatments where there was a non-significant increase in drymatter yield could be explained taking into account the imbalance in the N,P and K content of the plants. While N and K content increased with zinc content, the P content decreased significantly. This probably caused a reduction in growth.
- 6) The growth and nutrient uptake for 0.03 ppm zinc as Zn-EDTA soil application was found to be relatively high for such a small dose of zinc especially as soil application. Since a product manufactured by a commercial firm (who recommended such a dose) was used, it is suspected that an unknown compound (possibly a growth hormone) is possibly mixed with this material which enhanced the growth and nutrient uptake.

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