

STUDIES ON NITROGEN, SULPHUR AND ZINC NUTRITION IN RICE

नव्रजन, गंधक एवं जस्ता का धान के पोषण पर अध्ययन



THESIS

**SUBMITTED IN
PARTIAL FULFILMENT OF THE REQUIREMENTS
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IN
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Dedicated
To
my
Venerable
Parents

Sujit....

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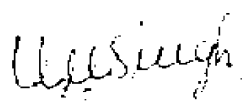
C E R T I F I C A T E

This is to certify that the thesis entitled, “**Studies on nitrogen, sulphur and zinc nutrition in rice**” submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy in Soil Science and Agricultural Chemistry** of the **Chandra Shekhar Azad University of Agriculture and Technology, Kanpur** is a record of bonafide research work carried out by **Mr. Sujit Kumar Dubey**, Id. No. **CA-5455/02** under my supervision and guidance.

The thesis embodies the results of his original research work carried out by himself.

Place: Kanpur

Date: May 25, 2007


(U.N. Singh)

**CHANDRA SHEKHAR AZAD UNIVERSITY OF
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CHEMISTRY)**



C E R T I F I C A T E

We, the undersigned members of the Advisory Committee of Mr. Sujit Kumar Dubey, Id. No. CA-5455/02 a candidate for the degree of Doctor of Philosophy in Agriculture with major in Soil Science and Agricultural Chemistry agree that the thesis entitled, "Studies on Nitrogen, Sulphur and Zinc Nutrition in Rice" may be submitted by him in partial fulfilment of the requirements for the degree.

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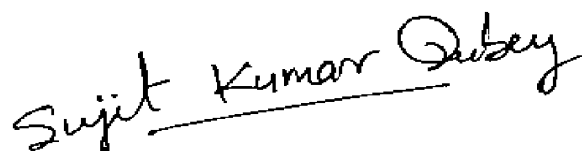
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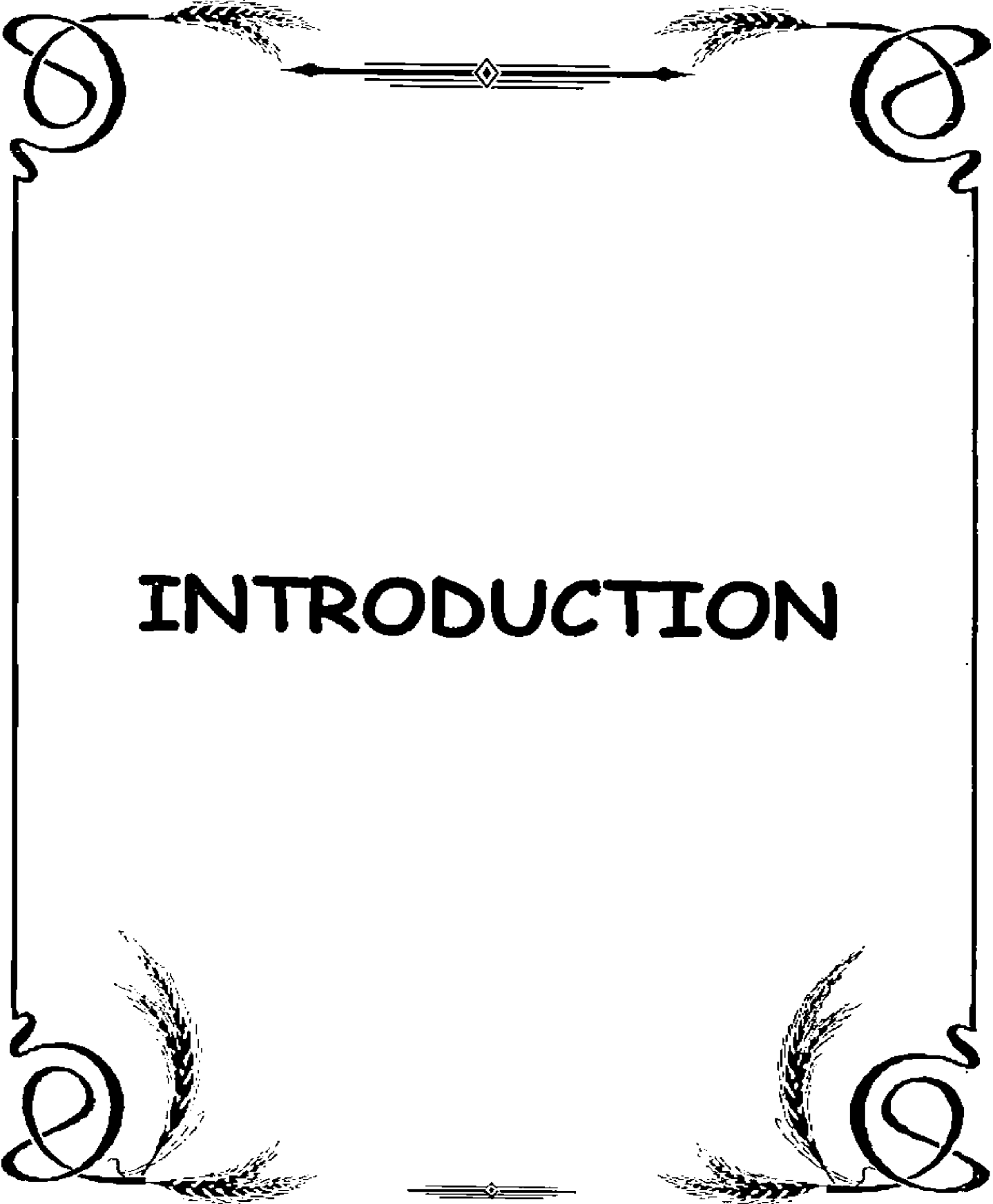
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CONTENTS

CHAPTER	PARTICULARS	PAGE No.
I	INTRODUCTION	1-6
II	REVIEW OF LITERATURE	7-60
III	MATERIALS AND METHODS	61-73
IV	EXPERIMENTAL FINDINGS	74-157
V	DISCUSSION	158-179
VI	SUMMARY AND CONCLUSION	180-189
	BIBLIOGRAPHY	I-XXVII

LIST OF ILLUSTRATIONS

FIG. No.	PARTICULARS	AFTER PAGE No.
3.1	Meteorological observations during <i>kharif</i> periods of 2003 & 2004	62
3.2	Layout plan of field experiment	64
4.1	Effect of N, S and Zn on test weight of grains	97
4.2	Effect of N, S and Zn on grain yield of rice	99
4.3	Effect of N, S and Zn on straw yield of rice	101
4.4	Effect of N, S and Zn on N content (%) in rice grain	106
4.5	Effect of N, S and Zn on N content (%) in rice straw	107
4.6	Effect of N, S and Zn on P content (%) in rice grain	112
4.7	Effect of N, S and Zn on P content (%) in rice straw	114
4.8	Effect of N, S and Zn on K content (%) in rice grain	118
4.9	Effect of N, S and Zn on K content (%) in rice straw	120
4.10	Effect of N, S and Zn on S content (%) in rice grain	124
4.11	Effect of N, S and Zn on S content (%) in rice straw	126
4.12	Effect of N, S and Zn on Zn content (mg kg^{-1}) in rice grain	130
4.13	Effect of N, S and Zn on Zn content (mg kg^{-1}) in rice straw	132
4.14	Effect of N, S and Zn on N uptake (kg ha^{-1}) in rice grain	133
4.15	Effect of N, S and Zn on N uptake (kg ha^{-1}) in rice straw	135
4.16	Effect of N, S and Zn on P uptake (kg ha^{-1}) in rice grain	137
4.17	Effect of N, S and Zn on P uptake (kg ha^{-1}) in rice straw	138
4.18	Effect of N, S and Zn on K uptake (kg ha^{-1}) in rice grain	140
4.19	Effect of N, S and Zn on K uptake (kg ha^{-1}) in rice straw	141
4.20	Effect of N, S and Zn on S uptake (kg ha^{-1}) in rice grain	143
4.21	Effect of N, S and Zn on S uptake (kg ha^{-1}) in rice straw	144
4.22	Effect of N, S and Zn on Zn uptake (g ha^{-1}) in rice grain	146
4.23	Effect of N, S and Zn on Zn uptake (g ha^{-1}) in rice straw	147
4.24	Response curves of rice to applied N, S and Zn	148
4.25	Effect of N, S and Zn on crude protein content (%) in rice grain	149
4.26	Effect of N, S and Zn on crude protein content (%) in rice straw	151
4.27	Effect of N, S and Zn on crude protein production (kg ha^{-1}) by rice grain	153
4.28	Effect of N, S and Zn on crude protein production (kg ha^{-1}) by rice straw	154
4.29	Effect of N, S and Zn on amylose content (%) of rice	156
4.30	Effect of N, S and Zn on starch content (%) of rice	157



INTRODUCTION

Among cereal crops, rice is the principal staple food crop of the world. Rice is predominantly an Asian crop, 90 per cent of which is being produced and consumed in South East Asian countries. Rice is the most important and staple food crop of India. It plays a vital role in our national food security and is means of livelihood for millions of households. India has the largest area under rice (44.6 m.ha) with a production of about 90 million tonnes. It ranks second only to China (Mishra, 2005). It contributes 45 per cent of India's cereal production and thus holds the key to sustain food sufficiency in the country. To sustain share of rice in total food grain production and thereby sustaining the current level of sufficiency (2.05 tonnes/ha), the minimum production and productivity requirement of rice has been estimated to be about 140 million tonnes and 3.2 tonnes/ha, respectively by the year, 2025 (**The Hindu Survey of Indian Agriculture, 2006**).

The state of Uttar Pradesh is the largest rice growing state after West Bengal in the country. Here, rice is grown on 5.95 m.ha which produces 13.01 m. tonnes annually with an average productivity of 2.187 t/ha (Uttar Pradesh Ke Krishi Ankde, Krishi Bhawan, Lucknow, 2003-2004). Though state of Uttar Pradesh is very important state in respect of rice cultivation but its productivity is not satisfactory. In productivity Punjab is on the top while Uttar Pradesh at 7th position after Haryana, Tamil Nadu, Andhra Pradesh, Karnataka and West Bengal. Therefore, there is urgent need and scope of increasing rice productivity in Uttar Pradesh.

With the limited possibilities of area expansion, the only alternative left out is to produce more per unit area and per unit time to feed the growing population. Adoption of high yielding varieties is one of the main components to achieve this goal. High yielding varieties require more water in shape of irrigation, careful use

of biocides and overall better management in comparison to tall and indigenous varieties. With the adoption of intensive cropping system coupled with the use of high yielding varieties of crops and heavy use of high analysis NPK fertilizers, the deficiencies of certain secondary and micronutrients besides major nutrients are posing serious problems and yield of most crops suffer stagnation. This stagnation can be broken only by balanced use of primary, secondary and micronutrients.

Nitrogen is the main primary nutrient. As a constituent of protoplasm, it is associated with the activity of every living cell, young plants contain more nitrogen than those approaching maturity. However, plants continue to absorb nitrogen upto maturity. It ranks as *prima donna* in the realm of plant nutrition. In plants, it is the main constituent of protoplasm-the very basis of life and is also a constituent of enzymes and nucleo-proteins serving thereby as catalyst and director of metabolism. It is also an essential component of chlorophyll and respiration energy carrier ATP. It has been considered to be the most important nutrient for the development of plant and life could hardly be conceivable without it, because all vital processes are associated with the presence of a functionally reactive plasma in the proteins of which nitrogen is the most important constituent. It helps in building up vegetative growth and regulates the utilization of other nutrients, like phosphorus and potassium. In cereals it increases the plumpness of grains and their protein contents, while due to its deficiency the crop growth is greatly stunted on which account chlorophyll and carbohydrates assimilations are greatly diminished resulting in poor flower formation and premature fruit development, which in turn, reduce the growing period of crops. Leaves lose their green colour uniformly, assuming a pale yellow colour. On the other hand, excess of this nutrient also adversely affects the crop yield through excessive vegetative growth, and a poor, small and ineffective root system. Higher carbohydrates required for strengthening the tissues are not produced and the plants become prone to lodging.

Among primary nutrients, nitrogen is the principal element being universally deficient in Indian soils. It has been called the 'kingpin' in crop fertilization because

of its universal response under most of the geographical conditions. Rice plants require large amount of nitrogen at the early and mid-tillering stages to maximal tillering stage. It needs considerable amount of nitrogen at the panicle initiation stage. Application of nitrogen in rice results into a dark green colour to plant, a rapid vegetative growth (increases height and number of tillers, the latter being particularly important to increase grain yield), increase in size of the leaves and grains and increase in protein content of the grains. The amount of nitrogen released in soils is usually related closely to the amount of organic matter in soil. These natural sources of nitrogen are supplemented by large amounts of commercial fertilizers.

The present day investigations indicate that the Indian soils are highly deficient not only in the major nutrients but also in secondary and micronutrients. Sulphur is one of the most important secondary plant nutrients. Its essentiality was established by Hart and Peterson (1911) and Hart and Tottingham (1915). On an average, many crops absorb more S than phosphorus. Plants absorb S mostly through roots in the sulphate (SO_4^{2-}) form and to a much lesser extent from the atmosphere in gaseous (SO_2) form.

Sulphur is one of the nature's super nutrient. It is now recognized as the fourth major nutrient in addition to nitrogen (N), phosphorus (P) and potassium (K). It influences the plant growth in three ways firstly by acting as a nutrient, secondly by improving the soil pH and augmenting nutrients availability and thirdly by protecting the plant from pests and diseases. As a nutrient, sulphur is a basic requirement for protein synthesis especially S-containing amino acids i.e. methionine, cystine and cysteine. It is a constituent of several other biologically active compounds like vitamins (Thiamine and biotin), lipoic acid, acetyl co-enzyme A, ferredoxin and glutathione. It is involved in the formation of chlorophyll, activation of enzymes, in the formation of glucosinolates (mustard oils) and the disulphide-sulphydryl groups which provide pungency in crucifers, onion and garlic. It is a component of co-enzyme A which is responsible for acylation of

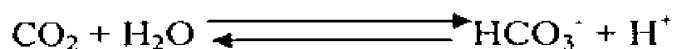
acetate and other fatty acids like thiamine-pyrophosphate (TPP). Sulphur improves root growth, crop yield, seed formation, oil percentage in oil seeds, plant proteins, cereal quality for milling and baking, nodule formation in the roots of leguminous plants and nutritional quality of crops. Methionine is the limiting essential amino acid for human beings, it is a sulphur containing amino acid and serves as methyl donor in important metabolic reactions in plants.

In the event of sulphur deficiency, protein synthesis is hampered. Thus, plants begin to show sulphur deficiency. Field scale deficiencies of sulphur in soils and plants are continuously increasing due to impoverishment of soil sulphur. Sulphur deficiencies have been reported from over seventy countries including India. Some major causes for growing incidence of sulphur deficiencies are, lack of balance use of NPK fertilizers, increasing depletion of soil S through higher removal of sulphur and under higher cropping intensity.

The Govt. of India has set a target of 235 to 240 million tonnes of food grain production along with other crops for the year 2010. At this production level an estimated 1.54 million tonnes of S will be removed which is 40 per cent higher than the 1990 figures. S application brings out significant increases in crop yields. Mean yield increases due to S application are in the range of 634 to 813 kg ha⁻¹ for cereals, 168 to 428 kg ha⁻¹ for pulses and 144 to 566 kg ha⁻¹ for oil seeds. The average yield responses to S for crops grown in S deficient soils are 17.5 per cent in rice, 25.3 per cent in wheat, 30.0 per cent in rapeseed and mustard and 37.7 per cent in groundnut (Tandon, 1991).

Besides major nutrients, deficiency of micro nutrients are also emerging. About 47 per cent of the soils in India are deficient in zinc. Zinc has generally been reported deficient in rice growing areas of India, therefore, to have a good harvest of rice, it is necessary to apply zinc in sufficient quantities as per requirement of the soil and crop.

Zinc is an indispensable micronutrient for proper plant growth and development. It can be absorbed by roots predominantly as exchangeable cation (Zn^{2+}) or through leaves when sprayed on the foliage. The essentiality of Zn for crop plants was established several decades ago and its deficiency/toxicity problem has been recognized in many parts of the world. Zinc is known to participate in plant metabolism as an activator of several enzymes. Zinc may also acts as activator for some phosphate transferring enzymes such as hexase, kinase or trios-phosphate dehydrogenase. Furthermore, the increasing Zn deficiency affects indirectly the enzymes of carbohydrate metabolism and thereby, alters the normal metabolism of plants. Carbonic anhydrase (CA) is the first discovered Zn-containing enzyme which catalyses the hydration of CO_2 .



Carbonic anhydrase has an important function of CO_2 equilibrium in green cells. A number of enzymes including enolase are activated by Zn^{2+} ion. This enzyme is shown to be localized in the chloroplasts. It is closely involved in the N-metabolism of plants. Normal metabolism of IAA (indole acetic acid), an indispensable plant hormone has been found to impair under Zn deficient condition. The characteristic morphological changes in Zn deficient plants such as stunted stem growth, little leaf and small fruit size are attributed to altered IAA metabolism (Marschner, 1991). However, the actual role of Zn in IAA metabolism is still controversial. There are two different thoughts, first, Zn deficiency decreases IAA level by enhanced oxidation and second, the reduced IAA level is the result of decreased tryptophan biosynthesis, the precursor of IAA. Moreover, the characteristic growth retardation in Zn-deficient plants was also in relation to gibberellin. A decrease in gibberellin like substances in Zn- deficient maize plants has been reported. Possible involvement of gibberellin might be due to conversion of L-tryptophan (inactive) to D-tryptopahan (active) for IAA biosynthesis. Zinc deficiency may cause toxicity to other elements like Fe due to ionic imbalances in

Zn-deficient plants. Plants subjected to Zn stress have been found to have altered metabolism of nitrogen, phosphorus and carbohydrates.

The physiological disorder widely known as '*Khaira*' disease in rice is caused by zinc deficiency as first noticed by Nene (1968) in Tarai soils. Symptoms of the disorder is characterized by discolouration of lower leaves which, in general, occurs after two weeks of transplanting. Plants get stunted and roots are scanty. Zinc deficiency has also been associated with a number of nutritional disorder observed in maize and commonly known as 'white bud'. The external signs of Zn-deficiency are stunted growth and chlorotic fading of leaves. Tsui (1948) suggested that zinc is required for the synthesis of tryptophan which is precursor of IAA. Apparently, the role of zinc in auxin formation is concerned with its functions in N-metabolism.

Keeping in view the above facts regarding vital roles of nitrogen, sulphur and zinc nutrition in rice, the present investigation entitled "**Studies on nitrogen, sulphur and zinc nutrition in rice**" was planned and undertaken with the following objectives:

1. To study the effect of N, S & Zn application on yield and yield attributing characteristics of rice,
2. To assess the effect of nitrogen, sulphur and zinc on nutrient concentration and their uptake/removal by rice,
3. To study the effect of N, S & Zn on the quality characteristics of rice, and
4. To compute the optimum requirement of N, S & Zn for maximum yield.

**REVIEW
OF
LITERATURE**

Nitrogen, sulphur and zinc, being essential plant nutrient have vital significance in crop production. The use of nitrogen, sulphur and zinc containing fertilizers is becoming a common practice throughout the world because of their widespread deficiency in soils supporting cereals, vegetables and fruit crops. In this chapter, an attempt has been made to review the nitrogen, sulphur and zinc nutrition to plant system, effect on growth and yield attributes, chemical composition and nutrient uptake, interaction effect and quality aspects in cereal crops. The relevant literatures related to present investigation have been reviewed here under the following heads:

1. Effect of nitrogen, sulphur and zinc on growth characters of rice.
2. Effect of nitrogen, sulphur and zinc on yield and yield attributes of rice.
3. Effect of nitrogen, sulphur and zinc on content and uptake of nutrients.
4. Effect of nitrogen, sulphur and zinc on quality parameters of rice.

1. EFFECT OF NITROGEN, SULPHUR AND ZINC ON GROWTH CHARACTERS OF RICE

Russel and Chapman (1988) stated that the application of 11.5 to 46.0 mg S pot^{-1} as H_2SO_4 increased shoot dry matter yield pot^{-1} by upto 85 g. Addition of HNO_3 or H_3PO_4 to pots, rice gave very low yield of 3-4 g dry matter pot^{-1} in the absence of added S but gave dry matter yield of 58-67 g/pot with K_2SO_4 . H_2SO_4 also gave higher yield and K_2SO_4 had no additional effect.

Mukhi and Shukla (1991) observed that application of 25 ppm S alone or with 5 to 10 ppm Zn increased yield of most of the plant parts of rice in submerged soil condition. The yield of all plant parts except root at earing

increased with 5 ppm Zn and all levels of S. Application of 20 ppm Zn and 75 ppm S generally decreased yield and the decrease was well marked in root and grain.

Chandra (1992) conducted an experiment on rice with three methods of stand establishment, viz., direct seeding, beasi method and transplanting and three levels of N such as 30, 60 and 90 kg N/ha. results revealed that transplanting increased the plant height, functional leaves, grains per panicle, grain yield and protein content. A dose of 30 kg N/ha had resulted in an increase in grain yield with all the three cultivation methods.

Zhang *et al.* (1992) conducted a pot experiment on rice and maize and reported that soaking of seeds in 0.1 percent ZnSO_4 and application of 10 ppm ZnSO_4 increased significantly dry matter yield. Responses of Zn application in several Kharif crops were reported by **Li *et al.* (1992)**.

Maske *et al.* (1997) conducted a field experiment in *kharif* (monsoon) 1993 at Nagpur and rice cvs. HMT- Sona, Sindewahi-75 and Sakoli-7 were grown at spacings of 20 x 15 or 15 x 10 cm and given 0, 40, 80 or 120 kg N/ha. Plant height, leaf area hill⁻¹, number of functional leaves hill⁻¹, number of shoots hill⁻¹, dry matter hill⁻¹ and grain yield increased significantly with increased N rate.

Chopra *et al.* (1998) conducted a field experiment to find out the response of direct seeded rice to different moisture regimes and sowing dates in Kashmirvalley. A uniform dose of 80 kg N, 20 kg P_2O_5 and 16 kg K_2O ha⁻¹ was applied through urea, DAP and MOP, respectively. Results showed substantial improvement in growth and yield attributes due to higher translocation of photosynthates.

Mandal and Haider (1998) conducted investigation in Bangladesh where rice cv. BR-11 was given all combinations of 0, 4, 8, 12 kg Zn and 0, 10, 20 kg S per hectare. Addition of 8 kg Zn + 20 kg S ha⁻¹ showed the best performance in growth and yield of the crop.

Patra *et al.* (1998) conducted a green house experiment to study the effect of sulphur application and water management practices on mineral nutrition, growth and yield of rice in six different S deficient wetland rice soils. Under continuously flooded condition, rice plants showed characteristics S-deficiency symptoms and produced lowest grain yield and dry matter. Application of fertilizer S during active tillering or panicle initiation stage and reflooding increased crop yield by eliminating S-deficiency.

Panda and Sahu (1999) grown rice cv. Kalinga 90 in pots at soil Zn levels of 50, 200 or 400 mg/kg and found contents of chlorophyll a and b, carotenoid, sugars, amino acids and protein and yields and biomass production increased with 50 mg Zn compared with the control, but decreased at higher concentrations.

Ram *et al.* (1999) studied the effect of two sources (pyrites and gypsum) and four levels of S application (0, 30, 60 and 90 kg/ha) on growth, yield, S-use efficiency and uptake in rice (cv. Saket-4) in a reclaimed salt affected soil in Uttar Pradesh. Application of S at 90 kg/ha gave highest yield which was on par with that obtained with 60 kg S/ha. These doses of sulphur, however produced significantly higher yield than an application of 30 kg S/ha.

Stalin *et al.* (1999) conducted field experiments with rice Cv. IR-64 to study the response of different nitrogen (N) application strategies. Basal incorporation of green manure (*Sesbania rostrata*) @ 6.25 t ha⁻¹ in combination with application of 150 kg N ha⁻¹ as urea in 5 splits resulted in the highest dry matter production, N content, N uptake and grain yield when compared with other strategies. All treatments received common doses of P (60 kg P₂O₅, as superphosphate), K (60 kg K₂O, as muriate of potash) and ZnSO₄ (25 kg) applied basally.

Kano *et al.* (2000) reported that application of 40 kg N/ha as normal fertilizer increased plant height, number of tillers and green matter and dry matter yield of leaf and stem and of whole crop.

Shanmugam and Veeraputhran (2000) studied that application of either green manure (*Sesbania aculeate*) at 6.25 t ha⁻¹ or FYM at 12.5 t ha⁻¹ combined with Azospirillum (2 kg ha⁻¹) significantly increased the growth attributes of rice. Among the levels of N (112.5, 150 and 187.5 kg ha⁻¹) with or without 25 kg ZnSO₄ ha⁻¹, combined application of 187.5 kg N ha⁻¹ + 25 kg ZnSO₄ ha⁻¹ recorded significantly higher growth attributes than 150 kg N ha⁻¹ + 25 kg ZnSO₄ ha⁻¹. Application of GM with Azospirillum recorded significantly shorter period for 50 per cent flowering, highest number of productive tillers m⁻², filled grains per panicle, panicle length and grain yield (5282 and 521 kg ha⁻¹) in both years. The highest level of N (187.5 kg ha⁻¹) with Zn application recorded significantly higher yield attributes and yield (5516 and 5376 kg ha⁻¹) than 150 kg N ha⁻¹ with Zn.

Liu *et al.* (2002) were studied crop yield and grain quality of rice cultivars Shanyou 63 and Zhendao 88 by applying N fertilizer at 300 kg/ha during different growth stages. Application of N fertilizer with the ratio of basal fertilizer; tiller fertilizer; spikelet-protecting fertilizer of 4:2:4 not only enhanced stem productivity, increased photosynthetic rate and leaf N content at heading stage, promoted dry matter production from heading to maturity and increased yield and N-utilized efficiency, but also improved rice milling quality, reduced chalky percentage and increased grain protein content.

Singh and Singh (2002) conducted a field experiment to study the effect of different nitrogen (50, 100 and 150 kg/ha) and sulphur levels (0, 20 and 40 kg/ha) on rice cultivars and significant increase in plant height, tillers m⁻¹ row length, dry matter production, panicles m⁻¹ row length, panicle length and grains panicle⁻¹ was obtained with increasing levels of nitrogen and sulphur upto 150 kg N/ha and 40 kg S/ha, respectively.

Chandel *et al.* (2003) conducted a field experiment to study the effect of sulphur nutrition on growth and sulphur content in rice and mustard grown in sequence and they recorded increasing sulphur levels in rice significantly

improved leaf area index, tiller number, dry matter production, harvest index and sulphur content in rice upto 45 kg S ha⁻¹.

Gadade *et al.* (2004) conducted a field study on response of Basmati rice genotypes to different levels of fertility under upland irrigated condition at MAU, Parbhani during 1999-2000 revealed that the growth (plant height and no. of tillers⁻²) and yield attributes (panicle length, grain weight panicle⁻¹ and test wt.) showed favourable response upto 80:50:50 kg NPK ha⁻¹ (recommended dose) respectively. Beyond this dose (80:50:50 kg NPK ha⁻¹) increase in fertilizer dose, did not improve the growth and yield attributes.

Kulandaivel *et al.* (2004) evaluated the levels and mode of application of zinc and iron on grain yields of hybrid rice and wheat crops and also the changes taking place in the micronutrient status in the soil and they found that the levels and mode of application of zinc and iron considerably increased the growth, yield attributes and yield of rice-wheat cropping system and they also reported application of 30 kg ZnSO₄ + 5 kg FeSO₄/ha through chelating with FYM was found to be the best combination for rice.

Rautaray (2004) conducted field experiments to study the tillering behaviour and yield performance of some rice varieties. A uniform fertilizers dose of 50-50-50 N-P₂O₅-K₂O kg ha⁻¹ was applied basally and another 50 kg N was top dressed in two equal splits at 25 and 55 DAT (days after transplanting) corresponding to tillering and panicle initiation/early development stages, respectively. Study on tillering behaviour revealed that significant increase in tiller number occurred at third week of transplanting and maximum varieties differed in duration, but the stage of maximum tillering was similar for them. The percentage increase in the number of early tillers was more for high tillering varieties. The increase in tiller number at late tillering stage (fifth week after transplanting to maximum tillering stage) was significant only for Vijeta (3.28%) and Mahsuri (2.36%).

Singh and Singh (2004) showed ameliorative effects of zinc application on rice in alkali soil. The increase in growth and yield attributes were dose

dependent. Soil application of 10 kg Zn/ha was adequate in partially reclaimed alkali soil with initial pH 10.3, exchangeable sodium percentage of 85 and electrical conductivity of soil solution (1:2) 2.1 dS/m. Zinc modified the elemental composition of plant tissues favourably and thereby accelerated plant growth and yield.

Sriramchandrashekharan *et al.* (2004) conducted field experiments on S- deficient clay loam soil to evaluate the effect of S (0, 20, 40 and 60 kg/ha) and organic fertilizers (*Sesbania aculeate*, at 12.5 t/ha, sulphitation pressmud at 10 t/ha, lignite flyash at 20 t/ha⁻¹ and FYM at 12.5 t/ha⁻¹), applied alone or in combination, on soil fertility and the yields of the main and succeeding rice crops (residual effect). Data were recorded for plant height, number of productive tillers per hill, leaf area index, chlorophyll content, no. of panicles/m², number of grains/panicle, thousand grain-weight, grain and straw yield. The growth and yield of rice increased with increasing level of S fertilizer upto 40 kg/ha.

Tripathi and Tripathi (2004) conducted a field experiment during the 1996 and 1997 kharif season in Kanpur, Uttar Pradesh, India, to study the zinc requirement of rice (CSR-10). The treatments compared 3 modes of zinc application in the nursery and 4 levels of ZnSO₄ (0, 15, 30 and 45 kg/ha). Application of 25 kg ZnSO₄/ha in rice nursery recorded maximum growth, yield attributes, yield and harvest index, followed by dipping of seedlings in 2% ZnSO₄ solution. Application of 30 kg ZnSO₄/ha resulted in significantly higher grain and straw yield, harvest index, seed weight per panicle and 100 seed weight.

Verma *et al.* (2004) conducted a field study in M.P., India during 1998 to investigate the effect of planting dates (20 July and 5 and 20 August) and N rates (50, 100 and 150 kg/ha) on the leaf growth, chlorophyll and N contents and grain yield by hybrid rice cv. Proagro 6201. Observations were recorded at 30, 60 and 90 days after transplanting (DAT). The leaf number upto 60 DAT, leaf area, N

content in the third leaf and chlorophyll a content increased with increasing N rate upto 150 kg N ha⁻¹.

Singh and Sharma (2005) conducted a field experiment and revealed that application of FYM @ 10 t/ha to rice increased the plant height, LAI, CGR and dry matter accumulation resulting in higher grain (43.51 q/ha) and straw yield (6.48 q/ha) of rice than control. The increasing levels of fertilizer dose significantly increased the growth characters and yield of rice upto 100, 50, 25 kg of N, P₂O₅ and K₂O ha⁻¹, respectively.

Singh *et al.* (2005) conducted pot experiment to determine the effect of N and Si applications on the growth, yield and yield components of rice cv. Swarna in Alfisols. The treatments comprised 60, 90, 120 and 150 kg N and 0, 50, 100 and 150 kg Si/ha applied before transplanting. N and Si applications had significant influence on dry matter production in all crop growth stages. N at 180 kg/ha produced the highest dry matter at physiological maturity. The number of productive tillers, grains per panicle and test weight increased markedly with increasing N levels upto 180 kg/ha. N and Si applications significantly increased all yield components except for test weight.

2. EFFECT OF NITROGEN, SULPHUR AND ZINC ON YIELD AND YIELD ATTRIBUTING CHARACTERISTICS OF RICE

A. Effect of nitrogen on yield and yield attributing characters of Rice

Singh *et al.* (1979) conducted investigation on the effect of different levels of nitrogen, phosphorus and potassium on the yield of drilled rice var. IR 8 at Varanasi during 1969 and 1970 and they recorded significant increase in nutrient composition, uptake by rice crop and in grain yield with increase in nitrogen dose from 80 to 160 kg/ha beyond which no further increase was observed from 160 to 200 kg.

Knade and Kabra (1986) obtained highest yield of rice at 150 kg N/ha. **Antil *et al.* (1989)** reported that yields increased with increasing N rates in rice.

Song (1990) reported that straw and grain yield of rice increased with the higher planting density and the higher nitrogen fertilizer level.

Amarsingham (1990) reported that fertilizer N application significantly increased the grain yields over that of the unfertilized treatment, but fertilizer nitrogen source viz., ammonium sulphate and urea, N rates and timing of application had no significant effect on grain yield.

Balasubramanian and Palaniappan (1991) found that growth and yield parameters increased with an increase in fertilizer rate upto 150 + 75 kg N + K ha⁻¹. A fertilizer dose of 150 + 75 and 100 + 50 kg N + K/ha was found optimum to increase grain yield during the *kharif* and 150 kg N+75 kg K/ha during *rabi* season increased the straw yield.

Choudhary and Bhuiyan (1991) reported that grain yield of BR 1 and BR 14 varieties of rice increased significantly upto 120 kg N ha⁻¹, but in case of BR 3, yield increase was significant upto 80 kg N/ha and for BR 802-118-3-1, N application at 120 kg/ha only significantly increased the grain yield over the control.

Balasubramanian et al. (1993) conducted trials at Coimbatore and rice with or without green manures and given 0, 100, 150 or 200 kg N/ha. In the green manure treatments, *Pongamia glabra* (*P. pinnata*) or *Crotalaria juncea* was incorporated at 12.5 t/ha a week before transplanting 25-d-old rice seedlings and they reported grain yield was increased by green manures in 2 of the 3 growing seasons and by applied N in each growing season.

Mazid (1993) reported that nitrogen and sulphur had a significant interaction effect on grain yield of rice. Maximum grain yield of rice was obtained with 145 kg N/ha. **Mishra et al. (1993)** conducted a field experiment with rice Cv. Jagannath given a combination of 0, 40, 80 or 120kg N with 0, 20, 40, or 60kg P₂O₅, and 0, 20, 40, or 60kg K₂O ha⁻¹. 25 kg ZnSO₄ ha⁻¹ was also given with 120kg N+60kg P₂O₅+40kg K₂O. The highest net return and the highest mean grain yield of 5.95 t/ha was obtained with the highest N, P and K

rates, which was slightly higher than where NPK+Zn were applied (5.90t). The control yield was 3.47 t.

Patnaik and Sathe (1993) reported that the grain yield increased with increasing N rates. Grain yield increases with S and K applications were relatively less marked than with N. The highest grain yield was obtained with the application of 150kg N+60kg K₂O+60kg S. S utilization decreased with increase in S application, increased with increasing N rate and was greater in pots supplied with K.

Singh and Om (1993) conducted a field experiment on clay loam soil at Kaul, Haryana, rice Cvs. Pusa 33, HKR 119, HKR 120 and PR 106 were given 0, 90, 120, 150 or 180 kg N/ha and they obtained in both seasons, the highest grain yields were obtained in all the cultures with 180 kg N.

Mondal *et al.* (1994) have tried integrated nutrient management on sandy clay loam soil at Kalyani, West Bengal in rice cv. MW-10. They reported highest mean yield of 3.37 t/ha with the use of 75% of recommended NPK fertilizers + 10t/ha FYM, but it was not significantly higher from applying 100% NPK through fertilizers.

Khanda and Dixit (1996) reported that the rice yield increased with increasing N rate. Combined application of zinc and nitrogen increased grain yield by 72% compared with nitrogen alone. Economic return was increased by combined N and Zn application, while among N rates the highest return per rupee invested was given by 90kg N ha⁻¹.

Medhi *et al.* (1996) reported that addition of N, regardless of sources increased grain yield of rice significantly. **Muthukrishnan *et al.* (1996)** conducted field experiments at the TamilNadu Rice Research Institute to study the reponse of 6 short duration rice varieties to 0, 40, 80, 120 and 160 kg N/ha and found that increasing levels of nitrogen upto 120 kg N/ha increased grain yields and ADT 36 produced the highest grain yield in both the years.

Tiwana and Narang (1997) reported that the grain yield of rice increased by 16.2% under chemical fertilizer series with 180-30-30 over 120-30-30 N, P_2O_5 and K_2O , kg/ha in rice-wheat sequence.

***Singh *et al.* (1998)** carried out a field experiment during wet season of 1993 and 1994 to study the response of new rice (*Oryza sativa* L.) genotypes to nitrogen levels in flash flood conditions; the results revealed that variety 'Barh Avarodhi' has the maximum grain yield (2.82 tonnes/ha) which was 11.8, 32.6 and 45.2% more than grain yield of 'NDGR 24', 'Madhukar' and 'Chakia 59', respectively and application of 90 kg N/ha gave significantly higher grain yield over 30 kg N/ha and control. However, yield differences between 60 and 90 kg N/ha was non-significant. The optimum economic dose corresponding profit were Rs 7.971; 7.076 ; 5.443 and 4.965 ha⁻¹ for 'Barh Avarodhi', 'NDGR 24', 'Madhukar' and 'Chakia 59', respectively.

Khalid and Chaudhary (1999) reported that nitrogen level N₂ i.e. 80 kg/ha⁻¹ appeared to be optimum to get higher grain yield, higher percentage of seed protein and amylose content. Application methods in general had non-significant influence on quality characteristics. **Marr *et al.* (1999)** studied the effect of nitrogen fertilizer on yield, nitrogen and mineral elements in rice; N application increased yield, grain N content and the content of some minerals. In the 1992-93 and 1993-94, 125 kg and 100 kg N ha⁻¹ increased yields by 63% and 71% (from 6.8 to 11.1 t and from 5.9 to 10.1 t ha⁻¹), respectively. **Pandey *et al.* (1999)** have studied the effect of FYM with chemical N fertilizers on grain yield of scented rice Cvs. Madhuri-II and Pusa Basmati-1 at Raipur. They observed that application of FYM @ 10t/ha, fertilizer @ 80 kg N/ha and FYM @ 5 t/ha + 40 kg N ha⁻¹ fertilizer were as effective as 120 kg N ha⁻¹ fertilizer for grain yield and N uptake.

Panda *et al.* (1999) conducted a field experiment to evaluate the effect of continuous manuring in rice-rice cropping system. Application of 120 kg N, 80 kg P_2O_5 and 40 kg K_2O ha⁻¹ in each season was found beneficial for rice-rice cropping system and application of 120 kg N ha⁻¹ gave significantly higher grain

yield over 40 and 80 kg N ha⁻¹. In pooled data, the application of 120 kg N ha⁻¹ increased the grain yield to the tune of 31.35% and 9.71% during kharif and 36.61% and 10.35% during rabi compared with N₄₀ and N₈₀, respectively. Significant response of rice cultivars to higher levels of N and /or NPK fertilizers from 90 to 120 kg N/ha with and without recommended doses of P and K has been reported by Raju *et al.* (1990), Singh and Shree Devi (1997), Singh *et al.* (1997), Thakur *et al.* (1997), Behera (1998), Gangaiah and Prasad (1999) and Mohammad *et al.* (2001).

Tripathi *et al.* (1999) recorded highest grain and straw yield of rice with 150,26,31 and 2kg ha⁻¹ N,P₂O₅,K₂O and Zn respectively applied through gypsum urea II, SSP,MOP and ZnSO₄, respectively. These rates of N, P, K and Zn applied combinedly

Awan *et al.* (2000) studied the effect of N on the yield of rice and were applied six different doses of nitrogen to both the green manured and ungreen manured plots and found that application of N fertilizer alongwith organic matter significantly increased the plant height at maturity, number of tillers per plant, number of spikelets per panicle, 1000-grain weight, paddy yield and harvest index than control. The maximum paddy yield of 7.15 t/ha was produced by plot where 150 kg N/ha was applied and the control plot produced minimum yield of 4.63 t/ha.

*Bhowmick and Nayak (2000) conducted a field experiment in dry (boro) season of 1996-97 and 1997-98 on a low land alluvial soil (Entisol) to study the performance of hybrids (CNHR 2 and CNHR 3) and high-yielding varieties (IR 36 and IR 64) of rice (*Oryza sativa* L.) at 5 levels of fertilizer nutrition and reported 'CNHR2' got the maximum panicles (413.4/m²), higher number of filled grains/panicle (111.0), moderate test weight (21.0 g) and gave the highest grain (7.1 tonnes/ha) and straw (6.95 tonnes/ha) yields. Grain and straw yields increased by increasing level of nutrition for hybrids upto N₁₈₀P₉₀K₉₀ + 30 ZnSO₄ kg/ha and for high yielding varieties upto N₁₂₀P₆₀K₆₀. Higher benefit : cost ratio (BCR) was obtained at N₁₅₀P₇₅K₇₅ and hybrid 'CNIIR 2' gave the highest BCR.

Chopra and Chopra (2000) conducted a field experiment to study the effect of row spacing and nitrogen levels on growth, seed yield and seed quality of scented rice (*Oryza sativa*) Cv. Pusa Basmati. Row spacing did not influence yield attributes, and seed and straw yields. Significant linear increase in seed yield was recorded upto 80 kg N/ha and thereafter a marginal reduction in seed yield was observed at 120 kg N/ha. However, straw yield increased upto the highest rate of N. The response of seed yield to N levels was quadratic. The highest response was observed at 40 kg N/ha and thereafter it decreased with the increase in N level. The optimum economic rate of N was 98.5 kg/ha with an additional profit of Rs 8075/ha.

Hemalatha *et al.* (2000) reported that all the organic nitrogen sources improved the rice yield, quality and soil fertility. Among the various organic sources, in situ incorporation of dhaincha at 12 t/ha remarkably increased the grain (18%) and straw (16%) yields of rice over no organic manure, owing to increase in growth and yield attributing characters of rice.

Subbiah and Kumaraswamy (2000) reported that rice yield increased by increasing nitrogen levels. Results showed that the rice yields recorded in treatments with any one of the organic manures plus recommended levels of N, P_2O_5 and K_2O and gypsum at 500 kg ha⁻¹ was significantly higher than the rice yield in the treatment that received N, P_2O_5 and K_2O alone.

***Duraismi *et al.* (2001)** were conducted field experiments to study the effect of time of N application, on yield and economics of irrigated rice and they observed that application of 150 kg inorganic N in five splits with 6.25 t ha⁻¹ green leaf manure significantly improved the yield components, yield of grain and straw and N use efficiency and recovery, with high net returns and benefit:cost ratio. Skipping of N application at active tillering and panicle initiation stages caused significant yield reductions; in addition to nitrogen they also applied a uniform dose of 60 kg P_2O_5 in the form of superphosphate, 30 kg K_2O in the form of MOP and 25 kg $ZnSO_4$ ha⁻¹ basally at the time of transplanting, another 30 kg K_2O ha⁻¹ applied at panicle initiation to all the plots.

Ikramullah and Kumar (2001) reported that yield of rice was increased upto 100 kg N/ha; grain yield increased by 22, 49 and 46% with 50, 100 and 150 kg N/ha, respectively, over the control treatment. Grain yield increased significantly upto 100 kg N ha⁻¹.

Subbiah *et al.* (2001a) conducted a field experiment to study the response of three recently released rice hybrids to 5 graded levels of nitrogen. The varieties DRRH1, APCR2 and PROAGRO 6201 were tested under 0, 50, 100, 150 and 200 kg ha⁻¹ N and the influence of incremental fertilizer doses was significant upto 200 kg N ha⁻¹ in 1995 and 150 kg N ha⁻¹ in 1996, accounting for 7.7 and 30.8 per cent increase in yield over 150 and 100 kg N ha⁻¹, respectively. The highest mean yield of 7.28 t ha⁻¹ with economic returns was obtained in PROAGRO 6201. Economic N optimum and maximum were worked out for the hybrids as 200 and 253 in 1995 and 213 and 269 kg ha⁻¹ in 1996, respectively.

Mendhe *et al.* (2002) reported that Nitrogen @ 125 kg ha⁻¹ significantly increased plant height (130.09 cm), number of effective tillers hill⁻¹ (9.29), number of grains panicle⁻¹ (130.09), grain (30.74 q) and straw (45.1 q) yield over 75 and 100 kg N ha⁻¹. Further increase upto 150 kg N ha⁻¹ significantly increased the yield but the magnitude of response was very low and in most of the characters, it was at par with 125 kg N.

Sitaramayya *et al.* (2002) conducted a long term experiment to evaluate yield stability and soil fertility changes on continuous cropping and manuring over years in an inceptisol; the results indicated that the magnitude of mean response at N₁₂₀ was 746 kg ha⁻¹ in kharif and 712 kg ha⁻¹ in rabi season. Stability analysis of mean yield of rice revealed that stable yield is possible to realize under 80:40:40 kg NPK ha⁻¹ fertilizer dose.

Sudha and Chandini (2002) reported that the highest NPK rate was superior in increasing N, P and K uptake, and grain and straw yields. The results suggests that NPK upto 105:52.5:52.5 kg/ha and S upto 25 kg/ha, alongwith organic manures either as 10 t FYM or 5 t vermicompost per ha, were effective in the improvement of the grain yield of rice.

Dongarwar *et al.* (2003) conducted a field experiment to test the response of hybrid rice KJTRH-1 in comparison with two conventional varieties Jaya and Swarna to different fertilizer doses. There was significant increase in grain yield with successive increase in fertilizer dose. The highest grain yield was obtained with 150:75:75 kg NPK ha⁻¹. Hybrid KJTRH-1 was significantly superior over conventional varieties. Interaction effect was at par with 150:75:75 kg NPK ha⁻¹ and 125:62.5:62.5 kg NPK ha⁻¹.

Maiti *et al.* (2003) studied the effects of nitrogen fertilizer rate (0, 120 and 140 kg/ha) on the performance of 1 cultivar (IET - 4786) and 4 hybrid varieties (ProAgro 6Y213, ProAgro 6Y3024, ProAgro 6111N and ProAgro 6201) of rice at Mohanpur, West Bengal and reported that the hybrid varieties had 10.4, 38.9, 9.30 and 32.5% higher number of panicles, number of filled grains per panicle, 1000-grain weight and grain yield, respectively, than the high yielding cultivar IET-4786 and also found that the application of 140 kg N/ha resulted in the highest increase in grain yield (by 76.2%), number of panicles (by 109.00%), number of filled grains per panicle (by 26.2%), and 1000-grain weight (5.08%) respectively, over the control.

*Parwar *et al.* (2003) found that the fertilizer dose of 150:75:75 kg NPK ha⁻¹ (150% RDF) gave significantly higher grain yield of paddy (41.80 q ha⁻¹) than 125% RDF, 100% RDF (100:50:50 NPK kg/ha) and 75% RDF. The increase in grain yield due to 150% RDF and 125% RDF was 22.65% and 11.67%, respectively over 100% RDF. On the basis of net incremental cost/benefit ratio, the fertilizer dose of 125% RDF (125:62.5:62.5 kg NPK ha⁻¹) was found to be more economical since it recorded the highest (2.57) net ICBR.

Raghuwanshi *et al.* (2003) conducted a field experiment to study the effect of different N levels (0, 40, 60, 80 and 100 kg/ha) on grain yield and yield attributes of scented rice (cv. JR 503-7). The seedlings supplied with 80 kg N/ha recorded the maximum values for all the yield attributes (number of effective tillers per hill, panicle length, panicle wt. and number of fertile grains per panicle), which resulted the highest grain yield during both years (60.16 and

63.45 q/ha in 2001 and 2002, respectively). The highest gross monetary return, net monetary return and benefit:cost ratio was achieved with 80 kg N/ha.

Gunri *et al.* (2004) reported that the each unit increase in N level led to significant increase in yield attributing characters and yield of rice; the highest grain yield was recorded with the highest level of N (140 kg/ha).

***Ram *et al.* (2004)** reported that the yield and related characters increased with increasing fertilizer levels upto 150 kg N/ha and 80 kg K/ha. Maximum benefit : cost ratio was obtained with 120 kg N/ha ad 40 kg K/ha.

Singh *et al.* (2004) found that N levels had a significant effect on yield attributes (except 1000-grain weight), yields and nutrient accumulation upto 120 kg N ha⁻¹. The maximum grain yield (5.87 t ha⁻¹) was recorded at the highest level of N nutrient (180 kg N ha⁻¹) and was 4.2, 15.5 and 39.3% higher than in the 120, 60 and 0 kg N ha⁻¹ treatments, respectively.

Arivazhagan and Ravichandran (2005) reported that application of 150:50:75 kg NPK/ha resulted in the highest number of panicles hill⁻¹ (9.06), panicle length (19.6 cm), 1000-grain weight (20.05 gm), grain yield (5.06 t/ha) and straw yield (6.10 t/ha). Basal skipping of K₂O resulted in the highest grain and straw yields (5.35 and 6.74 t/ha). A similar trend was observed in yield attributes with respect to time of application of K to N, conjoint application of N and K.

Naik and Paryani (2005) found that nitrogen application significantly increased plant height and grain yield upto the level of 150 kg ha⁻¹. Varying the number of seedlings hill⁻¹ had no marked effect on yield attributes, yields and harvest index. Amongst the rice hybrids, PBH-71 produced significantly highest number of grain panicle⁻¹ (157.9), grain (64.4q/ha⁻¹) and straw (94.4 q ha⁻¹) yield.

B. Effect of S on yield and yield attributes of rice

Acharya (1973) reported that the yield of seedlings of cv. Ptb – 10 grown in pots, increased significantly with increasing rate of application of sulphur but at the rate of 90 ppm, the yield decreased. Das and Dutta (1973) noted that the sulphur application in paddy wheat rotation increased the grain yield of both the crops upto fifth crop. The sixth crop of wheat did not show response of sulphur application. Randhawa (1973) observed the application of N, P_2O_5 and K_2O @ 95, 80 and 60 kg ha⁻¹ and sulphur @ 0, 25 and 50 kg ha⁻¹ in different varieties of wheat showed response to sulphur application. It was noted that N, P and K application failed to give any response unless 150 kg gypsum was added in that soil.

Dargan *et al.* (1976) conducted a field trial on berseem, rice and maize and reported that application of S as gypsum increased grain yield of rice. Tiwari *et al.* (1983 b) conducted a green house experiment to study the effect of sulphur fertilization on rice in soils of district Kanpur (U.P.) and recorded an increase in yield of rice by sulphur application by more than 10 per cent, highest being at 30 per cent.

Alam *et al.* (1985) recorded significant improvement in yield of rice plants under submerged condition with S application. Ammonium sulphate was found to be a superior source of S as compared to all other sources (gypsum, elemental S and sulphur coated urea).

Islam *et al.* (1987) reported that paddy yield increased about 8 per cent with 30 kg S ha⁻¹ as gypsum. Ahmed *et al.* (1988) found that the treatment with N @ 120 ppm and S @ 30 ppm ($N_{120}S_{30}$) was found to be the best one with respect to yield and N – S composition of rice followed by $N_{120}S_{60}$ treatment.

In a symposium [Symposium on Sulphur in balanced fertilization] Tiwari (1989) reviewed the research work done on “Sulphur in balanced fertilization in northern India”. He advocated that in Uttar Pradesh, the yield

increase due to S varied from 207 to 838 kg ha⁻¹ with corresponding response ratio of 10.4 to 41.9 in rice, 117 to 324 kg ha⁻¹ with response ratio of 5.9 to 16.2 in mustard, 559 kg ha⁻¹ with response ratio of 28 in groundnut and 186 kg ha⁻¹ with response ratio of 9.3 in sunflower.

Akhtar *et al.* (1994) conducted a field trial in Bangladesh where rice was given 0, 25 or 50 kg S and 0, 5, 10 or 20 kg Zn ha⁻¹ and observed that at one site 50 kg S + 25 kg Zn ha⁻¹ gave the highest grain yield (5.9 t/ha compared with the control yield of 4.61 t) while at another site 25 kg S + 10 or 20 kg Zn per hectare decreased grain yield. Raju *et al.* (1994) observed in their investigations at Maruteru, Andhra Pradesh that the application of 25 kg or 50 kg S ha⁻¹ increased significantly rice yield with 5 kg of Zn ha⁻¹. Panicle production was also higher. Similar observations have also been reported in rice cropping pattern by Hoque and Jahirruddin (1994).

Tripathi and Sharma (1994) found that S application @ 40 kg ha⁻¹ gave significantly higher seed yield (2.10 t ha⁻¹) of Indian mustard. The residual effect of S @ 80 kg ha⁻¹ to Indian mustard reflected in maximum grain yield (3.22 tonnes ha⁻¹) of succeeding rice crop in mustard-rice cropping sequence. Hoque and Jahirruddin (1994) conducted a field experiment at Mymensingh (Bangladesh) with 20 kg S ha⁻¹ and recorded increase in the yield of rice.

Ganeshmurthy *et al.* (1995) conducted a pot experiment in 20 soils of Port Blair (Andaman and Nicobar Islands) with rice (IR-20). The soils were mixed with a basal dressing of N, P and K @ 120:60:60 N, P₂O₅ and K₂O ha⁻¹, respectively and S was applied at the rate of 60 kg ha⁻¹, 15 soils out of 20 responded significantly with the application of S. Thakur *et al.* (1996) conducted a field experiment during the rainy season of 1993 on silty clay soil at Pusa to determine the effects of different sources of sulphur (20 kg S/ha) on lowland rice. Marginal improvements in grain yields were observed under different S treatments, but the effects were not significant. Sahu and Nanda (1997) conducted two field experiments one in black soil (BS) and another in laterite soil (LS) to determine the response of rice cvs. Jajati (on BS) and Lalat

(LS) to sulphur (0-60 kg/ha) in Orissa. Mean grain yield increased with upto 40 kg S ha⁻¹ (5.06 t/ha) on black soil and was highest with 60 kg S ha⁻¹ (4.26 t) on the laterite soil.

Gupta *et al.* (1998) conducted a field experiment in Kharif seasons of 1996 and 1997 at the Regional Agricultural Research Station, R.S. Pura, Jammu, India to study the effects of sulphur sources (Sulphur powder, gypsum, iron pyrites) and sulphur dose (0, 10, 20, 30 or 40 kg S/ha) on rice cv. PC-19 yield and sulphur uptakes and reported that rice grain yield was increased by 14.2, 24.2, 25.6 and 20.1% with the four rates of sulphur, respectively over control. The optimum dose was 20 kg S/ha.

Hasan (1998) applied NPK @ 80-60-40 kg ha⁻¹ with two levels of S (10 and 20 kg ha⁻¹) as CaSO₄. 2H₂O and three levels of zinc (3, 6 and 9 kg ha⁻¹) as ZnO. Application of S or Zn resulted in significant increase in yield of both the crops. Rice significantly responded to S application producing 1.22 t ha⁻¹ over control by applying 10kg S ha⁻¹. In the same year rice yield increased significantly by application of 6kg Zn ha⁻¹ which might go to better utilization of N and P for grain production through greater metabolic activities. Rice responded by giving 102 and 130kg additional rough rice per kg S and per kg Zn applied at 10kg S and 3kg Zn ha⁻¹, respectively. He found maximum yield of 5083 kg ha⁻¹ with NPK + Zn at 9 kg ha⁻¹ and with sulphur NPK+10kgS, NPK+20kg S were 6.12 and 5.64 t ha⁻¹ respectively in 1993.

Patra *et al.* (1998) conducted a green house experiment to study the effect of sulphur application and five water management practices on mineral nutrition, growth and yield of rice in six different S deficient wet land rice soils. Under continuously flooded condition, rice plants showed characteristics S deficiency symptoms and produced lowest grain yield and dry matter. Application of fertilizer S during tillering or panicle initiation stage increased crop yield by eliminating S-deficiency.

Sarkunan *et al.* (1998) conducted a pot experiment under flooded condition on P and S deficient sandy loam soil. Treatments consisting of the

combination of 4 levels of P (0, 25, 50 and 100 mg kg⁻¹ soil) as ammonium phosphate and four levels of S (0, 10, 25 and 50 mg kg⁻¹ soil) as ammonium sulphate were applied. Increasing levels of P from 0 to 100 mg kg⁻¹ increased progressively the grain yield from 16.9 to 42.5 g pot⁻¹. S addition of 25 mg kg⁻¹ soil resulted in 9 per cent increase in grain yield.

Gautam Kumar (1999) observed that 50 kg sulphur ha⁻¹ as gypsum and 10 kg Zn ha⁻¹ as ZnSO₄ significantly increased the yield attributes i.e. panicle plant⁻¹, number of grains per panicle, grains weight panicle⁻¹ etc. in rice and wheat crops under rice-wheat cropping sequence.

Ram *et al.* (1999) observed the effect of two sources (pyrites and gypsum) and four levels of S (0, 30, 60 and 90 kg/ha) on growth, yield, S-use efficiency and uptake in rice (cv. Saket-4) in a reclaimed salt affected soil in Uttar Pradesh, India. Application of S at 90 kg/ha gave highest yield which was on par that obtained with 60 kg S/ha. These doses of sulphur, however, produced significantly higher yield than application of 30 kg S/ha.

Sakal *et al.* (1999) evaluated effect of sulphur on yield, N, P, K and S nutrition of crops in a field experiment under a rice-wheat system in a highly calcareous soil at R.A.U., Pusa Farm, Bihar. The optimum level of S for rice and wheat appeared to 40 and 60 kg Sha⁻¹, respectively. The grain yield response at optimum S level in rice was 871 kg ha⁻¹ and in wheat it was 659 kg ha⁻¹. Sulphur application showed a synergistic effect on N and an antagonistic effect on P and K content in rice and a synergistic effect in N, P and K content in wheat.

Subbiah and Kumaraswamy (2000) observed the results of four field experiments conducted on a sandy clay loam soil in Tamil Nadu, showed that the rice yields recorded in treatments with any one of the organic manures plus recommended levels of N, P₂O₅ and K₂O and gypsum at 500 kg ha⁻¹ were significantly higher than received N, P₂O₅ and K₂O alone. **Subbaiah *et al.* (2001b)** conducted multi-locational trials on rice during 1993 to 1995 to sulphur nutrition clearly indicated that continuous application of diammonium phosphate

in conjunction with sulphur containing fertilizer improved the grain yield in lowland ecosystem.

Sarfraz *et al.* (2002) conducted a field experiment to study the effect of sulphur on yield and chemical composition of rice. Sulphur is applied at the rate of 20 kg ha⁻¹ from two sources i.e. Ammonium Sulphate and Potassium Sulphate with fertilizers. NPK were applied at the rate of 110-90-70 kg ha⁻¹. The results showed that number of tillers m⁻², 1000-grain weight; paddy and straw yields significantly increased by applying NPK + sulphur over control but NPK without sulphur produced non-significant results.

Mythili *et al.* (2003) found that NPK (100:50:50, N: P₂O₅:K₂O kg ha⁻¹) Zn as ZnSO₄ (5 kg Zn ha⁻¹) and S as gypsum (50 kg S ha⁻¹) coupled with green manure (*Sesbania aculeata* at 10 t ha⁻¹) produced the highest grain (5627 kg ha⁻¹) and straw (5723 kg ha⁻¹) yields.

Tiwari *et al.* (2003) observed S deficiency in sugarcane, rice, wheat and potato as 50.4, 54.0, 50.4 and 52.0%, respectively, considering 0.15% as the critical limit in plants. The significant response of crops to different rates and sources of S in farmer fields of the Varanasi region as well as at research stations was observed. The application of 40 kg S/ha as S-95 gave significantly higher yields of rice, wheat, mustard and chickpea over no S application treatment followed by same level of gypsum in farmers fields.

Hedge and Sudhakarbabu (2004) reported that the rice yield increased by 27% over control with the use of recommended NPK+S @ 45kg ha⁻¹. Yield of rice increased from 6699kg (NPK alone) to 8123kg by NPK+S 45 (S @ 45kg ha⁻¹) ha⁻¹. Rice yield also increased by the use of Zn with the N, P, K fertilizer @ 180:90:90 kg ha⁻¹. Yield obtained without zinc was (NPK only) 5.9 t ha⁻¹ and with Zn (NPK- 180:90:90;) was 7.4 t ha⁻¹

C. Effect of Zn on Yield and Yield Attributing Characteristics of Rice

Panda and Nayak (1974) reported that application of zinc increased significantly the number of effective tillers per m², plant height, number of

grains panicle⁻¹ and 1000-grain weight on both 'Jaya' and 'Ratna' varieties of rice of different locations.

Dargan *et al.* (1976) conducted field trials on maize, berseem and rice grown on highly sodic soil and reported that application of sulphur as gypsum with zinc as zinc sulphate (45 kg/ha) increased the yield of crops. **Gill and Singh (1978)** stated that the application of ZnSO₄ @ 20 kg ha⁻¹ increased significantly the productive tillers, panicle length, number of grains panicle⁻¹ and grain yield in rice. **Agarwala *et al.* (1980)** conducted 18 field trials at 15 locations in U.P. on wheat, rice and maize grown having less than 0.39 ppm Zn in non-calcareous soils and less than 0.74 ppm in alkaline soils. Zinc application increased significantly the grain yield of rice, wheat and maize. **Nagarajan and Manickam (1986)** observed that the optimum rate of Zn varied from 28.5 to 45.4 kg ZnSO₄ ha⁻¹ depending on soil type.

Balakrishnan and Natarajaratnam (1986) stated that NPK and Zn gave the highest paddy yield with 25 kg ZnSO₄ ha⁻¹. Applied Zn increased the number of tillers plant⁻¹, panicle length, number of total grains and filled grains panicle⁻¹ and test weight. **Babiker (1986)** reported that zinc sulphate fertilizer application @ 0, 25, 50 and 75 kg ha⁻¹ in nursery and field experiments on rice increased leaf area index, plant height, productive tillers, panicle length, number of filled and unfilled grains per panicle, 1000-grain weight (test weight) and yield.

Vyas *et al.* (1990) conducted a field trial in the Kharif (Monsoon) season of 1985 on a clay soil at Raipur, Madhya Pradesh, rice cv. Samradhi was given 0-20 kg Zn ha⁻¹. Grain yield and total N uptake were highest with 5 kg Zn/ha (3.75 t/ha and 74.64 kg/ha, respectively). **Anandswaroop (1991)** reported significant positive response of rice crop to the application of Zn in sodic soils. Sodic soils were found to be deficient in Zn. **Indulkar and Malewar (1991)** reported that irrespective of sources, 4 kg Zn ha⁻¹ application to rice improved significantly the grain and straw yields of crop.

Rashid and Fox (1992) were estimated zinc requirements of leaves and seeds using two Zn-deficient sub-soils. These were fertilized with 0, 1, 3, 9 or 27

mg Zn kg⁻¹ of soil. The order of grain yield response to Zn fertilization was: wheat < sorghum < rice < millet < soybean < cowpea < corn. Fertilizer Zn requirements for near-maximum grain yield was highest for cowpea (7.5 mg kg⁻¹ soil) and lowest for wheat (0.5 mg kg⁻¹ soil). Zinc concentrations (mg kg⁻¹) in recently matured leaves associated with 95% maximum yields were similar for seven species: corn and millet, 24; soybean, 22; cowpea, 21; sorghum, 20; rice, 19; and wheat, 17.

Sahay *et al.* (1992) assessed the response to Zn and B in paddy and wheat under different soil agro-climatic conditions of Bihar during 1987-90, 30 field trials on paddy and 26 on wheat with 4 levels of zinc sulphate were conducted in districts of Madhubani, Munger, Saran, and Siwan with the recommended rate of NPK. The range of yield response to 25 kg/ha zinc sulphate in paddy was from 1.093 to 1.111 t/ha and in wheat from 0.585 to 0.835 t/ha.

Das *et al.* (1994) reported that maize grains yield increased with increasing levels of Zn from 0 to 10 kg Zn ha⁻¹ in sandy loam calcareous soil of Pusa. **Tomar *et al.* (1994)** conducted a field experiment to study the response of high yielding rice cv. IR-28 and Kiran to 0-100 kg ZnSO₄ ha⁻¹. Application of 50 and 75 kg ZnSO₄/ha increased grain yield significantly, the yield response was greater in Kiran. Additional yield of 1.10 t/ha was obtained with 75 kg ZnSO₄/ha over no Zn. Nutritional quality of the grain was not affected significantly but increase in P and Zn and decrease in Ca content was observed. In rice straw, P and Zn levels decreased, and Ca and Mg levels increased as compared with rice grain.

Nandram (1996) reported that the addition of Zn and FYM along with 100% NPK enhanced the mean grain yield of rice by 12% and 14%, respectively, compared with 100% NPK alone. A Zn deficiency disease in rice known as khaira, was prevalent in the control and 100% NPK treatment, but disappeared after the addition of either Zn or FYM.

Shi *et al.* (1996) conducted a field experiment on neutral purple soil (Entisol) representative of the Sichuan Basin, China, where N (150 Kg/ha), P (75

Kg/ha), K (75 Kg/ha), Si (75 Kg/ha), Zn (22.5 Kg/ha) and Mg (22.5 Kg/ha) were applied singly or in combination to rice as basal fertilizer. In all treatments involving Si fertilization, over 9000 Kg of grain were harvested from each hectare, with a 8-13% increase over the treatment with NPK. This fertilization increased productive tillers, grain number per spike, and 1000-seed weight, resulting in yield increase. Combined application of Si, Zn and Mg facilitated the uptake of N, K, Zn and Mg by the plants.

Channal and Kandaswamy (1997) reported that the application of 37.5 kg ZnSO₄ and gypsum + dhaincha produced the highest rice yield of 5.63 tha⁻¹.

Chen and Fan (1997) conducted a field experiment at the Rice Research Institute of Yunnan Agricultural University, Kunming, on soils low in P and Zn, rice cultivars Xunza 29, Hexi 35 and Yungeng 34 were given 0 or 5 Kg Zn/ha and 60, 150 or 200 Kg P/ha. Application of Zn and P significantly increased yield, especially in Hexi 35 and Yungeng 34. Grain protein contents were increased by P application and amylose contents of milled rice were increased by Zn application.

Alam *et al.* (1998) studied the effect of zinc application with or without copper on yield and composition of rice genotype Basmati-385 and a mutant DM-25 in a pot culture experiment. Rice genotypes responded to Zn application much more in presence of Cu than its application alone. The Zn X Cu interaction significantly increased grain and straw yield and total Zn uptake by both rice genotypes. However, Basmati-385 compared to the mutant DM-25 gave higher response to Zn in the presence of Cu. Higher Zn and Cu uptake by Basmati-385 was attributed to its higher straw yield rather than its differential concentration in grain and straw.

Channabasavanna and Biradar (2001) reported that the application of poultry manure with 25 kg ZnSO₄/ha recorded significantly higher yields over the rest of the treatments. The increase in yield was attributed to panicles per hill and seeds per panicle. The residual effect was attributed to panicle per hill and seeds per panicle. The residual effect was more prominent when rice husk was

applied. Pressmud did not respond to applied ZnSO_4 while crop responded to zinc upto 50 kg ha^{-1} when no organic manure was applied.

Mian *et al.* (2001) reported that deficiencies in soil zinc (Zn) may limit yield of rice and wheat in rice tract of the Punjab (Gujranwala and Lahore Divisions). The build up of phosphorus (P) due to its continuous application could also reduce the plant Zn concentrations. There were two levels of P (100 and $200 \text{ Kg P}_2\text{O}_5 \text{ ha}^{-1}$) and three levels of Zn i.e. 0 , 3.5 and 7 for wheat and 0 , 5 and 10 Kg ha^{-1} for rice. Wheat yield data revealed that Zn addition at the rate of 3.5 Kg ha^{-1} improved the grain yield significantly while there was no difference in the yield in treatments, receiving 100 and $200 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$. A reverse situation was attained in rice where high P ($200 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) did increase the paddy yield significantly while Zn at the rate of 5 - 10 kg ha^{-1} was not successful to enhance the yield. The reason was satisfactory levels of soil Zn built up to 1.6 - 2.8 mg/kg soil due to residual effect of Zn applied to previous crop i.e. wheat.

Kumar *et al.* (2002) reported that among the various sources of zinc, chelated zinc resulted in the highest grain (2.923 t/ha) and straw (4.861 t/ha) yield; nitrogen (1.16%), phosphorus (0.28%), potassium (0.47%) and zinc (2.201%) contents of grain; and nitrogen (0.52%), phosphorus (0.096%), potassium (0.54%) and zinc (5.188%) contents of straw. The application of zinc and phosphorus significantly increased yield and nutrient uptake. Among the zinc rates, 10 ppm gave the highest grain (3.000 t/ha) and straw (4.825 t/ha) yields.

Muhammad *et al.* (2002) reported that the number of tillers/pot, number of grains/panicle, 1000 -grain weight and grain yield increased significantly with the application of Zn. Fe and Mn alone or in various combinations. However, additional increase in rice yield and yield contributing growth parameters was noted in treatment comprising 10 mg Zn/kg along with 5 mg Mn/kg and a basal dose of N, P and K fertilizers.

Jadhav *et al.* (2003b) studied the effects of Zn fertilizer with or without FYM on the performance of rice cv. Ratnagiri in Konkan, Maharashtra. The treatments consisted of NPK (recommended rate of 100:50:50 kg/ha), NPK + Zn at 15, 30 or 45 kg/ha, NPK + FYM (10 t/ha), and NPK + FYM + Zn at 15, 30 or 45 kg/ha. N was applied at transplanting (50 kg/ha), tillering (25 kg/ha) and panicle initiation stages (25 kg/ha). P, K and Zn fertilizers were applied during transplanting. The highest grain yield (57.7 q/ha), straw (53.8 mg/kg and grain 44.5 mg/kg) Zn contents and total Zn uptake (575.7 g/ha) were obtained with NPK + FYM + Zn at 45 kg/ha. Straw yield was generally higher with the combination of Zn, FYM and NPK compared to NPK only.

3. EFFECT OF N, S & Zn ON CONTENT AND UPTAKE OF NUTRIENTS

A. Effect of N on content and uptake of nutrients

Singh *et al.* (1979) obtained the significant increase in nutrients composition, uptake by rice crop and in grain yield were obtained with increase in nitrogen dose from 80 to 160 kg/ha, beyond which no further increase was observed from 160 to 200 kg.

Increasing N rates increased total nitrogen uptake in grain and straw of rice was observed by **Sudhakar *et al.* (1986)** and **Singh *et al.* (2004)**.

Shukla and Sharma (1986) reported an increase in N, P, K, Ca and Fe contents at tillering and grains at harvest due to increasing NPK rates with or without pyrite application.

Application of N and P increased the N, P and K uptake by rice (**Baijhitov and Moiseeva, 1987**). Optimum application of N increased potassium uptake by 57% over control plots and N and P application increased K uptake 145% (**Tandon and Sekhon, 1988**). **Tripathi and Upadhyay (1988)** also reported the increased N, P and K uptake by application of fertilizers.

Concentration of N, P, K, Fe, Cu and Mn increased significantly due to graded application of phosphorus. All the P levels depressed Zn uptake (Alam & Azmi, 1989). Nutrient uptake increased significantly with increasing NPK level upto 100% recommended doses through fertilizers (Bhandari *et al.*, 1996).

Amarsingham (1990) reported that fertilizer N and native soil N were major sources for early growth and reproductive stages, respectively of the rice crop. Plant uptake was highest at panicle/flowering stages and top dressing 7 days before panicle initiation increased plant N uptake.

Narang *et al.* (1990) reported that the application of 120-13-25 kg (N-P-K) ha⁻¹ with green manuring or application of 180-13-25 kg (N-P-K) ha⁻¹ without green manuring to rice increased the N, P and K uptake. At these level of fertilizer application rice removed 198, 31 and 230 kg N, P and K ha⁻¹ annum⁻¹. Enhanced rate of micronutrients (Zn, Fe and Mn) removal in rice was also noticed.

Balasubramaniyan *et al.* (1991) reported that incorporation of green manure at 12.5 t/ha and fertilizer combinations (N + K₂O Kg/ha) 0, 100 + 50, 150 + 75, 200 + 100 and 250 + 125 significantly increased the N, P and K uptake possibly due to the enhanced availability of these nutrients due to green manure effect. Uptake was higher with high dose of inorganic fertilization.

Balasubramanian *et al.* (1993) conducted trials at Coimbatore, Tamil Nadu and rice cv. IR 62 was grown in rabi (winter) 1986, cv. IR 50 in Kharif (monsoon) 1987 and cv. IR 60 in rabi 1987, with or without green manures and given 0, 100, 150 or 200 kg N/ha and found that plant uptake of N, P and K was generally increased by green manures and N fertilizer application.

Mazid (1993) reported that the lowest S level (0.6 mg/l) and application of high N (180 mg/l) increased the total N concentration in the straw of rice but not in the grains. Increasing S from 0.6 to 5 mg/l decreased straw N concentration, but further increase in S concentration had no further effect on straw N. At 0.6 mg S/l adding high N (120 or 180 mg/l) did not increase N

uptake or had no adverse effect. Sulphur at 5 mg/l significantly increased total N uptake and leaf CO₂ assimilation when 60 or 120 mg N/l was applied. A high N rate (180 mg/l) increased N uptake when S supply was increased to 10 mg/l. The critical level of S was 5mg/l at 60 and 120 mg N/l and 10 mg/l at 180 mg N/l.

Monapara *et al.* (1993) applied 0, 40, 80 or 120 kg N/ha and found that grain yield and uptake of N, P and K by grain increased with increasing rate of N application. **Chakraborty and Mandal (1993)** conducted a field experiment on rice (cv. Ratna) with N, P, K-fertilization and indicated that the application of fertilizer depressed the availability of Fe, Mn, Cu and Zn during the later part of the submergence with the initial increase in Fe and Mn. Nitrogen depressed the availability of micro nutrients and the depression was more when P and K were combined with it. The uptake of all the micronutrients and N, P and K by rice shoot as well grain and straw increased because of increased dry matter production.

Bhardwaj and Omanwar (1994) have observed improvement in available N, P and organic carbon under organic manuring with chemical fertilizers compared to its initial soil fertility in rotational cropping.

Matiwade and Sheelavantar (1995) were studied the effects of 0-100% of their recommended N rate with or without *Sesbania rostrata* green manure in a field trial in 1989-90 with rice and reported that N contents of leaves, stems and panicles and N uptake were higher with green manure alone than with 100% N alone. Green manure + 100% N gave the highest N content and uptake.

Murali and Reddy (1995) conducted a field trial at Rajendranagar, Andhra Pradesh, rice Cvs. WGL 48684, RNR 99377, RNR 32341 and Surekha were given 80, 120 or 160 kg N/ha in 3 split applications at sowing, tillering and panicle initiation. The highest shoot dry matter (11754 kg/ha) and N, P and K uptake were recorded with cv. RNR 99377. Shoot dry weight increased significantly with increasing levels of nitrogen upto 160 kg/ha. N and K uptake increased significantly with upto 160 kgN/ha, while P uptake increased with upto 120 kg N/ha.

Singh *et al.* (1995) studied the effect of 0-180 kg N/ha on yield and nutrient uptake of wetland rice cv. PR 106 and found that the combined application of cattle manure and urea showed no positive interaction effects. Total N uptake by rice was also significantly higher from urea than manure. Apparent N recovery ranged from 35 to 48% for urea and was about 20% for cattle manure. Phosphorus and K uptake by rice increased in response to N application from urea and cattle manure but the differences between the two treatments were small.

Khanda and Dixit (1996) reported that the rice yield increased with increasing N rate. Uptake of N and Zn increased progressively with increased levels of nitrogen. Among the methods of application, soil application of Zn was superior to foliar spray.

Laza *et al.* (1996) reported that plant nitrogen (N) content increases with N application in rice, but little is known of the maximum N uptake rate (NUR) immediately after application. Leaf and stem dry matter and N content correspondingly increased with NUR. The high uptake rate immediately after N application indicates high N absorbing capacity of the rice root system.

Medhi *et al.* (1996) conducted a green house experiment to study the changes on the nutrients in soil and soil solution and growth of rice treated with organic manures and prilled urea (Pu) and found that the concentration of P, K⁺, Fe²⁺ and Mn²⁺ in the soil and soil solution were higher with Pu and organic sources than control. Addition of N, regardless of sources, increased grain yield significantly. Nitrogen and Mn uptake by grain also increased significantly with the addition of N.

Tiwana and Narang (1997) carried out field investigations at PAU, Ludhiana, to study the micronutrient uptake spectrum of rice and wheat in rice-wheat cropping system under heavy fertilization from rabi 1990 to Kharif 1992 and found that four cationic micronutrients Zn, Fe, Mn and Cu content in straw and grain at harvest, in rice increased with increase in fertilizer N. Uptake of Zn, Fe, Mn and Cu also increased with each increment of 60 kg N/ha upto the

highest level of 240 kg N/ha. The 180-30-30 fertilizer level increased the uptake of Zn, Fe, Mn and Cu by 14.0, 14.1, 16.3 and 40.4% in rice; respectively over 120-30-30/120-60-30 N P₂O₅K₂O. Kg/ha. The mean total uptake of Zn, Fe, Mn and Cu in rice at different fertilizer levels under chemical fertilizers series (N-P₂O₅-K₂O as 180-30-30 kg/ha, respectively) was 381, 825, 831 and 73 g/ha as against 334, 723, 714 and 52 g/ha at 120-30-30, respectively.

Singh *et al.* (1998) conducted a field experiment to study the response of promising cultures and varieties of rice (*Oryza sativa* L.) to nitrogen levels and found that the performance of 'Rajshree' rice was the best, particularly at lower levels of nitrogen (0, 40 and 80 Kg N/ha). As far as N uptake in grain and straw was concerned, 'Radha' was the only variety which responded significantly upto 160 Kg N/ha.

Fu *et al.* (1999) studied the effect of N application on N concentration, N uptake and growth of rice. Leaf, culm and root N concentrations were highest during active tillering. N concentrations in these organs declined thereafter until maturity. The sources of N in panicles were 30-35%, 17-38% and 6-20% from leaves, culms and roots, respectively. The panicle accounted for 58-60% of total N in rice plants. N absorption continued until maturity. N uptake rates were 1.33-8.17, 6.03 and 0.05-1.02 kg m⁻²/day at mid tillering, heading and at spikelet growth stages, respectively.

Kamal *et al.* (1999) undertaken a study to evaluate the growth, grain protein content and nutrient uptake of 17 modern rice cultivars grown under irrigated condition Bangladesh Agriculture University, Mymensingh. Cultivars were given 80 kg N, 20 kg P, 25 kg K, 10 kg S and 3 kg Zn/ha. The highest N, P, K, S and Zn uptake (236.17 kg/ha) was observed in BR 3 followed by BR 14 and BR 18 while the lowest N, P, K, S and Zn uptake (149.86 kg/ha) was found in BR 6.

Marr *et al.* (1999) reported that the nitrogen application increased yield, grain N content and the content of some minerals. In the 1992-93 and 1993-94, 125 kg and 100 kg N/ha increased yields by 63% and 71% (from 6.8 to 11.1 t

and from 5.9 to 10.1 t/ha), respectively. The same N rates increased grain N content from 12.9 to 14.5 g/kg in 1992-93 and from 11.4 to 12.6 g kg⁻¹ in 1993-94. Grain S content was significantly increased in 1992-93 from 1.04 to 1.21 g/kg and from 0.82 to 0.94 g/kg in 1993-94. Total accumulation of all minerals (except B and Na in 1992-93 and Cu in 1993-94) increased with N application. Yield increase, driven by N fertilizer, was the major influence on increased uptake of N, S, P, K, Mg, Ca, Fe, Mn and Zn from the soil.

Panda *et al.* (1999) conducted a field experiment to evaluate the effect of continuous manuring in rice-rice cropping system. Application of 120 kg N, 80 kg P₂O₅ and 40 kg K₂O ha⁻¹ found beneficial for rice-rice cropping sequence in each season. N, P and K uptake both during *kharif* and *rabi* seasons increased linearly with increase in N levels over the years. In pooled data, the additional uptake of N, P and K due to 120 kg N ha⁻¹ over 40 kg N ha⁻¹ accounted to 17.4, 2.9 and 15.2 kg ha⁻¹, respectively. The increase in N, P and K uptake may be attributed to increasing grain yield.

Statin *et al.* (1999) conducted field experiments with rice cv. IR 64 in kharif season to study the response for different nitrogen (N) fertilization application strategies and found that the N content in the above-ground biomass was highest at AT (Active tillering) stage and decreased in the course of the growth period probably due to the dilution effect with pronounced formation and translocation of other constituents like cellulose and starch in the plant and also found N application generally increased the N content at different growth stages. N uptake characterizes the supply of N to the rice plant and increased substantially during the growth period. At harvest, total N uptake (grain + straw) ranged from 74.1 to 166.3 kg N ha⁻¹ in 1994 season and from 78.3 to 180.8 kg N ha⁻¹ in 1995 season.

Suresh *et al.* (1999) found that the yield, N uptake, number of tillers and productive tillers were higher under neem cake coated urea and urea gypsum than the conventionally used prilled urea on equal nutrient basis of 125 kg N ha⁻¹. Tripathi and Tiwari (2002) observed that the amount of N and P in the plants

at various growth stages were significantly influenced by application of N and P. Every increment of nitrogen from 0 to 40, 40 to 80 and 80 to 120 kg ha⁻¹ increased total N uptake by 49.55, 34.30 and 27.17%, total P uptake by 40.33, 27.06 and 20.32% and total K uptake by 32.43, 20.70 and 17.25% respectively. All the differences were found significant (**Mhaskar and Thorat, 2005**).

Raghavaiah *et al.* (2000) conducted field experiments to study the effects of N and P fertilizer on high-yielding rice cultivars (Tellahansa, Rasi and Pothana) and found that the percentage of N in the plants at 30 DAT was high and then decreased from 50 to 70 DAT under the Large Granular Urea (LGU) fertilizer treatment. Liquid ammonium polyphosphate (APPG) resulted in higher grain and straw N content and uptake than the other P fertilizers.

Jaiswal and Singh (2001) have reported that nitrogen at 120 kg/ha increased the N uptake in rice by 41.9 and 34.8% over 60 kg N/ha in grain and straw, respectively. They explained higher N uptake at increased N application due to better established roots, better plant growth and yield. **Shanmugam and Veeraputhran (2001)** found that N uptake was influenced by organic and inorganic N with Zn application in rice. It was also observed that application of 187.5 kg N + 25 kg ZnSO₄ ha⁻¹ significantly increased available N, P, K, Zn and organic carbon.

Duhan and Singh (2002) reported that the rice yield and uptake of micro-nutrients increased significantly with increasing N levels. Moreover, application of N alongwith GM (green manuring) showed additive effect on these parameters. Under all GM treatments, the yield and uptake were always higher with 120 Kg N/ha than with lower levels of N. The highest uptake of all micronutrients were obtained where 120 Kg N ha⁻¹ was applied under sunhemp as GM.

Singh and Singh (2002) conducted a field experiment to study the effect of different nitrogen levels (50, 100 and 150 kg ha⁻¹) and sulphur levels (0, 20 and 40 kg ha⁻¹) on rice and found that the total nitrogen uptake, grain, straw and grain protein yields significantly improved with increasing levels of nitrogen and

sulphur application being maximum at 150 kg N ha⁻¹ and 40 kg S ha⁻¹, respectively. Sulphur uptake was also augmented by nitrogen and sulphur application.

Sitaramayya *et al.* (2002) reported that the magnitude of mean response at N₁₂₀ was 746 Kg ha⁻¹ in Kharif and 712 Kg ha⁻¹ in *rabi* season. The uptake trend of major nutrients indicated 8.7 and 21.3 % increase in case of N, and 11.5 and 23.1% hike of P at their higher rates of application compared to N₄₀ and P₀, respectively.

Maiti *et al.* (2003) were studied the effects of nitrogen fertilizer rate (0, 120 and 140 kg/ha) on the performance of one high yielding cultivar (IET-4786) and 4 hybrid varieties of rice at Mohanpur, West Bengal and found that the hybrid varieties recorded greater nitrogen (112.59 – 120.10 kg/ha), phosphorus (112.672 – 120.179 kg/ha) and potassium (115.148 – 23.505 kg/ha) uptake than IET – 4786 (89.101, 89.261 and 91.914 kg/ha, respectively). The application of 140 kg N ha⁻¹ resulted in the highest nitrogen (136.701 kg/ha), phosphorus (132.029 kg/ha) and potassium (135.167 kg/ha) uptake.

Swamy and Mandal (2003) studied the effects of polyrice (a commercial fertilizer containing N, P, K, Zn, Mn, Fe, B and Mo) and N application on the performance of rice cultivars IR-64, BPT – 5204 and MTU – 1010 in hyderabad, Andhra Pradesh, during the Kharif season of 1999. N as urea was applied in equal splits at 120 kg ha⁻¹. Among the cultivars, MTU – 1010 recorded the highest grain (5052 kg/ha) and straw (5322 kg/ha) yields, grain (1.49%) and straw (0.66%) N contents, total N uptake (105.36 kg/ha) and N recovery (29.8%), whereas BPT – 5204 registered the highest gross returns (35626 rupees ha⁻¹), net returns (25183 rupees/ha) and benefit:cost ratio (2.39). Among the N treatments, N application during transplanting, tillering, panicle initiation and 50% flowering with polyrice resulted in the highest total N uptake (116-18 kg/ha), N recovery (38.89%), gross returns (32320 rupees/ha) net returns (21440 rupees/ha) and benefit:cost ratio (1.96).

Vijayabaskar *et al.* (2004) revealed that the nitrogen and potassium content in leaf and stem increased with increased doses of nitrogen and potassium. The potassium content in leaf was higher in NLR 30491 (2.15 per cent) compared to NLR 33633 (2.01 per cent). **Parihar (2004)** found that intreaction effects between organic and inorganic sources of nutrient were significant and 100% recommended NPK along with FYM @ 5 t/ha gave the highest yield (5610 kg/ha) and total NPK uptake.

Arivazhagan and Ravichandran (2005) reported that the nutrient uptake in grain and straw increased with the increase in the level of N and K. Among the time of K application, basal skipping of K recorded that highest grain N and K uptake of 65.62 and 18.55 kg ha⁻¹, respectively and straw N and K uptake of 41.63 and 89.03 kg ha⁻¹.

B. Effect of Sulphur on content and uptake of nutrients

Wallihan and Sharpless (1974) stated that N concentration in the index leaves was a direct linear function of the S concentration upto the levels giving maximum yield. N and S were similarly balanced at deficiency levels of both elements. **Ismundaji (1975)** stated that S application was most effective when applied together with NPK. The NPK and S contents were more critical than the P content. **Pillai and Singh (1975)** showed a correlation with S content of the flag leaf with grain yield of rice.

Martel and Zizka (1977) stated that N-S ratio was five times higher in the grain than straw. **Ivanic (1977)** reported that applied S increased the uptake of S more in straw than grain and decreased the P and Mg content of grain. **Pasricha *et al.* (1977)** reported that S fertilization enhanced significantly N and S uptake by maize. **Shukla and Prasad (1979)** observed a decrease in Zn concentrations of shoot with S application in groundnut. This adverse effect of S on Zn concentration in shoot was neutralized with the application of Zn.

Moss *et al.* (1981) reported that the nitrogen and sulphur application accelerated the absorption of S in wheat crop. The content was found to vary

from 0.08 to 0.15 per cent in grain. Most of the deficient rice plants contained less than 0.16 per cent S in leaf blades and shoots at tillering and 90 percent of the optimum yield was associated with 0.17 per cent or more S (Tiwari *et al.*, 1983 a,b).

Alam *et al.* (1985) noted that application of S from different sources enhanced its content in rice plants under submerged condition. Singh and Karrwasra (1987) reported that the application of S upto 80 ppm increased the tissue S and Zn concentration and supplemental application of S and Zn increased their uptake. Application of one of the two nutrients depressed the concentration of the others in the shoot but when applied together there was significant increase in their uptake. In general, S and Zn appeared to be synergistically related. Ahmed *et al.* (1988) reported that applications of N and S at the level of $N_{120}S_{30}$ considerably increased the N and S uptake at all the growth stages. The lowest N:S ratio of rice plant approached 10 particularly under $N_{120}S_{30}$ treatment at all the growth stages.

Kochar *et al.* (1990) reported that application of S increased significantly the S concentration in maize from 0.040 to 0.152 per cent, whereas Zn decreased it from 0.106 to 0.089 per cent. Addition of S increased significantly the S uptake to 18.1 mg pot^{-1} whereas Zn increased it significantly from 9.5 to 12.9 mg pot^{-1} upto 2.5 ppm Zn rate and decreased beyond that. Application of 10 ppm S increased the Zn uptake from 14.9 to $286 \text{ } \mu\text{g pot}^{-1}$ but decreased significantly when the rate of S was 20 and 40 ppm.

Mukhi and Shukla (1991) while studying the effect of S and Zn on yield and their uptake in rice crop in submerged soil conditions concluded that Zn generally increased S in all plant parts except husk at maturity and root at earing. Sulphur uptake drastically increased with 20 ppm Zn and 75 ppm S and occurred mostly from sowing to earing; zinc concentration and uptake generally decreased with 75 ppm S.

Malarvizhi *et al.* (1993) conducted a field experiment in Madurai, TamilNadu during the wet seasons of 1986-88 using rice cv. IR 20 on an Alfisol,

non saline soil of pH 7.3. Treatment combinations included recommended doses of NPK fertilizer (100:50:50 kg N, P_2O_5 and K_2O ha⁻¹) alongwith 3 sources of sulphur (gypsum, elemental sulphur or sulphur sludge) at 4 levels (25, 50, 75 or 100 kg S ha⁻¹). At a rate of 100 kg S ha⁻¹ application available S in the soil was significantly increased from tillering to post harvest stage in both seasons. It is suggested that yield increase are due to the role of S in the synthesis of protein and methionine. However, application of S showed a non significant relationship with P and K status in the soil.

Manchanda *et al.* (1993) conducted a field experiment in a sandy loam soil, rice Cv. PR 106 was given 25-100 ppm N as urea and 5 ppm S as SSP or gypsum. S and N contents in leaves and stems, and S uptake in leaves and stems were higher with SSP than gypsum. N:S ratio decreased with increasing N rate.

Mazid (1993) showed the results of the greenhouse experiments that the lowest S level (0.6 mg/l) and application of high N (180 mg/l) increased the total N concentration in the straw but not in the grains. Increasing S from 0.6 to 5 mg/l decreased straw N concentration, but further increase in S concentration had no further effect on straw N. Sulfur at 5 mg/l significantly increased total N uptake and leaf CO₂ assimilation where 60 or 120 mg N/l was applied. The critical level of S was 5 mg/l at 60 and 120 mg N/l and 10 mg/l at 180 mg N/l.

Ganeshmurthy *et al.* (1995) evaluated S status of rice soils growing in Andaman and Nicobar Islands through soil and plant tests. Of the 20 soils tried, 15 gave marked response to S application. the critical level of plant S determined by these methods was 0.175% at 40 days after sowing.

Sinha *et al.* (1995) observed from a field experiment conducted in calcareous soils of Bihar that application of S increased significantly the concentrations of S, P, Zn and Fe in maize shoot at knee-high stage. The uptakes of S, P, Zn and Fe in maize grain and stover increased significantly with increasing levels of S. There was a significant positive correlation with concentrations of S in shoot at knee-high stage and S uptake by grain.

Singh *et al.* (1997) reported that application of 0 to 90 mg P, 0 to 60 mg S and 0 to 20 mg Zn Kg⁻¹ soil enhanced the concentration and uptake of S and Zn. Application of S increased significantly the concentration and uptake of Zn upto 40 mg S kg⁻¹ soil. However, application of 60 mg S kg⁻¹ soil decreased significantly Zn concentration and uptake. The interaction effects of P X Zn, P X S and S X Zn were significant in concentration and uptake of S and Zn. Application of S upto 40 mg kg⁻¹ soil and Zn upto 5 mg Zn kg⁻¹ soil also increased significantly the concentration and uptake of P, however, high rates of S and Zn decreased P uptake.

Poongothai *et al.* (1999) showed that sulphur application significantly enhanced S uptake by rice. Application of gypsum along with green manure increased the sulphur use efficiency, straw and grain yield.

Sakal *et al.* (1999) evaluated the effect of S on the yield, N, P, K and S nutrition of crops in a field experiment under a rice-wheat system in a highly-calcareous soil at RAU, Pusa farm, Bihar. The optimum level of S for rice and wheat appeared at 40 and 60 kg Sha⁻¹, respectively. Sulphur application showed a synergistic effect on N and an antagonistic effect on P and K content in rice and a synergistic effect on N, P and K content in wheat. Application of S enhanced the utilization of N, P, K and S by rice and wheat crops. The average N, P, K and S removal by rice (grain + straw) was 87, 12, 113 and 13 kg ha⁻¹ and by wheat was 164, 14, 142 and 15 kg ha⁻¹, respectively.

Singh *et al.* (1999) summarized the effect of long term fertilizer treatment on organic matter, available P, K and Zn in residual soil after 10 cycles of Rice-Wheat system. They reported that in comparison to control and chemical fertilizers, addition of chemical fertilizer + FYM in rice crop significantly increased the available contents of P, K, S and Zn in residual soil.

Singh (2000) reported that S content increased with its application whereas a reduction in S content in wheat grain and straw was noted with increasing levels of Zn. The uptake of S by wheat grain and straw increased

significantly with both S and Zn addition. Uptake of S increased by wheat crop upto 5 mg Zn Kg⁻¹.

Wani and Refique (2000) conducted a field experiment during kharif 1995 in Shalimar, Jammu and Kashmir, rice cv. K-39 was given 0, 10, 20, 30 and 40 or 50 kg S/ha. Yield and S, N, P and K uptake increased with increasing S rate upto 40 kg, then decreased or remained the same.

Nad *et al.* (2001) observed the required application of sulphur is one half to one third the amount of nitrogen and the ratio becomes narrower in mustard (*Brassica juncea*), followed by wheat and rice. Easily available forms of sulphur, like ammonium sulfate and gypsum, as compared to pyrite or elemental sulphur, maintained adequate N to S ratio in rice.

Sarfraz *et al.* (2002) conducted a field experiment to study the effect of sulphur on yield and chemical composition of rice. Sulphur was applied at the rate of 20 kg ha⁻¹ from two sources i.e. ammonium sulphate and potassium sulphate. The results showed that NPK concentration and their uptake in paddy and straw significantly increased by applying NPK + S over control. Sulphur concentration and its uptake only in straw were significantly higher by sulphur application over NPK treatment.

Sudha and Chandini (2002) studied the effects of N:P₂O₅, K₂O (100, 125 or 150% of the recommended rate of 70:35:35 kg/ha) and sulphur fertilization (0.0, 12.5 or 25.0 kg/ha) on the performance of rice. The highest NPK rate was superior in increasing N, P and K uptake and grain and straw yields, however S uptake was reduced under such NPK level due to the antagonistic effect of high P levels on S uptake. Sulphur application upto the highest level resulted in the increased uptake of N, P, K and S. **Sen *et al.* (2002)** have been reported deficiency of sulphur (S) in soils from six districts of West Bengal, India. To combat this deficiency problem, application of sulphur through single superphosphate in a sulphur deficient areas was found beneficial. Sulphur application not only helped to increase yield in both the crops but also helped to

control the movement and distribution of different cationic micronutrients in both the crops. .

Islam *et al.* (2006) reported that the concentrations of P and S were increased with increasing doses of P and S in wheat, rice and mungbean plants using three rates of P (0, 17.6 and 35.2 kg Pha⁻¹ for each crop) and three rates of S (0, 20 and 40 kg Sha⁻¹ for wheat and rice and 0, 10 and 20 kg Sha⁻¹ for mungbean). Interactions between P and S resulted in antagonistic effect on P concentration in wheat and rice plants when P and S were applied at higher combinations. The PXS interactions showed additive and beneficial effects on the concentrations and uptake of S by wheat and rice plants. The uptake of P and S by wheat and rice plants was not affected by due to P X S interactions. The highest grain yield of rice was obtained with the application of 17.6 kg P + 20 kg Sha⁻¹.

C. Effect of Zn on content and uptake of nutrients

Hofuer and Kovanci (1973) reported that uptake of Zn by test crop maize was greater from labeled ZnCl₂ than Zn₂P₂O₇ as source of Zn. Increasing the P supply in nutrient solution caused a 2-3 per cent increase in P concentration but did not increase Zn concentration. **Pathak *et al.* (1975)** reported an increase in zinc content and uptake of nutrients by rice due to zinc fertilization. **Singh (1976)** stated that the increasing P rates increased P contents in leaves and stems, Zn decreased them by 26 per cent in leaves and 12 per cent in stems. P uptake increased with applied P and /or Zn due to increased dry matter production. Zn uptake increased with lower dose of P, but decreased with higher P rate. The main site of Zn accumulation in plant was the stem. **Singh and Prasad (1978)** stated that the N uptake increased by Zn and Zn+Mn application, while P and K uptake was decreased by Zn and Mn, respectively. Zn decreased the Mn content of maize plant. **Dev and Shukla (1980)** reported that pattern of Zn and N responses in shoot and root dry matter production further indicated that the efficiency of applied N and Zn was interdependent in maize.

Singh *et al.* (1983) observed that zinc application progressively increased its concentration in grain and straw. The maximum Zn removal was recorded in rice-rabi maize and minimum in groundnut-wheat rotations. Zinc application increased significantly the uptake of Zn by maize crop at harvest. Zn content ranged from 36.6 to 102.2 ppm Zn in crops. Gukova *et al.* (1985) observed that seed treatment with ZnSO_4 markedly increased the Zn contents in seed, their germination percentage and plant height. The optimum Zn content in seeds was 250 mg Kg^{-1} dry matter. Sharma *et al.* (1986) reported that Zn concentration in plant tissues and Zn uptake by grain and straw of rice increased significantly with the Zn application. Increase in Zn concentration and uptake in plants and its addition has also been reported by several researchers (Singh and Abrol, 1987, Ahmed *et al.*, 1992, Prasad and Umar, 1993). Singh and Sakal (1987) reported that Zn content in tolerant varieties had significant effect of Zn than did susceptible varieties of rice. The use of 3rd leaf of screen lines and for genetic studies of Zn content was advocated. Biswapati *et al.* (1988) observed the transformation of Zn in soil fraction under submerged condition in the presence and absence of added organic matter and its relationship with Zn nutrition of rice plants. Application of organic matter caused a decrease in the concentration of Zn in shoot and root of rice plants. Sedberry *et al.* (1988) reported that application of Zn resulted in a significant increase in the uptake of N by rice plant at each stages of plant growth.

In a field experiment with *kharif* crops, response to added sulphur were significant only when adequate supply of Zn was made. In absence of zinc application, responses to applied sulphur were non-significant. Increasing supply of sulphur to soil caused significant decrease in Zn content of the plant and vice-versa. Which indicated antagonistic relationship (Tiwari, 1989). Both synergistic and antagonistic results between S and Zn have been reported and the relationship between these two is not very clear (Takkar *et al.*, 1989).

Singh *et al.* (1989) showed comparative effect of mono and hepta hydrate zinc sulphate on zinc nutrition of maize and bajra crops and reported that dry matter yields of both crop (g pot^{-1}) increased upto the level of 10 ppm Zn. Zinc

content and uptake increased with increasing level of Zn from 15.36 to 35.25 ppm. Zn uptake was higher in maize than bajra.

Sahay *et al.* (1992) conducted field trials on paddy and wheat with four levels of Zn and B with the recommended rate of NPK. The concentration and uptake of Zn in grain and straw of paddy were significantly enhanced by Zn application. Zn concentration in grain ranged from 18.24 to 27.13 ppm and in straw from 18.34 to 25.28 ppm.

Singh and Kumar (1993) stated that in a pot experiment with wheat, the uptake of Zn increased significantly upto 10 mg kg^{-1} over control, mainly due to higher grain and straw yields. Gupta *et al.* (1993) conducted a green house experiment on effect of Zn and N contents on maize and reported that there was marked improvement in Zn uptake with $(\text{NH}_4)_2\text{SO}_4$ compared to urea. Zn application increased significantly the uptake of Zn in the presence of all the three sources of N. However, uptake was maximum when Zn was added together with $(\text{NH}_4)_2\text{SO}_4$. Zn uptake increased with the increase of Zn application. N uptake increased with increased levels of Zn.

Mali and Sheikh (1993) studied the effect of zinc sources (zinc sulphate, zincated suphala) with or without FYM applied to *kharif* [monsoon] rice and found that yield and N, P and Zn contents of both crops increased with Zn application and were highest with zincated suphala.

Dixit and Patro (1994) reported that the total NPK and Zn uptake increased with NPK and zinc application except P uptake which decreased slightly with Zn application. Uptake of NPK and Zn increased with increased plant density. Singh and Sharma (1994) given 20 kg ZnSO_4 , 0.5 kg chelated Zn or 0.5 kg Zn-EDTA ha^{-1} as a basal application, top dressing or in 3 foliar sprays of 0.5%, 0.1% and 0.01% for the 3 sources, respectively to rice cv. Sarju-52. Grain yield was highest with a basal dose of 20 kg ZnSO_4/ha (3.74 t/ha) followed by 3 foliar sprays of ZnSO_4 (3.58 t/ha); Zn-EDTA as a top dressing or 3 foliar sprays gave the lowest grain yield. Zinc uptake followed a similar

pattern to yield. **Singh *et al.* (1994)** reported that Zn uptake increased with increased rate of Zn application and was highest with $7.5 \text{ mg Kg}^{-1} \text{ ZnSO}_4$.

Tomar *et al.* (1994) conducted a field experiment in kharif (monsoon) 1983 on clay loam soil at Tikamgarh to study the response of high yielding rice cv. IR-28 and Kiran to 0-100 kg ZnSO_4/ha . Application of 50 and 75 kg ZnSO_4/ha increased grain yield significantly. Nutritional quality of the grain was not affected significantly but increase in P and Zn and decrease in Ca content was observed. In rice straw, P and Zn levels decreased and Ca and Mg levels increased as compared with rice grain.

Sahu *et al.* (1996) concluded from a pot experiment that the application of Zn increased significantly the content and uptake of N with increased level of Zn 0.5 mg Kg^{-1} but the uptake increased upto the Zn level of 2.5 mg kg^{-1} . Content of Ca and Mg were not affected significantly by Zn levels but the uptake was highest at 2.5 mg ka^{-1} Zn level. **Channal and Kandaswamy (1997)** conducted a pot culture experiment using a sodic soil to study the utilization of applied zinc by rice on CO-43 as influenced by amendments (compost coir-pith, dhaincha, gypsum or dhaincha (*Sesbania* sp.) + gypsum) and application rates of Zn (0-50 kg/ha). Incorporation of gypsum + dhaincha resulted in the highest utilization of applied zinc. Among the Zn rates tested, utilization of applied Zn was highest in treatments receiving $37.5 \text{ kg ZnSO}_4/\text{ha}$.

Kumar and Singh (1997) conducted a field experiment during kharif (monsoon) 1990 at Bihar Agricultural College Farm, Sabour, rice cv. Sita was given 0, 12.5 or 25 kg ZnSO_4/ha by soil application in the nursery or 3-week-old seedlings were sprayed with 0.5% ZnSO_4 , or seedling roots were dipped in 2% ZnO solution. Of the nursery treatments, dipping roots in ZnO gave the highest Zn concentration at all growth stages. Zn concentration was greatest at active tillering and then gradually decreased, with the post transplanting treatment giving the highest Zn concentration at tillering being soil application of 25 kg ZnSO_4 .

Trivedi *et al.* (1998) summarized the results of a field experiment conducted on Vertic Ustochrept on rice. The treatments consisted 4 levels of Zn (0, 5.6, 11.2 and 16.8 kg Zn ha⁻¹) through ZnSO₄·7 H₂O. Zinc uptake increased significantly with successive rise in Zn levels upto 11.2 kg ha⁻¹. Nandram (1996) reported that the addition of Zn and FYM alongwith 100% NPK enhanced the mean grain yield of rice by 12 and 14 per cent and that of wheat by 13 and 16 per cent, respectively. The application of Zn and FYM alongwith 100% NPK resulted in increased uptake of Zn from the soil.

Kamal *et al.* (1999) undertaken a study to evaluate the growth, grain protein content and nutrient uptake of 17 modern rice cultivars grown under irrigated condition in the Bangladesh Agricultural University, Mymensingh. Cultivars were given 80 kg N, 20 kg P, 25 kg K, 10 kg S and 3 kg Zn/ha. The highest N, P, K, S and S and Zn uptake (236.17 kg/ha) was observed in BR3 followed by BR14 and BR18 while the lowest N, P, K, S and Zn uptake (149.86 kg/ha) was found in BR 6. **Patnaik and Raj (1999)** reported that the soil application of ZnSO₄ increased the grain yield of rice. Application of 75 kg ZnSO₄ gave the highest cumulative effect. Zinc content in the index leaf samples increased with the increase in the ZnSO₄ application. The uptake in the zinc sulphate treated plots was significantly more than the control plot.

Prasad *et al.* (2000) reported that yield of rice significantly increased with the application of Zn upto 10 ppm. Zinc concentration in plant tissue and zinc uptake by grain and straw also increase significantly with the zinc application. A level of 0.84 ppm 0.01 MEDTA extractable Zn, 0.875 ppm neutral N NH₄OAC + 0.01% Dithizone extractable Zn and 0.75 ppm DTPA extractable Zn in soils were found to be critical, below which response to Zn application is expected, whereas 31.0 ppm, 24.45 ppm, 15.50 ppm and 20.02 ppm Zn concentration was estimated to be critical at tillering, flowering, grain and straw, respectively.

Kumar *et al.* (2002) studied the effects of zinc sources and zinc and phosphorus rates (0, 10, 20 or 30 ppm) on the performance of rice and found

that, the application of zinc and phosphorus significantly increased yield and nutrient uptake. Among the zinc rates 10 ppm gave the highest grain (3.000 t/ha) and straw (4.825%) yields, grain (1.16%) and straw (0.52%) nitrogen content, and straw potassium content (0.55%). The zinc contents of grain (2.303%) and straw (5.323%) were highest at 30 ppm zinc, whereas the phosphorus content of grain (0.31%) and straw (0.102%) were highest at 0 ppm zinc.

Muhammad *et al.* (2002) applied two rates of Zn (0 and 5 or 10 mg/kg soil) and one rate of each Fe and Mn (5 mg/Kg soil) along with a basal dose of NPK (100 + 50 + 50 mg/Kg) in various combinations before transplanting of rice seedlings. The Zn and Mn concentration in the grain 46.53 and 99.40 mg Kg⁻¹, respectively in the treatment where 10 mg Zn Kg⁻¹ was applied along with NPK + Mn. The maximum Fe was 166.1 mg Kg⁻¹ in grain where 5 mg Zn/Kg was applied along with NPK + Fe.

Jadhav *et al.* (2003b) obtained highest grain yield (57.7 q/ha), straw (53.8 mg/kg) and grain (44.5 mg/kg) Zn contents and total Zn uptake (575.7 g/ha) with NPK (100:50:50) + FYM (10 t/ha) + Zn at 45 kg/ha. The application of NPK + FYM + Zn at 30 kg/ha resulted in the highest total N (97.10 kg/ha) and P uptake (12.0 kg/ha), whereas NPK+Zn at 15 kg/ha⁻¹ gave the highest total K uptake (128.2 Kg/ha).

Patil and Meisheri (2003) conducted pot culture experiments to investigate the direct and residual effects of applied Zn in rice-rice cropping system. The Zn uptake by grain and straw and its content in the soil were increased when Zn was applied; the increase were significantly higher when Zn was combined with FYM. The Zn uptake and available Zn in the soil increased significantly when Zn was applied for the first crop. The treatments comprising application of 25kg ZnSO₄ and 10kg chelated Zn ha⁻¹ were at par.

Khan *et al.* (2004) conducted a pot culture study to evaluate the effect of different levels of zinc on the Zn content of leaf, soil, roots and starch content of rice in 8 different calcareous soil series of D.I. Khan, Pakistan. Zn as ZnSO₄ was applied at 0, 5, 10 and 15 kg ha⁻¹ along with the basal rates of 120 kg N, 90 kg

P_2O_5 and 60 kg K_2O . Zn content of root, leaves before and after flowering and of soil before flowering and after harvest increased. Maximum Zn content of rice leaf before and after flowering was observed with 15 kg Zn ha^{-1} in the soil series.

Tripathi and Tripathi (2004) conducted a field trial to study the zinc requirement of rice (cv. CSR-10) in relation to different modes of zinc application in the nursery. Zinc content and uptake in grain and straw of rice increased significantly upto 45 kg $ZnSO_4$ ha^{-1} , whereas maximum values were found with the application of 25 kg $ZnSO_4$ ha^{-1} in nursery treatments.

4. EFFECT OF NITROGEN, SULPHUR AND ZINC ON QUALITY PARAMETERS OF RICE

A. Effect of N on quality characteristics of rice

Gomez (1979) reported that the amylose and protein content of rice grains is influenced by temperature, nitrogen fertilization and other environmental factors.

Lima-E-Silva and Brandao (1986) reported a decrease in the hulled rice protein content of rice cvs, IR-634-9-5-4 and IR-665-4-1 due to application of 45 kg N ha^{-1} . The highest brown rice protein content was in IR-665-4-1 receiving 90 kg N ha^{-1} . Protein and total free amino acids increased due to fertilizers application. The highest value was with 600 kg ha^{-1} pyrite and 120:60:60 kg NPK ha^{-1} . The total carbohydrate content declined slightly. It appears that protein synthesis and its accumulation in the grain intensified with pyrite and NPK, at expense of carbohydrates (**Awasthi *et al.*, 1989**).

Sabhamuni (1990) on the basis of two years study on rice found that application of 180 kg N and 120 kg K_2O/ha resulted in maximum crude protein and true protein contents. The starch content was not affected but the mineral matter was increased as compared to control.

Wakamatsu (1991) reported that the measurements of mineral levels in 5 samples of rice cv. Sasanishiki grain showed the level of N was lower in

polished than in unpolished grain. In 4 samples the flavour value decreased as the amylose content increased. As the total rate of applied N increased from 70 to 100 kg/ha the unpolished grain yield increased from 6.93 to 7.06 t/ha but the grain protein content decreased from 7.1 to 6.8%. Increasing the rate of N also increased the amylose content and the number of grains m^{-2} but decreased the ripening percentage and the N uptake.

Zhou *et al.* (1992) reported that at booting and grain filling stages, late nitrogen application might markedly increased nitrogen assimilation and photosynthetic rate of hybrid japonica rice cv. Danyon No. 3. As a result of late N application at grain filling, flag leaf chlorophyll content remained high, leaf senescence was delayed, and the contents of protein, 8 essential amino acids and threonine in rice grain were increased. It was concluded that late nitrogen application to rice not only increased yield but also improved seed quality compared with the control.

Deka and Borah (1993) studied the effect of urea, ammonium sulphate (AS) and diammonium phosphate (DAP) on mean N-uptake, plant N-content, grain yield and grain protein yield. The result of the experiment revealed that the source of N fertilizer had significant effect on soil $NO_3 - N$, $NH_4 - N$, plant nitrate content, mean N-uptake, plant N-content, grain and grain protein yields in both Mahsuri and Pankaj varieties of rice. Application of fertilizer increased the soil mineral nitrogen in both the varieties. Among the sources, DAP resulted the highest grain protein yield in Pankaj whereas Mahsuri, it was with urea.

Rao *et al.* (1993) were presented data on the effect of N (0, 30, 60, 90 kg/ha) on 3 yield and 5 quality characters of 7 varieties of scented rice raised during the wet and dry seasons of 1988-90 at Cuttack. N application did not adversely affect different quality traits such as alkali value, volume expansion and water uptake. Higher levels of N increased the amylose content of the long slender varieties by 3.0-9.9%.

Kumar *et al.* (1996) conducted a field trial to test the effect of five levels of nitrogen (0, 30, 60, 90 and 120 Kg/ha) on four scented rice varieties (Haryana

Basmati-1, Pusa Basmati-1, Kasturi and Taraori Basmati). Taraori Basmati not only proved to be the highest yielder (3000 Kg/ha), but its grain quality was also the best having the longest kernels (7.85 mm) and the highest L/B ratio (4.67). A rate of 60 Kg N/ha was optimum for scented rice and nitrogen did not affect the grain quality markedly. The breadth of kernel increased marginally, which caused the L/B ratio to decrease slightly with increase in N rate.

Trivedi and Verma (1996) conducted a pot experiment with rice Cv. IR-8 given the equivalent to 80 kg K as KCl or K₂SO₄ and /or 2 kg Mo as molybdate and each treatment was supplied with or without 100 kg N/ha. Grain yield and content of carbohydrates and protein were highest with N + K₂SO₄ + Mo.

Patel *et al.* (1997) conducted a field experiment during Kharif 1992 and 1993 to study the effect on rice yield and N uptake of different N levels and applied saw dust, rice straw, soil and FYM preconditioned with urea. Quality and yield were increased significantly at applications of 80 kg N/ha as compared with rates of 40 kg N/ha ; whereas a further increase in N rate to 120 kg N/ha had no further significant effect.

Moorthy *et al.* (1998) conducted an experiment at the CRRI, Cuttack to assess the optimum nitrogen requirement for yield and quality related traits in long slender, non scented rice varieties and found that grain yield increased with increasing N dose, and N levels did not have any adverse influence on the various quality traits. Hathipanjari and Sabita were the most promising varieties with respect to both yield component and quality traits.

Hemalatha *et al.* (1999) grown rice in a field trial with *Sesbania aculeata* or *Crotolaria juncea* incorporated as green manures before transplanting or was given farmyard manure or 50, 75 or 100% of the recommended N fertilizer rate with or without inoculation with *azospirillum* and found that grain quality (amylose and crude protein content) was greatest with *Sesbania aculeata* and 50% N + *Azospirillum*.

Souza *et al.* (1999) reported in a greenhouse pot trial, upland rice cv. IAC-47 was given foliar applications of a liquid fertilizer containing 32% N as 12.8% urea, 9.6% ammonium (NH_4) and 9.6% nitrate (NO_3) at rates corresponding to 0, 40, 80 or 120 kg N ha⁻¹, applied in equal splits at 10 and 20 days after anthesis. Nitrogen significantly increased grain crude protein content without decreasing grain weight, the greatest increase with 80 kg N. Application of 120 kg N ha⁻¹ increased the free amino N and a decrease in soluble sugar content.

Subbiah and Kumaraswamy (2000) observed the results of four field experiments conducted on a sandy clay loam soil in Tamil Nadu, India and showed that the quality parameters like protein content, bran oil content, total amylose content, hot water insoluble amylose content, percentage recovery and hardness in the rice grain improved under the treatment that received green manure plus N, P_2O_5 and K_2O at recommended levels plus gypsum at 500 kg ha⁻¹.

Upadhyay and Tripathi (2001) were applied different levels of fertilizers to 35 rice cultivars during 1992-93 to determine their effect on yield and crop quality and found that increase in fertilizer levels increased protein and mineral content, kernel and grain length while decreasing length: breadth ratio, water uptake and starch content. None of the fertilizer levels significantly increased crop quality, whereas genetic parameters of the cultivars improved crop quality significantly.

Khanna *et al.* (2002) studied impacts of pesticides in different concentrations with recommended fertility level of N_{100} P_{60} K_{30} in a long duration rice variety (Jaya) for amylose and protein content in a field experiment at R.S. Pusa, Jammu. Significant increase in the amylose content was observed due to nitrogen fertilizer and herbicides application compared to non-weedy check. Similarly protein content was also increased due to herbicide application compared to weeded checks.

Maeda *et al.* (2002) reported the effect of nitrogen fertilizer on the taste of rice with low amylose content (cv. Fu-line No.191) as compared with that of control rice (cv. Yumeakari). Both cultivars increased protein content after being fertilized at the spikelet growth stage.

Singh and Singh (2002) reported that the total nitrogen uptake, grain, straw and grain protein yields significantly improved with increasing levels of nitrogen and sulfur application being maximum at 150 kg N ha⁻¹ and 40 kg S ha⁻¹, respectively.

Tripathi and Tiwari (2002) revealed that nitrogen and phosphorus application tended to increase protein of rice grain.

Amjid *et al.* (2003) observed that the amino acid composition of rice cv. IR 9-60 as affected by different levels (30, 60 and 90 kg/ha) of nitrogen (as urea) studied in Peshawar, Pakistan. The grain yield and protein content significantly increased with increase in the level of nitrogen. Protein and carbohydrate production per unit area showed a similar trend. Higher levels (60 and 90 kg/ha) of nitrogen reduced the lysine content of grain, but the resulting protein still contained sufficient amount of all the essential amino acids to satisfy the adult human requirements.

Jadhav *et al.* (2003a) conducted a field experiment to determine the effect of N fertilizer on the yield and quality of rice Cv. Basmati-370 and found that N at 120 kg/ha have the highest grain yield, amylose content, head rice recovery and kernel length.

Premi and Kalia (2003) carried out a field experiment to investigate the effect of organic and inorganic sources of N on yield, yield attributes and quality of rice, cv. HPU-74 and found that dhaincha + 25% recommended N also enhanced the milling percentage and head rice recovery, amylose content and minimized the gelatination temperature.

Jin Jun *et al.* (2004) observed an increase in protein content in rice grain with increased level of nitrogen. **Shen Ming Xing *et al.* (2004)** reported that the

long term (20 year) NPK application significantly decreased the amylose content and increased the protein content of rice.

Panda and Srivastava (2004) reported that the treatment, 120 ppm N as enriched digested sludge (N enriched to 10%) with 30 ppm S as K_2SO_4 in split doses was observed best with respect to chlorophyll content (33.9 SPAD), dry matter content (96.38 g/pot), LAI (4.8), alkali value (4.5), amylose content (23.55%), protein content (7.20%) and yield of rice (grain yield = 66.3 g/pot & straw yield = 73.9 g/pot). A positive correlation was also observed between N and S application.

Leesawatwong *et al.* (2005) investigated the effects of N fertilization on grain N concentration, endosperm storage protein distribution and milling quality of rice. Applied N increased head rice N concentration in all cultivars whereas % unbroken rice was increased in KLG 1 and CNT1. KDML 105 cultivar, on the other hand already had high % unbroken rice and more abundant storage protein in the lateral region with the grain of low N concentration. Furthermore, N fertilization may enhance the nutritional quality of rice grain by increasing the glutelin content, which is rich in lysine.

Liu *et al.* (2005) evaluated the relationship between the application of N fertilizer at the middle growing stage and grain protein content and starch viscosity in rice. Results showed that grain protein content increased with increasing the amount of N applied and grain starch viscosity was significantly affected by the different nitrogen rates.

B. Effect of s on quality characteristics of rice

Stewart and Porter *et al.* (1969) reported that one part of sulphur was required for every 12-15 part of nitrogen to ensure maximum production of both maize dry matter and protein content of grains. **Singh and Singh (1970)** reported protein content in different rice varieties between 9 to 11 percent **Baba (1971)** reported that the protein content ranged from 6.56 to 12.86 percent when 90 kg of nitrogen per hectare was applied.

Verma *et al.* (1973) observed that the application of sulphur with NPK markedly increased the protein content of kernels.

Das *et al.* (1975) found that sulphur fertilization increased the grain yield of maize with no effect on protein content of the grains. Further they observed that the S application had a favourable effect on the content of essential and S-containing amino acids in the grains of maize, wheat and rice, thus maintaining and improving protein quality.

Pasricha and Randhawa (1975) reported that sulphur fertilization increased significantly the protein nitrogen in plant tissue. The data regarding sulphur application on alfalfa indicated that one part of sulphur required for every 11 to 12 parts of N to ensure maximum production of proteins (**Aulakh *et al.* 1976**).

Suzuki (1977) investigated that sulphur functions in to ways with respect to the assimilation of N in plant. Firstly, lack of sulphur retards the incorporation of ammonium into aminoacids especially into glutamic acid. Secondly, it supplies the metabolic decomposition of arginine whose N could be used for the formation of certain vital amino acids in the normal nutritive state of plants.**Kushwaha and Srivastava (1978)** reported that there was an increase in protein content of green gram fertilized with N, P and S. On alkaline calcareous soils of Rajasthan, sulphur treatment improved sugar content by 5-6 percent as compared to untreated plots (**Saroha and Singh, 1979**).

International Rice Research Institute (1979) surveyed the different Asian countries and found that Indian and Srilankan people referred the rice with 27.0 to 30.0 percent of amylose content.

Kamat *et al.* (1981) showed a significant effect of sulphur application on amino acid contents and reported that S-application increased cystine by 50% and methionine by 29 per cent in grain over control. Sulphur is associated with upto 34 percent increase in protein content and there was a significant relationship with S uptake and protein content (**Sagare and Bhalkar, 1986**).**Saraf (1988)** also reported that sulphur application increased not only

grain yield but also the protein content. Tiwari (1989) noted that 7 percent increase in grain protein content of black gram with the application of 60 kg S ha⁻¹.

Shukla (1992) applied N, P and K @ 120:60:60 kg ha⁻¹ and pyrite @ 600 kg/ha and found that grain protein tended to increase with increasing levels of fertilizer and pyrite whereas the chemical composition including amylose, total carbohydrate, tryptophan and lysine did show a proportional rise. In consonance of the general phenomenon while the protein content in the grain in the present set of experiments tended to increase with increasing levels of nitrogen, the lysine content declined at higher levels of production. The combination of pyrite @ 600 kg ha⁻¹ with NPK (120:60:60) gave the highest value of protein content. Although variation in total carbohydrate content of grain was observed but without any definite trend, pyrite (600 kg ha⁻¹) with NPK (120:60:60) resulted in significantly lower value of carbohydrates in the grain. Amylose in the grain also showed a similar trend.

Ram and Dwivedi (1992) reported that the protein content in black gram was significantly higher than the control due to sulphur application. Minimum protein content (20.18%) in the control and the maximum content of protein (22.62%) was recorded with the application of gypsum as a main source of sulphur.

Malarvizhi *et al.* (1993) conducted field experiments in Madurai, Tamil Nadu during the wet seasons of 1986-88 using rice cv. IR 20 on an Alfisol, non saline soil of pH 7.3; treatment combinations included recommended doses of NPK fertilizers (100:50:50 kg ha⁻¹) along with 3 sources of sulphur (gypsum, elemental sulphur or sulphur sludge) at 4 levels (25, 50, 75 or 100 kg S ha⁻¹). At a rate of 100 kg S ha⁻¹, available S in the soil was significantly increased from tillering to post harvest stage in both seasons. Application of sulphur resulted in an increase in plant protein content and S-containing amino acids with the application of sulphur sludge at 100 kg S ha⁻¹ resulting in an 83% increase in crude protein content when compared to the control.

Srikrishna (1995) observed that seed protein content and S-containing amino acids enhanced with 40 kg S ha⁻¹ and 5 kg Zn ha⁻¹ application in a field trial conducted at Kanpur. **Tripathi *et al.* (1997b)** also observed that S @ 40 kg ha⁻¹ and Zn @ 5 kg ha⁻¹ application had a significant positive effect on S-containing amino acids.

Mishra (1999) conducted a field trial in wheat on Kanpur soil with N and S application and reported that carbohydrate content in grain increased significantly with increasing levels of sulphur up to 40 Kg ha⁻¹. This increase was at par with lower level.

Sakal *et al.* (1999) evaluated the effect of sulphur on yield, N, P, K and S nutrition of crops in a field experiment under a rice-wheat system in a highly calcareous soil. The optimum level of sulphur for rice and wheat appeared to be at 40 and 60 kg S ha⁻¹, respectively. Protein content in rice and wheat grains was increased from 7.93 to 9.23 and 12.11 to 14.09%, respectively at their optimum S levels. Application of S enhanced the utilization of N, P, K and S by rice and wheat crops.

Wani *et al.* (2000) conducted a field experiment during kharif 1995 in Shalimar, Jammu and Kashmir, India, rice cv. K 39 was given 0, 10, 20, 30, 40 or 50 kg S/ha. Grain contents of crude protein, methionine, cysteine and cystine increased with increasing S rate upto 40 kg, then decreased slightly.

Chandel *et al.* (2003) conducted a field experiment at the Research Farm, BHU, Varanasi, during 1997-98 and 1998-99 to investigate the sulphur fertilizer effects on the quality of rice cv. Pant-12 with the application of four sulphur levels (0, 15, 30 and 45 kg/ha) and found that quality parameters viz. protein content in grain, protein yields and sulphur harvest index significantly influenced with increasing sulphur levels. Maximum values were obtained with the application of 15 kg S/ha.

C. Effect of Zinc on quality characteristics of rice

Youssef and Abdel-Rahman (1976) advocated the importance of zinc to beneficial effect on protein and starch quality of wheat grain.

Orabi and Abdel-Aziz (1982) reported that the application of Zn increased total carbohydrates, total proteins in the corn leaves as well as in the grains. **Ram and Murphy (1983)** reported that protein content of green gram increased significantly with increasing levels of Zn.

Krishnaveni (1983) suggested that lysine and tryptophan are the essential amino acids which are limiting factors for better quality of maize. He observed lysine content 0.34 to 4.34 per cent and tryptophan 0.46 to 1.0 per cent in different cultivars of maize. The content can be increased by the application of Zn.

Srinivasan and Natarajaratnam (1986) observed that the application of 12.5, 25 and 50 kg ZnSO₄ ha⁻¹ to 5 rice varieties grown on a Zn deficient soil increased starch content.

Keshwa and Jat (1992) studied the effect of Zn on pearl millet and reported that the content and yield of protein increased due to application of Zn.

Sahoo and Das (1992) observed the variability in concentration of reducing sugar, starch, protein and some trace elements (Zn, Fe, Mn and Cu) during development of different varieties of *boro* and *aman* seasons from panicle initiation to 35 days after flowering (DAF). In both seasons, reducing sugar content was changed in an irregular way while the amount of starch, total soluble protein and trace elements increased almost continuously from panicle initiation and reached maximum at 35 DAF. Accumulation of starch and trace elements was greater in *aman* season while the protein was higher in *boro* season in all the varieties.

Srikrishna (1995) observed that seed protein content and sulphur containing amino acids enhanced significantly with 40 kg S ha⁻¹ and 5 kg Zn ha⁻¹ application, in a field trial conducted at Kanpur.

Shi et al. (1996) conducted a field experiment where N (150 kg/ha), P (75 kg/ha), K (75 kg/ha), Si (75 kg/ha), Zn (22.5 kg/ha) and Mg (22.5 kg/ha) were applied singly or in combination to rice as basal fertilizer. Combined application of Si, Zn and Mg facilitated the uptake of N, K, Zn and Mg by the plants and

their transportation to the developing grains, increased protein content of the grain and helped the accumulation of starch in the seed, influencing, therefore, the yield and quality of the crop positively.

Chen and Fan (1997) applied Zn @ 0 or 5 kg/ha and P @ 60, 150 or 200 kg ha⁻¹ respectively in rice cultivars Xunza 29, Hexi 35 and Yungung 34 and reported that grain protein contents were increased by P application and amylose contents of milled rice were increased by Zn application.

Tripathi *et al.* (1997b) conducted a field trial on a Typic Ustochrept in U.P. on chickpea and reported that application of sulphur and zinc had significant positive effect on protein content. This increase was upto 40 kg Sha⁻¹ and 5 kg Zn ha⁻¹.

Fecencko and Lozek (1998) reported that crude protein content of maize grain was increased by 0.9 to 1.1 per cent due to 1.5 to 3.0 kg Zn ha⁻¹ application.

Panda and Sahu (1999) applied Zn levels of 50, 200 or 400 mg kg⁻¹ to rice cv. Kalinga. Contents of chlorophyll a and b, caroteniod, sugar, amino acids and protein and yields and biomass production increased with 50 mg kg⁻¹ Zn compared with the control but decreased at higher concentrations.

Triapthi and Tripathi (2004) found that the rice recovery, protein content, net return, benefit:cost ratio were maximum at 25 kg ZnSO₄ha⁻¹ in nursery treatment, whereas these parameters significantly increased with increasing levels of ZnSO₄ upto 30 kg/ha.

Khan *et.al.* (2004) conducted a pot culture study to evaluate the effect of different levels of Zn on the Zn content of leaf, soil, roots and starch content of rice. Zn as ZnSO₄ was applied at 0, 5, 10 and 15 kg ha⁻¹ along with the basal rates of 120 kg N, 90 kg P₂O₅ and 60 kg K₂O ha⁻¹. There was no effect of Zn on starch content in rice.

**MATERIAL
AND
METHODS**

Investigations were carried out to study the effect of nitrogen, sulphur and zinc on growth, yield and nutrient content, uptake and quality of rice (*Oryza sativa* L.). The climatic and edaphic conditions under which the present investigation was carried out, materials used and methods adopted are described here as under:

3.1 SITE OF EXPERIMENT

To carry out the present investigation, a field experiment was conducted at 'Fertilizer Research Station, Uttari-Pura, C.S.A. University of Agriculture and Technology, Kanpur during *Kharif* seasons of 2003 and 2004. In both the years, the experiment was laid out in different fields to avoid residual effects. Cultural operations adopted before transplanting of rice were similar during both the years of experimentation.

3.2 GEOGRAPHY AND CLIMATE

Geographically, the district Kanpur is a part of the tract known as the lower Doab located between river Ganga and Yamuna lying between parallels of 25°26' and 26°28' North latitude and 79°31' and 80°34' East longitude at an elevation of 125.9 meters from mean sea level in Gangetic alluvium of Central Uttar Pradesh.

The climate is subtropical, semi-arid with hot dry summer and severe cold winter. The average annual rainfall during 2003 was high as compared to the average of 2004. The distribution of rainfall was erratic during entire span of the year. Most of the rains are received from the last week of June to middle of September. April, May and June are the most dry months, while July, August and September are wettest months. The meteorological observations during the

experimental seasons of 2003 and 2004 in which the experiments were conducted are given in Table 3.1 and depicted in Fig 3.1.

Table 3.1 Meteorological observations during kharif seasons of investigation

Months	Rainfall (mm)	Atmospheric temp. ($^{\circ}\text{C}$)		Relative humidity (%)	Wind velocity (km hr $^{-1}$)
		Maximum	Minimum		
2003					
June	50.4	39.1	26.6	58.6	6.3
July	334.0	33.8	24.7	79.2	5.6
August	129.2	32.6	25.0	80.8	3.0
September	453.6	30.9	23.4	86.0	2.3
October	00.0	31.9	16.9	68.4	1.6
November	00.0	28.2	10.2	67.6	1.8
2004					
June	119.2	36.3	26.4	66.5	9.3
July	275.0	34.1	26.4	75.8	7.2
August	98.0	33.2	26.2	83.3	7.8
September	203.0	33.8	25.0	78.2	4.6
October	23.0	31.6	19.4	73.5	3.0
November	00.0	28.9	12.9	70.1	2.2

3.3 SOIL OF THE EXPERIMENTAL FIELD

Surface soil samples (0-0.15 m) were initially drawn out from randomly selected parts of the field before transplanting with the help of *Khurpi* and a composite sample was obtained by mixing them thoroughly. The quantity of soil sample was reduced to about one kg through quartering technique. The soil sample was then subjected to mechanical and chemical analyses in order to determine the textural class and fertility status. The representative sample so drawn was dried and made free from inert and foreign materials by passing through 2 mm standard sieve before analysis. The important physio-chemical characteristics were determined which are presented in Table 3.2.

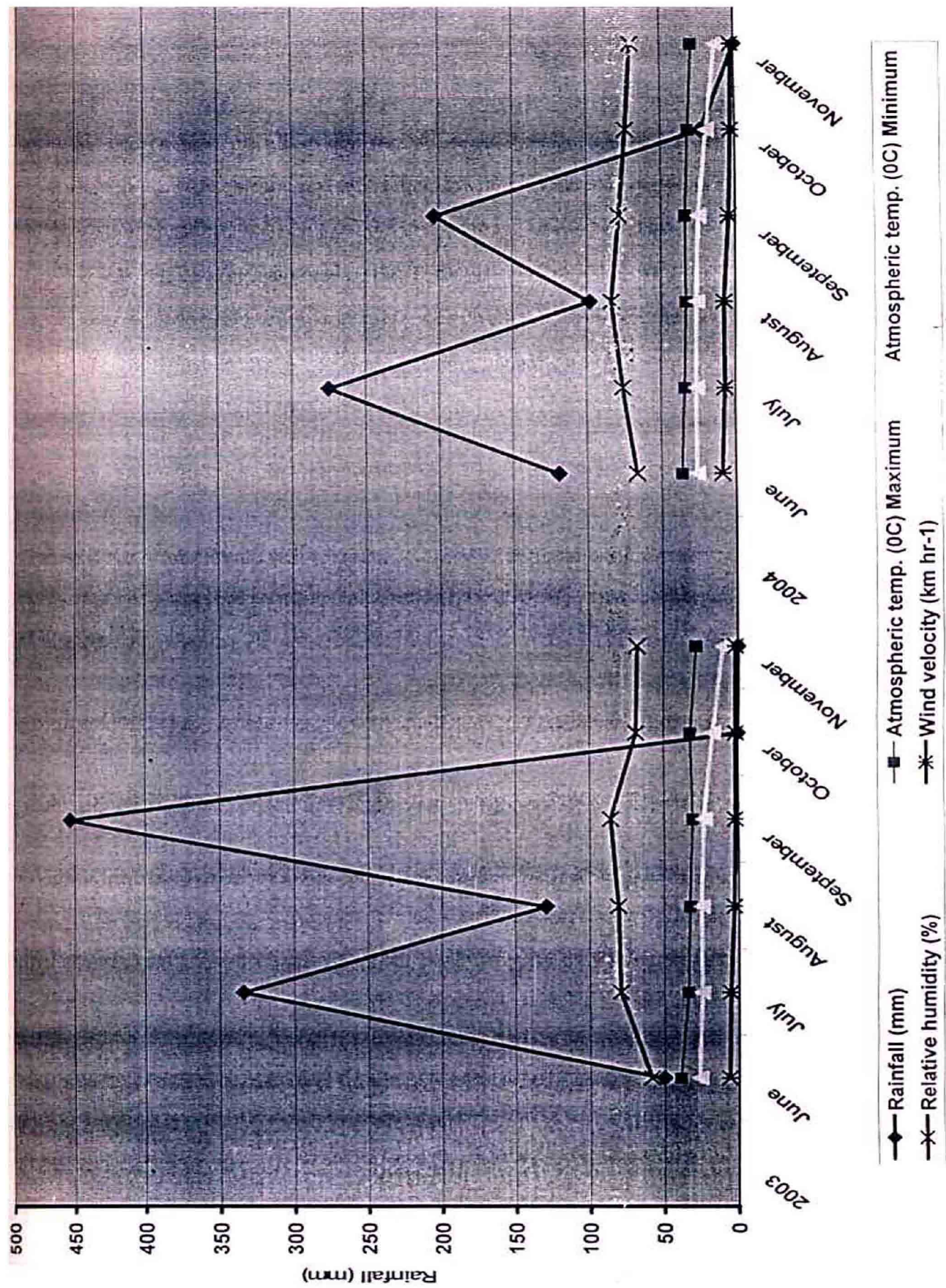


Fig 3.1: Meteorological observations during *kharif* periods of 2003 & 2004

Table 3.2: Physico-chemical characteristics of soils of experimental field

Characteristics	2003	2004
(A) Mechanical analysis		
Sand (%)	59.24	58.85
Silt (%)	21.10	21.31
Clay (%)	19.64	19.20
Texture	Sandy loam	Sandy loam
(B) Physico-chemical properties		
pH	7.9	7.8
EC (dSm ⁻¹)	0.32	0.30
Organic carbon	4.9 g kg ⁻¹	5.1 g kg ⁻¹
Cation exchange capacity [Cmol (p ⁺) kg ⁻¹]	12.60	12.50
Total N (%)	0.047	0.049
Available N (kg ha ⁻¹)	190.0	194.0
Available P (kg ha ⁻¹)	9.90	9.70
Available K ₂ O (kg ha ⁻¹)	170.2	168.8
Available S (kg ha ⁻¹)	8.70	8.60
Available Zn (mg kg ⁻¹)	0.48	0.46

3.4 DETAILS OF EXPERIMENT

The experiment was laid out in Factorial Randomized Block Design with 3 replications. Three levels of each of nitrogen and sulphur and two levels of zinc were tested as follows:

Levels of Nutrients	Notation
Levels of Nitrogen	
60 kg N ha ⁻¹	N ₁
120 kg N ha ⁻¹	N ₂
180 kg N ha ⁻¹	N ₃
Levels of Sulphur	
20 kg S ha ⁻¹	S ₁
40 kg S ha ⁻¹	S ₂
60 kg S ha ⁻¹	S ₃
Levels of Zinc	
5 kg Zn ha ⁻¹	Zn ₁
10 kg Zn ha ⁻¹	Zn ₂
Absolute control- without N, P, K, S & Zn	Absolute control

Treatment combinations	3 x 3 x 2 = 18 + 1 (Absolute control) = 19
1. N ₁ S ₁ Zn ₁	= T ₁
2. N ₁ S ₂ Zn ₁	= T ₂
3. N ₁ S ₃ Zn ₁	= T ₃
4. N ₂ S ₁ Zn ₁	= T ₄
5. N ₂ S ₂ Zn ₁	= T ₅
6. N ₂ S ₃ Zn ₁	= T ₆
7. N ₃ S ₁ Zn ₁	= T ₇
8. N ₃ S ₂ Zn ₁	= T ₈
9. N ₃ S ₃ Zn ₁	= T ₉
10. N ₁ S ₁ Zn ₂	= T ₁₀
11. N ₁ S ₂ Zn ₂	= T ₁₁
12. N ₁ S ₃ Zn ₂	= T ₁₂
13. N ₂ S ₁ Zn ₂	= T ₁₃
14. N ₂ S ₂ Zn ₂	= T ₁₄
15. N ₂ S ₃ Zn ₂	= T ₁₅
16. N ₃ S ₁ Zn ₂	= T ₁₆
17. N ₃ S ₂ Zn ₂	= T ₁₇
18. N ₃ S ₃ Zn ₂	= T ₁₈
19. Absolute control	= T ₁₉

Design	- Factorial- Randomized Block Design (Factorial RBD)
Replications	- 3
Gross plot size	- 5 x 4 M = 20 m ²
Net plot size	- 4.4 x 3.4 = 14.96 m ²
Crop	- Rice [(Cv. Vijeta) – MTU-1001]
Line to line and plant to plant distance	- 20 x 15 (cm)
Duration	- Kharif (2003 and 2004)

3.5 Layout plan

Layout plan of the experiment is presented in Fig. 3.2.

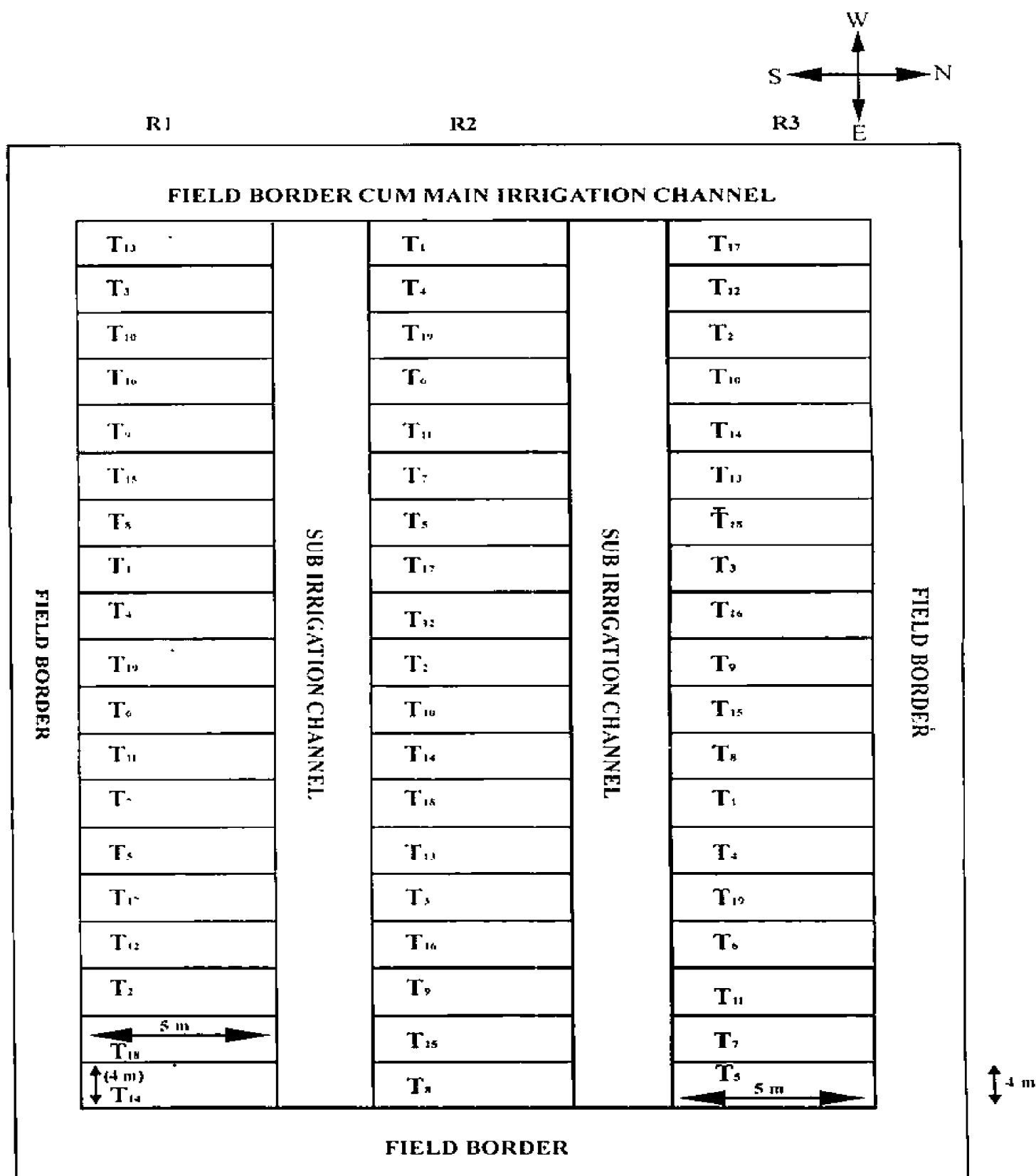


Fig 3.2: Layout plan of field experiment

3.6 DETAILS OF OPERATION AND OBSERVATIONS IN RICE CROP

3.6.1 Selection of variety

Rice (*Oryza sativa* L.) variety 'Vijeta' (MTU-1001) was selected for the investigation . It is a high yielding variety. Seed of this variety was obtained from the Department of Genetics and Plant Breeding, C.S.Azad University of Agriculture and Technology, Kanpur.

3.6.2 Land preparation

The experimental field was ploughed once with soil turning plough just after harvest of previous Rabi crop. In first week of June, irrigation was applied and at proper soil moisture, field was ploughed with tractor drawn disc harrow followed by planking. Layout was done by marking plots in which sulphur and zinc fertilizers were applied as per treatments by broad casting. The field was again ploughed with disc harrow and left. At the time of transplanting, the field was watered by tubewell and ploughed twice with cultivator. Sufficient planking was done to bring proper puddling condition. After it, permanent layout was done by making ridges between plots. Irrigation channels etc. were also formed as given in Fig. 3.2.

3.6.3 Application of fertilizers

Rice crop was fertilized as per treatments. The sources of N, P, K, S and Zn used were urea, DAP, MOP, elemental sulphur and zinc oxide, respectively. Half of the N dose and full doses of P, K, S & Zn as per treatment were broadcasted uniformly in respective plots. After 24 hours of fertilizer application, watering was done in all plots for transplanting. Remaining half dose of N was applied in two equal splits at tillering and panicle initiation stages as per treatments. The actual amount of fertilizers of different treatment plots was weighed separately before application.

3.6.4 Transplanting

The nursery area was given a light irrigation before uprooting the seedlings at 25 days of sowing. Transplanting was done by manual labour using two seedlings per hill at the spacing of 20 x 15 cm on 15th, July and 12th, July during 1st and 2nd year, respectively.

3.6.5 Interculture and irrigation

The weeds were removed with the help of manual labour at 25th and 50th day of transplanting. Irrigations were applied as and when required.

3.6.7 Harvesting and Threshing

Harvesting of experimental rice crop was done at complete maturity on 28th and 26th November during 2003 and 2004, respectively. First, plot borders were harvested, separated by removing two rows from each side and three hills at both the ends of gross plots. Then net plots were harvested and left for sun drying in respective plots. After proper sun drying, the produce of individual net plot was tied in bundles and weighed for biological yield record. Weighed material of each net plot was threshed out by manual labour separately. Grain produce of each net plot was cleaned and weighed for grain yield record.

3.7 BIOMETRIC OBSERVATIONS

For recording biometric observations such as plant height, number of tillers, number of green leaves and dry matter production for both the years, five plants were randomly selected and tagged. However, for recording dry matter production, samples were randomly selected for each plot at 30th and 60th day of transplanting of crop. Plants were carefully dugout with a ball of soil along with roots. The root portion was washed out with tap water completely and roots were cut by scissors and whole plant was washed with demineralized water before putting in oven for drying.

3.7.1 Pre-harvest observations

1. Plant Height

Plant height (cm) was measured from the selected five tagged hill in each plot from ground level to top of the terminal leaf at 30th and 60th day of transplanting and at maturity of crop (before harvesting) and recorded the average value during both the years of study.

2. Number of tillers hill⁻¹

The number of tillers hill⁻¹ were counted in five tagged plants in each plot at 30th and 60th day of transplanting for both the years and their average was reported.

3. Biomass Accumulation

Five plants were selected randomly from each plot in both the years at 30th and 60th day of transplanting and were brought to the laboratory. The plant samples were cut into pieces and were dried in oven for 48 hours at 105^oC and then their dry weight were recorded.

4. Number of green leaves hill⁻¹

The number of green leaves were counted in five tagged hills for both the years at 30th and 60th day of transplanting and their average was reported.

3.7.2 Post harvest observations

1. No. of productive tillers m⁻²

The number of productive tillers were counted in one sq.m. area at three places in each plot and average value was reported for both the years.

2. No. of panicles hill⁻¹

The number of panicles hill⁻¹ were counted in five tagged hill in each plot and their average was reported for both the years.

3. Total number of spikelets hill⁻¹

The total number of spikelets (filled and unfilled) were also counted in five tagged hills in each plot and their average value was reported for both the years.

4. Number of filled grains panicle⁻¹

Number of filled grains panicle⁻¹ were counted in five tagged hills in each plot and their average was reported for both the years.

5. Weight of panicle (g)

The weight of a single panicle was recorded by weighing the total number of panicles in each hill (five tagged hills of each plot) divided by number of panicles hill⁻¹ and average value was reported for both the years.

6. Test weight of grains (g)

1000-grains from each plot were counted, weighed and reported as test weight (g) in both the years.

7. Grain and straw yield (qha⁻¹)

Crop was harvested when matured and bundle weight were recorded. Grains were separated plot wise and weighed and straw yield was computed after deducting grain weight from bundle weight during both the years and thus converted into tha⁻¹ by using a suitable conversion factor.

3.8 ANALYTICAL METHODS

(A) SOIL ANALYSIS

Mechanical analysis

Mechanical components of soil were determined by International Pipette Method as described by Piper (1966).

pH

It was measured in 1:2.5 soil water suspension by Elico-digital pH meter.

Electrical Conductivity

It was measured in the same soil-water suspension of which pH was determined and determined by conductivity meter (Jackson, 1973).

Cation Exchange Capacity

It was determined by neutral N-NH₄OAC method as described by Piper (1966).

Organic Carbon

It was determined by Walkley and Black's (1934) rapid titration methods as described by Jackson (1973).

Available nitrogen

It was determined by alkaline permanganate method as described by Subbiah and Asija (1956).

Available phosphorus

It was determined colorimetrically after extracting the soil with 0.5 M NaHCO₃ (pH 8.5) extractant as described by Olsen *et al.* (1954).

Available potassium

It was extracted with neutral N-NH₄OAC solution and was determined flame photometrically as explained by Jackson (1973).

Available sulphur

It was extracted by using 0.15 percent CaCl₂ (Williams and Steinbergs, 1959) and was determined by turbidimetric procedure (Chesnin and Yien, 1951).

Available zinc

Available zinc was extracted by DTPA solution (Lindsay and Norvell, 1978) and determined by Atomic Absorption Spectrophotometer (ECIL).

(B) PLANT ANALYSIS

The following methods were employed to analyse the plant samples:

Nitrogen

It was determined by Micro-Kjeldahl method (A.O.A.C. 1965).

Phosphorus

Ground plant samples were digested in a diacid mixture of HNO_3 and HClO_4 (4:1) and transferred to a 250 ml volumetric flask with the help of distilled water. The volume was made upto the mark and mixed well. The P was determined colorimetrically with the help of suitable aliquot by Vanado molybdo-phosphoric yellow colour method as described by Chapman and Pratt (1961).

Potassium

Potassium concentration in the diacid digest was determined flame photometrically as per procedure explained by Jackson (1973).

Sulphur

Total sulphur in the digest was determined turbidimetrically as described by Chaudhary and Cornfield (1966).

Zinc

Total zinc concentration in the same digest of plant samples was estimated with the help of Atomic Absorption Spectrophotometer (ECIL).

3.9 QUALITY PARAMETERS

3.9.1 Protein content

Total nitrogen in grain samples was determined by Micro-Kjeldahl method (AOAC, 1965) and grain protein content was calculated by multiplying the values with the factor 5.95 (dehusked) and 6.25 for straw protein content (Nicholos and Nason, 1957).

3.9.2 Starch content

Starch was estimated from oven dried finely ground flour, after removing the soluble sugars by extracting with hot 70 per cent ethanol according to the method described by Clegg (1956).

3.9.3 Amylose content

It was estimated according to the method described by Williams *et al.* (1970).

3.10 Statistical analysis

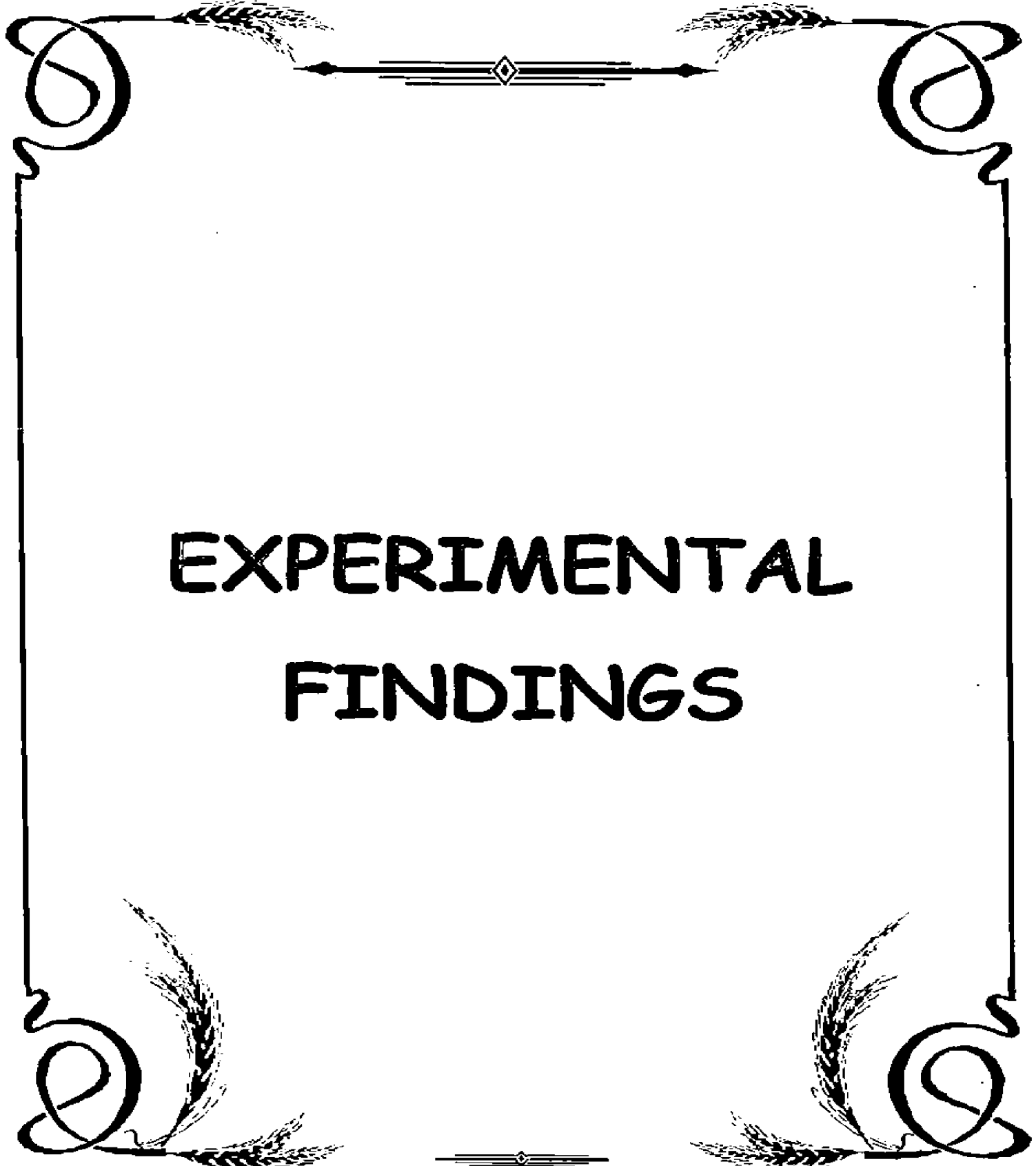
For determining the significant differences caused by different treatments, data were subjected to statistical analysis and significant response at 5 per cent level have been computed for whereas necessary critical differences have been worked out for comparison of mean values for various treatments and their effects. Standard error and critical difference values were calculated by the method suggested by Fisher (1937) as under:

$$\text{S.E. (diff.)} = \sqrt{\frac{2V_E}{r}}$$

$$\text{C.D. at 5\%} = \text{S.E. (diff.)} \times t (0.05 \text{ d.f.})$$

ANOVA FOR EXPERIMENTAL DESIGN

Source of variance	d.f.	S.S.	M.S.S.	F table	
				5%	1%
Replication	2				
N	2				
S	2				
N x S	4				
Zn	1				
N x Zn	2				
S x Zn	2				
N x S x Zn	4				
Absolute Control/treatments	1				
Error	36				
Total	56				



EXPERIMENTAL FINDINGS

EXPERIMENTAL FINDINGS

The present investigation entitled, “Studies on Nitrogen, Sulphur and Zinc nutrition in Rice” was planned and conducted during *Kharif* seasons of 2003 and 2004. An attempt was made to ascertain the degree of variation exhibited by rice during different stages of growth and development due to different levels of the application of nitrogen, sulphur and zinc. Observations were recorded on content and uptake of NPK, S & Zn at 30th and 60th day of transplanting and at maturity of crop and their uptakes in grain and straw of rice and also for quality characteristics of rice viz., protein, amylose and starch contents. Data on different characters during the experimentation were analysed statistically to derive some valid conclusions. The plant samples collected at various growth stages as well as at harvest of the crop were chemically analysed for N, P, K, S and Zn contents and their uptake by rice crop was also computed for during both the years.

4.1 EFFECT OF LEVELS OF NITROGEN, SULPHUR AND ZINC ON GROWTH, YIELD ATTRIBUTES AND YIELD OF RICE

4.1.1 Growth Characters

The data on growth characteristics viz., plant height (cm), number of tillers hill⁻¹, number of green leaves hill⁻¹ and biomass accumulation (g hill⁻¹) at 30th and 60th day of transplanting during both the years are presented in Tables from 4.10 to 4.17, respectively.

4.1.1.1 Height of Plants (cm)

The data in respect of height of plants recorded at 30th and 60th day of transplanting are presented in Tables 4.10 and 4.11, respectively. The data on plant height of rice during 2003 and 2004 as influenced by different levels of nitrogen, sulphur and zinc revealed that plant height increased significantly with increasing levels of nitrogen upto 180 Kg N ha⁻¹. However, the lowest height was recorded with the absolute control during both the

years. Sulphur application influenced the plant height upto 40 Kg Sha^{-1} during both the years. Likewise, application of zinc also influenced plant height significantly upto 5 Kg Zn ha^{-1} in comparison to absolute control during both the years, respectively.

4.1.1.1.1 Plant Height at 30th Day of Transplanting

Plant height increased significantly with increasing levels of nitrogen upto 180 kg Nha^{-1} . The maximum height was recorded as 60.12 and 60.89 cm at N_3 level and minimum as 37.32 and 38.41 cm with absolute control during 2003 and 2004, respectively. Plant height was influenced by sulphur application significantly upto 40 kg S ha^{-1} recording 56.72 and 57.54 cm during 2003 and 2004, respectively. However, plant height was noticed at par with 40 and 60 kg Sha^{-1} . Application of zinc also influenced plant height significantly upto 5 kg Zn ha^{-1} as against absolute control. The plant height recorded at 10 kg Zn ha^{-1} did not cross the level of significance over 5 kg Zn ha^{-1} .

However, interaction effects of $\text{N} \times \text{S}$, $\text{S} \times \text{Zn}$, $\text{N} \times \text{Zn}$ and $\text{N} \times \text{S} \times \text{Zn}$ during both the years were observed to be non-significant but maximum height of plants was recorded at $\text{N}_3\text{S}_3\text{Zn}_2$ level during both the years.

4.1.1.1.2 Plant Height at 60th Day of Transplanting

Plant height at 60th day of transplanting increased significantly with increasing levels of nitrogen upto 180 kg N ha^{-1} recording the minimum height with absolute control during both the years, respectively. Plant height was also influenced by the application of sulphur significantly upto 40 kg S ha^{-1} and thereafter it did not increase significantly. Zinc also influenced plant height significantly upto 5 kg Zn ha^{-1} during both the years but it was recorded at par as compared to 10 kg Zn ha^{-1} .

However, interaction effects of $\text{N} \times \text{S}$, $\text{N} \times \text{Zn}$, $\text{S} \times \text{Zn}$ and $\text{N} \times \text{S} \times \text{Zn}$ have been recorded to be non-significant but maximum height was recorded at $\text{N}_3\text{S}_3\text{Zn}_2$ level during both the years of experimentation.

Table 4.10: Effect of N, S and Zn on plant height (cm) of rice at 30th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	47.40	50.60	50.65	49.55	48.30	51.47	51.50	50.42
	Zn ₂	47.80	50.92	50.97	49.89	48.70	51.84	51.90	50.81
Mean		47.60	50.76	50.81	49.72	48.50	51.65	51.70	50.61
N ₂	Zn ₁	55.30	58.20	58.25	57.25	56.14	59.02	59.08	58.08
	Zn ₂	55.66	58.52	58.65	57.60	56.51	59.37	59.40	58.42
Mean		55.47	58.36	58.45	57.42	56.32	59.19	59.24	58.25
N ₃	Zn ₁	58.10	60.90	60.94	59.98	58.90	61.67	61.71	60.76
	Zn ₂	58.40	61.18	61.25	60.27	59.20	61.92	61.95	61.02
Mean		58.25	61.04	61.09	60.12	59.05	61.79	61.83	60.89
Mean of the means		53.77	56.72	56.78	55.76	54.62	57.54	57.59	56.58
Absolute Control					37.32				38.41

N	SE (diff.)	1.30	CD (5%)	2.63	SE (diff.)	1.29	CD (5%)	2.61
S	1.30	2.63	1.29	2.61				
Zn	1.04	2.10	1.03	2.09				
N x S	2.23	N.S.	2.21	N.S.				
S x Zn	1.82	N.S.	1.80	N.S.				
N x Zn	1.82	N.S.	1.80	N.S.				
N x S x Zn	3.17	N.S.	3.14	N.S.				
Absolute	2.28	4.63	2.27	4.60				
Control/Treatments								

Table 4.11: Effect of N, S and Zn on plant height (cm) of rice at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	72.12	75.44	75.55	74.37	73.42	76.69	76.75	75.62
	Zn ₂	73.02	76.29	76.35	75.22	74.22	77.44	77.49	76.38
Mean		72.57	75.86	75.95	74.79	73.82	77.06	77.12	76.00
N ₂	Zn ₁	79.32	82.42	82.47	81.40	80.57	83.62	83.72	82.63
	Zn ₂	80.17	83.22	83.28	82.22	81.32	84.32	84.37	83.33
Mean		79.74	82.82	82.87	81.81	80.94	83.97	84.04	82.98
N ₃	Zn ₁	82.08	85.08	85.10	84.08	83.28	86.13	86.20	85.20
	Zn ₂	82.88	85.73	85.80	84.80	83.98	86.78	86.81	85.85
Mean		82.48	85.40	85.45	84.44	83.63	86.45	86.50	85.53
Mean of the means		78.26	81.36	81.42	80.35	79.46	82.49	82.56	81.50
Absolute Control					61.02				62.42

N	SE (diff.)	1.30	CD (5%)	2.63	SE (diff.)	1.25	CD (5%)	2.53
S	1.30	2.63		1.25	2.53			
Zn	1.04	2.10		1.00	2.02			
N x S	2.23	N.S.		2.17	N.S.			
S x Zn	1.82	N.S.		1.78	N.S.			
N x Zn	1.82	N.S.		1.78	N.S.			
N x S x Zn	3.17	N.S.		3.05	N.S.			
Absolute Control/Treatments	2.28	4.63		2.20	4.46			

4.1.1.2. Number of Tillers hill⁻¹

The data on the number of tillers hill⁻¹ as affected by different rates of nitrogen, sulphur and zinc application are presented in Tables 4.12 and 4.13 at 30th and 60th day of transplanting, respectively.

4.1.1.2.1 30th Day of Transplanting

The data presented in Table 4.12 reveal that application of graded doses of nitrogen increased number of tillers hill⁻¹ significantly upto 180 kg N ha⁻¹ recording the maximum number of tillers as 8.35 and 8.58 hill⁻¹ during 2003 and 2004, respectively. However, minimum number was noticed with the absolute control during both the years of investigation. Similarly, application of sulphur increased significantly the number of tillers hill⁻¹ upto 40 kg S/ha whereas zinc dressings increased number of tillers hill⁻¹ upto 5 kg Zn ha⁻¹ during both the years, respectively and thereafter non-significant increases were recorded upto 60 kg S and 10 kg Znha⁻¹ application during both the years. Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were recorded to be non-significant on number of tillers during both the years of study.

4.1.1.2.2 60th Day of Transplanting

It is obvious from the data presented in Table 4.13 that application of nitrogen significantly affected the number of tillers upto its highest level of application i.e. 180 kg Nha⁻¹ resulting into maximum number of tillers hill⁻¹ (13.73 and 13.80) during 2003 and 2004, respectively. The minimum number was noted with absolute control during both the years, respectively. Application of sulphur also influenced significantly the number of tillers hill⁻¹ upto 40 kg S/ha and it was recorded as 12.62 and 12.73 tillers hill⁻¹ during 2003 and 2004, respectively. Thereafter, a non-significant increase was recorded upto 60 kg S/ha on number of tillers (hill⁻¹) during both the years. Similarly, application of zinc influenced the number of tillers hill⁻¹ significantly upto 5 kg Zn ha⁻¹, and thereafter, the increase was noticed to be non-significant upto 10 kg Zn/ha during both the years of experimentation.

Table 4.12: Effect of N, S and Zn on number of tillers hill⁻¹ at 30th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	5.37	6.47	6.50	6.11	5.69	6.78	6.81	6.42
	Zn ₂	5.62	6.69	6.73	6.34	5.94	7.00	7.04	6.66
Mean		5.49	6.68	6.61	6.23	5.81	6.89	6.92	6.54
N ₂	Zn ₁	6.75	7.65	7.72	7.37	7.07	7.96	7.99	7.67
	Zn ₂	7.00	7.87	7.90	7.59	7.32	8.18	8.20	7.90
Mean		6.87	7.76	7.81	7.48	7.19	8.07	8.09	7.78
N ₃	Zn ₁	7.65	8.60	8.63	8.29	7.87	8.76	8.80	8.47
	Zn ₂	7.80	8.70	8.73	8.41	8.10	8.96	8.99	8.68
Mean		7.72	8.65	8.68	8.35	7.98	8.86	8.89	8.58
Mean of the means		6.69	7.66	7.70	7.35	6.99	7.94	7.97	7.63
Absolute Control					3.22				3.51

N	SE (diff.)	0.42	CD (5%)	0.85	SE (diff.)	0.38	CD (5%)	0.77
S		0.42		0.85		0.38		0.77
Zn		0.33		0.68		0.30		0.60
N x S		0.72		N.S.		0.65		N.S.
S x Zn		0.56		N.S.		0.53		N.S.
N x Zn		0.56		N.S.		0.53		N.S.
N x S x Zn		1.02		N.S.		0.92		N.S.
Absolute Control/Treatments		0.73		1.49		0.66		1.33

Table 4.13: Effect of N, S and Zn on number of tillers hill⁻¹ at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	9.63	10.54	10.57	10.24	9.80	10.70	10.73	10.41
	Zn ₂	9.93	10.86	10.87	10.55	10.08	10.96	10.98	10.67
Mean		9.78	10.70	10.72	10.40	9.94	10.83	10.85	10.54
N ₂	Zn ₁	11.70	12.90	12.95	12.51	11.92	13.12	13.17	12.73
	Zn ₂	12.01	13.25	13.25	12.83	12.20	13.32	13.33	12.95
Mean		11.85	13.07	13.10	12.67	12.06	13.22	13.25	12.84
N ₃	Zn ₁	12.80	13.97	13.99	13.68	12.97	14.05	14.09	13.70
	Zn ₂	13.15	14.25	14.27	13.89	13.22	14.25	14.27	13.91
Mean		12.97	14.11	14.13	13.73	13.09	14.15	14.18	13.80
Mean of the means		11.53	12.62	12.65	12.27	11.69	12.73	12.76	12.39
Absolute Control					6.22				6.42

N	SE (diff.)	0.51	CD (5%)	1.03	SE (diff.)	0.47	CD (5%)	0.95
S	0.51	1.03	0.47	0.95				
Zn	0.40	0.82	0.37	0.75				
N x S	0.87	N.S.	0.80	N.S.				
S x Zn	0.71	N.S.	0.65	N.S.				
N x Zn	0.71	N.S.	0.65	N.S.				
N x S x Zn	1.24	N.S.	1.14	N.S.				
Absolute	0.89	1.82	0.82	1.67				
Control/Treatments								

Interaction effects of N x S, S x Zn, N x Zn, and N x S x Zn were noticed to be non-significant during both the years of investigation.

4.1.1.3 Number of Green Leaves hill⁻¹

The data recorded on the number of green leaves hill⁻¹ as affected by different rates of application of nitrogen, sulphur and zinc are presented in Tables 4.14 and 4.15 at 30th and 60th day of transplanting, respectively.

4.1.1.3.1 30th Day of Transplanting

Data presented in Table 4.14 reveal that number of green leaves hill⁻¹ increased significantly with increasing levels of N upto 180 kg N ha⁻¹ noting down the maximum number of green leaves hill⁻¹ as 52.84 and 54.34 during 2003 and 2004, respectively. However, the lowest values were recorded at absolute control. Similarly, graded levels of sulphur significantly increased number of green leaves upto 40 kg S/ha recording 49.65 and 51.15 hill⁻¹ during 2003 and 2004, respectively and thereafter the increase was not significant. Zinc dressings also increased the number of green leaves upto 5 kg Zn ha⁻¹ but increase in no. of green leaves at 10 kg Zn ha⁻¹ was observed to be non-significant during both the years.

Interactions effects of N x S, S x Zn, N x Zn and N x S x Zn were recorded to be non significant in respect of number of green leaves hill⁻¹ although the maximum number of green leaves were noted at N₃S₃Zn₂ level during both the years of experimentation.

4.1.1.3.2 60th Day of transplanting

Data presented in Table 4.15 clearly reveal that the effects of N, S and Zn on number of green leaves hill⁻¹ were similar as recorded on 30th day of transplanting during both the years. Effect of nitrogen show that the number of green leaves increased significantly upto 180 kg N ha⁻¹ (80.76 and 83.33) during both the years. The minimum values were recorded with the absolute control. Sulphur application also enhanced number of green leaves significantly upto 40 kg S ha⁻¹ during both the years. The zinc dressings

Table 4.14: Effect of N, S and Zn on number of green leaves hill⁻¹ in rice at 30th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	40.14	43.80	43.85	42.59	41.64	45.30	45.35	44.09
	Zn ₂	40.54	44.15	44.19	42.96	42.04	45.65	45.70	44.46
Mean		40.34	43.97	44.02	42.77	41.84	45.47	45.52	44.28
N ₂	Zn ₁	47.49	50.97	50.99	49.81	49.03	52.47	52.50	51.33
	Zn ₂	47.88	51.27	51.31	50.15	49.38	52.77	52.81	51.65
Mean		47.68	51.12	51.15	49.98	49.20	52.62	52.65	51.49
N ₃	Zn ₁	50.65	53.73	53.79	52.72	52.15	55.23	55.27	54.21
	Zn ₂	50.95	53.98	53.99	52.97	52.45	55.48	55.49	54.47
Mean		50.80	53.85	53.89	52.84	52.30	55.35	55.38	54.34
Mean of the means		46.27	49.65	49.69	48.53	47.78	51.15	51.19	50.03
Absolute Control					25.63				27.12

N	SE (diff.)	1.41	CD (5%)	2.85	SE (diff.)	1.40	CD (5%)	2.83
S	1.41	2.85	1.40	2.83				
Zn	1.15	2.33	1.14	2.31				
N x S	2.47	N.S.	2.46	N.S.				
S x Zn	1.98	N.S.	1.98	N.S.				
N x Zn	1.98	N.S.	1.98	N.S.				
N x S x Zn	3.45	N.S.	3.44	N.S.				
Absolute	2.53	5.13	2.53	5.13				

Table 4.15: Effect of N, S and Zn on number of green leaves hill⁻¹ in rice at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	57.42	63.63	63.64	61.56	60.02	65.84	66.84	64.26
	Zn ₂	58.32	64.19	64.24	62.25	60.92	66.69	66.94	64.81
Mean		57.87	63.91	63.94	61.90	60.47	66.26	66.89	64.54
N ₂	Zn ₁	71.54	77.23	77.28	75.35	74.12	79.83	79.92	77.95
	Zn ₂	72.37	78.03	78.07	76.15	74.97	80.63	80.67	78.75
Mean		71.95	77.63	77.67	75.75	74.54	80.23	80.29	78.35
N ₃	Zn ₁	76.92	82.30	82.30	80.50	79.42	84.70	84.72	82.94
	Zn ₂	77.72	82.65	82.68	81.01	80.22	85.45	85.47	83.71
Mean		77.32	82.47	82.49	80.76	79.82	85.07	85.09	83.33
Mean of the means		69.04	74.67	74.70	72.80	71.61	77.19	77.42	75.40
Absolute Control					39.50				41.60

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	2.42	4.90	2.39	4.84
S	2.42	4.90	2.39	4.84
Zn	1.92	3.89	1.89	3.83
N x S	4.16	N.S.	4.11	N.S.
S x Zn	3.37	N.S.	3.33	N.S.
N x Zn	3.37	N.S.	3.33	N.S.
N x S x Zn	5.52	N.S.	5.41	N.S.
Absolute	4.26	8.63	4.20	8.51
Control/Treatments				

affected the number of green leaves significantly upto 5 kg Zn ha⁻¹ during both the years. However, interaction effects were noticed to be non-significant during both the years of experimentation.

4.1.1.4 Biomass Accumulation (g hill⁻¹)

Data on biomass accumulation as affected by different rates of nitrogen, sulphur and zinc application are presented in Tables 4.16 and 4.17 at 30th and 60th day of transplanting, respectively.

4.1.1.4.1 30th Day of Transplanting

The data in respect of biomass accumulation at 30th day of transplanting presented in Table 4.16 reveal that application of nitrogen enhanced biomass accumulation significantly upto 180 kg N/ha recording 18.04 and 18.93 g hill⁻¹ during 2003 and 2004, respectively. Application of sulphur too significantly increased the biomass accumulation upto 40 kg S/ha and thereafter, it was noticed to be non-significant during both the years. The minimum biomass accumulation was recorded at absolute control. Application of zinc also increased biomass accumulation significantly upto 5kg Zn ha⁻¹ and thereafter, it was noticed to be non-significant during both the years of investigation.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were noticed to be non-significant during both the years of experimentation.

4.1.1.4.2 60th Day of Transplanting

Data presented in Table 4.17 obviously show that nitrogen application significantly affected biomass accumulation upto 180 kg N/ha recording the maximum values 27.73 and 29.22 g hill⁻¹ during 2003 and 2004, respectively. The minimum biomass accumulation was observed with absolute control during both the years. Similarly, sulphur application increased biomass accumulation significantly upto 40 kg S/ha during both the years. The zinc dressings also significantly increased biomass accumulation upto 5 kg Zn ha⁻¹ during both the years of investigation.

Table 4.16: Effect of N, S and Zn on biomass accumulation (g/hill) in rice at 30th day of transplanting

Treatments		2003			Mean		2004			Mean	
		S ₁	S ₂	S ₃			S ₁	S ₂	S ₃		
N ₁	Zn ₁	10.72	12.91	12.92	12.18		11.82	14.01	14.04	13.29	
	Zn ₂	11.22	13.36	13.38	12.65		12.32	14.46	14.48	13.75	
Mean		10.97	13.13	13.10	12.41		12.07	14.23	14.26	13.52	
N ₂	Zn ₁	14.52	16.61	16.63	15.92		15.62	17.71	17.73	17.02	
	Zn ₂	14.87	16.91	16.95	16.24		15.97	18.01	18.05	17.34	
Mean		14.69	16.76	16.79	16.08		15.79	17.86	17.89	17.18	
N ₃	Zn ₁	16.51	18.59	18.62	17.90		17.41	19.28	19.31	18.66	
	Zn ₂	16.81	18.86	18.88	18.18		17.91	19.85	19.87	19.21	
Mean		16.68	18.72	18.75	18.04		17.66	19.56	19.59	18.93	
Mean of the means		14.10	16.20	16.23	15.51		15.17	17.22	17.24	16.54	
Absolute Control					7.10					8.11	

N	SE (diff.)	0.95	CD (5%)	1.92	SE (diff.)	0.85	CD (5%)	1.72
S	0.95	1.92	0.85	1.72				
Zn	0.76	1.54	0.69	1.40				
N x S	1.63	N.S.	1.48	N.S.				
S x Zn	1.33	N.S.	1.20	N.S.				
N x Zn	1.33	N.S.	1.20	N.S.				
N x S x Zn	2.31	N.S.	2.07	N.S.				
Absolute	1.64	3.32	1.53	3.10				
Control/Treatments								

Table 4.17: Effect of N, S and Zn on biomass accumulation (g/hill) in rice at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	15.72	18.81	18.87	17.80	16.82	19.91	19.94	18.89
	Zn ₂	16.12	19.16	19.19	18.15	17.22	20.43	20.46	19.37
Mean		15.92	18.98	19.03	17.97	17.02	20.17	20.20	19.13
N ₂	Zn ₁	22.62	25.50	25.52	24.54	23.72	26.60	26.62	25.64
	Zn ₂	23.08	25.92	25.95	24.98	24.16	27.20	27.24	26.20
Mean		22.85	25.71	25.73	24.76	23.94	26.90	26.93	25.92
N ₃	Zn ₁	25.87	28.29	28.29	27.48	26.97	29.98	30.02	28.99
	Zn ₂	26.29	28.83	28.86	27.99	27.38	30.48	30.51	29.45
Mean		26.39	28.56	28.57	27.73	27.17	30.23	30.26	29.22
Mean of the means		21.72	24.41	24.44	23.52	22.73	25.76	25.79	25.09
Absolute Control					10.81				11.73

N	SE (diff.)	1.33	CD (5%)	2.69	SE (diff.)	1.42	CD (5%)	2.87
S	SE (diff.)	1.33	CD (5%)	2.69	SE (diff.)	1.42	CD (5%)	2.87
Zn	SE (diff.)	1.06	CD (5%)	2.14	SE (diff.)	1.13	CD (5%)	2.29
N x S	SE (diff.)	2.28	CD (5%)	N.S.	SE (diff.)	2.44	CD (5%)	N.S.
S x Zn	SE (diff.)	1.86	CD (5%)	N.S.	SE (diff.)	1.98	CD (5%)	N.S.
N x Zn	SE (diff.)	1.86	CD (5%)	N.S.	SE (diff.)	1.98	CD (5%)	N.S.
N x S x Zn	SE (diff.)	3.24	CD (5%)	N.S.	SE (diff.)	3.46	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	2.34	CD (5%)	4.76	SE (diff.)	2.49	CD (5%)	5.06

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn in respect of biomass accumulation were non-significant during both the years of experimentation.

4.1.2 Effect of N, S & Zn on Yield Attributes (Maturity Characteristics) of Rice

4.1.2.1 Height of Plants at Maturity (cm)

It is obvious from the data given in Table 4.18 that application of different doses of nitrogen and sulphur alone significantly increased the plant height at maturity during both the years. The plant height increased by nitrogen application significantly upto 120 kg N ha⁻¹. The maximum plant height was noted 107.46 and 106.49 cm at 180 kg N ha⁻¹ during 2003 and 2004, respectively which was at par with its lower level i.e. 120kg N ha⁻¹. The minimum plant height was noted with absolute control during both the years. Sulphur application significantly increased plant height upto 40kgSha⁻¹ and thereafter the increase was noticed to be non-significant. Application of different levels of zinc also increased plant height at maturity significantly upto 5kg Zn ha⁻¹ and thereafter, the increase was observed to be non-significant during both the years.

The interaction effects of N x S, S x Zn, N x Zn, and N x S x Zn were non-significant on height of plants at maturity. Maximum plant height was, however, recorded at N₃S₃Zn₂ level during both the years of experimentation.

4.1.2.2 No. of productive tillers (m⁻²)

It is obvious from the data portrayed in Table 4.19 that application of different doses of nitrogen significantly increased the number of productive tillers upto 120 kg N ha⁻¹ and thereafter, the increase was noticed to be non-significant and minimum number of productive tillers were noted with absolute control during 2003 and 2004, respectively. Application of graded doses of sulphur also affected number of productive tillers significantly upto 40 kg S ha⁻¹ and thereafter there was a non-significant increase upto 60 kg

Table 4.18: Effect of N, S and Zn on plant height (cm) of rice at maturity

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	97.72	100.81	100.89	99.80	96.92	99.94	99.99	98.95
	Zn ₂	98.17	101.21	101.24	100.20	97.64	100.11	100.14	99.29
Mean		97.94	101.01	101.06	100.00	97.28	101.02	101.06	99.12
N ₂	Zn ₁	103.43	106.41	106.45	105.43	102.58	105.52	105.55	104.55
	Zn ₂	103.83	106.81	106.85	105.83	102.78	105.82	106.85	104.81
Mean		103.63	106.61	106.65	105.63	102.68	105.67	105.70	104.68
N ₃	Zn ₁	106.11	107.80	107.89	107.26	105.22	106.90	106.98	106.36
	Zn ₂	106.76	108.10	108.14	107.66	105.61	107.12	107.15	106.62
Mean		106.43	107.95	108.01	107.46	105.41	107.01	107.06	106.49
Mean of the means		102.67	105.19	105.24	104.36	101.79	104.23	104.27	103.43
Absolute Control					76.21				75.12

N	SE (diff.)	1.24	CD (5%)	2.51	SE (diff.)	1.20	CD (5%)	2.43
S	1.24	2.51	1.20	2.43				
Zn	0.99	2.01	0.96	1.94				
N x S	2.14	N.S.	2.06	N.S.				
S x Zn	1.75	N.S.	1.68	N.S.				
N x Zn	1.75	N.S.	1.68	N.S.				
N x S x Zn	3.02	N.S.	2.92	N.S.				
Absolute	2.18	4.42	2.14	4.32				

Table 4.19: Effect of N, S and Zn on number of productive tillers m⁻² in rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	260.10	280.50	282.54	274.38	266.90	287.43	289.34	281.18
	Zn ₂	263.22	283.68	285.58	277.49	270.08	290.32	291.38	283.92
Mean		261.66	282.09	284.06	275.93	268.49	288.81	290.36	282.55
N ₂	Zn ₁	296.47	306.52	307.86	303.61	303.17	313.22	314.56	310.31
	Zn ₂	299.60	309.72	310.94	306.75	306.26	316.29	317.67	313.40
Mean		298.03	308.12	309.40	305.18	304.71	314.75	316.11	311.86
N ₃	Zn ₁	302.72	308.93	309.84	307.16	309.43	315.62	316.92	313.99
	Zn ₂	305.82	312.07	312.94	310.27	312.49	318.71	319.97	317.05
Mean		304.27	310.50	311.39	308.72	310.96	317.16	318.44	315.52
Mean of the means		287.98	300.26	301.61	296.61	294.72	306.91	308.30	303.31
Absolute Control					160.10				162.20

N	SE (diff.)	3.90	CD (5%)	7.90	SE (diff.)	4.03	CD (5%)	8.17
S	3.90	7.90	4.03	8.17				
Zn	3.12	6.32	3.22	6.53				
N x S	6.70	N.S.	6.93	N.S.				
S x Zn	5.46	N.S.	5.64	N.S.				
N x Zn	5.46	N.S.	5.64	N.S.				
N x S x Zn	9.51	N.S.	9.83	N.S.				
Absolute Control/Treatments	6.86	13.91	7.09	14.37				

Sh^a during both the years. Zn application significantly affected the number of productive tillers upto 5 kg Zn ha⁻¹ during both the years. The increase in the number of productive tillers m⁻² was noticed upto 10 kg Zn ha⁻¹ but this increase could not touch the level of significance during both the years of study.

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn are recorded to be non-significant on number of productive tillers m⁻², however, interactions have increasing trend on number of productive tillers but did not reach the level of significance and maximum number of tillers were recorded at N₃S₃Zn₂ level during both the years of experimentation.

4.1.2.3 Number of panicles (hill⁻¹)

It is obvious from the data presented in Table 4.20 that application of graded doses of nitrogen significantly increased number of panicles (hill⁻¹) upto 120 kg N ha⁻¹ and thereafter the increase was recorded to be non-significant during both the years. However, the lowest number was recorded with the absolute control. Sulphur application also increased number of panicles significantly upto 40 kg S ha⁻¹ recording 9.29 and 9.42 panicles (hill⁻¹) during 2003 and 2004, respectively. The number of panicles was also increased upto 60 kg S ha⁻¹ but it was noticed to be at par with each other during both the years of study. Application of zinc influenced the number of panicles (hill⁻¹) significantly upto Zn₁ level i.e. 5 kg Zn ha⁻¹ thereafter, increases non-significantly upto 10 kg Znha⁻¹ during both the years. At 5 kg Zn ha⁻¹ number of panicles (hill⁻¹) recorded during 2003 and 2004 were 8.97 and 9.17, respectively.

The interaction effect of N x S, S x Zn, N x Zn and N x S x Zn were noticed to be non-significant on number of panicles per hill but maximum number of panicles were recorded at N₃S₃Zn₂ level during both the years of experimentation.

4.1.2.4 Total number of spikelets (hill⁻¹)

Data presented in the Table 4.21 clearly revealed that total number of spikelets (hill⁻¹) was increased significantly with graded levels of nitrogen

Table 4.20: Effect of N, S and Zn on number of panicles hill⁻¹ in rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	7.46	8.50	8.56	8.17	7.86	8.57	8.62	8.35
	Zn ₂	7.65	8.87	8.91	8.47	8.02	8.71	8.76	8.49
Mean		7.55	8.68	8.73	8.32	7.94	8.64	8.69	8.42
N ₂	Zn ₁	8.80	9.45	9.50	9.25	9.01	9.66	9.71	9.46
	Zn ₂	8.96	9.60	9.65	9.40	9.17	9.81	9.85	9.61
Mean		8.88	9.52	9.57	9.32	9.09	9.73	9.78	9.53
N ₃	Zn ₁	9.21	9.62	9.66	9.49	9.42	9.82	9.87	9.70
	Zn ₂	9.35	9.75	9.78	9.62	9.56	9.95	9.97	9.82
Mean		9.28	9.68	9.72	9.56	9.49	9.88	9.92	9.76
Mean of the means		8.57	9.29	9.34	9.06	8.84	9.42	9.46	9.24
Absolute Control					5.15				5.32

N	SE (diff.)	0.32	CD (5%)	0.64	SE (diff.)	0.25	CD (5%)	0.50
S	0.32	0.64	0.25	0.50	0.25	0.50	N.S.	0.50
Zn	0.25	0.50	0.20	0.40	0.20	0.40	N.S.	0.40
N x S	0.55	N.S.	0.43	N.S.	0.35	N.S.	N.S.	N.S.
S x Zn	0.45	N.S.	0.35	N.S.	0.35	N.S.	N.S.	N.S.
N x Zn	0.45	N.S.	0.61	N.S.	0.61	N.S.	N.S.	N.S.
N x S x Zn	0.78	1.13	0.44	0.89	0.44	0.89		
Absolute Control/Treatments	0.56							

upto its highest level of application. The maximum numbers of spikelets were recorded as 928.08 and 948.31 hill⁻¹ at 180 kg N ha⁻¹ during 2003 and 2004, respectively. Application of sulphur increased the total number of spikelets significantly upto 40 kg S ha⁻¹ during both the years and thereafter, there was a non-significant increase upto 60 kg S ha⁻¹. Application of zinc also increased significantly total number of spikelets (hill⁻¹) upto 5 kg Zn ha⁻¹ recording 857.12 and 878.01 hill⁻¹ during both the years. The total number of spikelets increased upto 10 kg Zn ha⁻¹ but were noticed to be at par at 5 kg and 10 kg Zn ha⁻¹ during 2003 and 2004, respectively. The minimum number of spikelets (hill⁻¹) were noted at absolute control during both the years of study.

Interaction effects did not significantly affect the total number of spikelets (hill⁻¹), however, interactions have increasing trend on total number of spikelets (hill⁻¹) recording the maximum values at N₃S₃Zn₂ level during both the years of experimentation.

4.1.2.5 Number of Filled grains (panicle⁻¹)

Data portrayed in the Table 4.22 reveal that the number of filled grains (panicle⁻¹) increased by application of nitrogen significantly upto 120 kg N ha⁻¹ and thereafter, the increase was noted to be at par during 2003 and 2004, respectively. However, absolute control recorded the lowest values in respect of number of filled grains panicle⁻¹ during both the years. Application of sulphur significantly increased number of filled grains per panicle upto 40 kg S ha⁻¹ and were calculated to be 32.92 and 32.87 percent higher than recorded at absolute control during 2003 and 2004, respectively. Number of filled grains panicle⁻¹ recorded at absolute control were 60.05 and 60.89 panicle⁻¹ during both the years, respectively. Application of graded doses of zinc also increased the number of filled grains panicle⁻¹ significant upto 5 kg Zn ha⁻¹ recording 78.75 and 80.21 during 2003 and 2004 panicle⁻¹, respectively and thereafter the increase was observed to be non-significant upto 10 kg Zn ha⁻¹ application during both the years of study.

Table 4.21: Effect of N, S and Zn on total number of spikelets hill⁻¹ in rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	719.46	770.75	773.34	754.51	740.43	790.67	794.21	775.10
	Zn ₂	730.56	781.78	784.44	765.59	751.46	802.56	805.76	786.59
Mean		725.01	776.26	778.89	760.05	745.94	796.61	799.98	780.84
N ₂	Zn ₁	857.56	912.45	915.34	895.11	878.56	933.32	936.64	916.17
	Zn ₂	868.66	923.56	926.74	906.32	889.65	944.52	947.62	927.26
Mean		863.11	918.00	921.04	900.71	884.10	938.92	942.13	921.71
N ₃	Zn ₁	899.76	931.61	933.87	921.74	920.36	952.32	956.64	942.77
	Zn ₂	915.56	942.78	944.94	934.42	931.46	963.78	966.34	953.86
Mean		907.66	937.19	939.40	928.08	925.91	958.05	960.99	948.31
Mean of the means		831.92	877.15	879.77	862.95	851.98	897.86	901.03	883.62
Absolute Control					367.35				385.23

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	13.36	27.09	12.92	26.39
S	13.36	27.09	12.92	26.39
Zn	10.68	21.36	10.33	20.90
N x S	22.97	N.S.	22.22	N.S.
S x Zn	18.70	N.S.	18.08	N.S.
N x Zn	18.70	N.S.	18.08	N.S.
N x S x Zn	32.79	N.S.	31.60	N.S.
Absolute Control/Treatments	23.48	48.96	22.75	46.28

Table 4.22: Effect of N, S and Zn on number of filled grains panicle⁻¹ in rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	74.05	76.72	76.82	75.86	75.73	77.81	77.92	77.15
	Zn ₂	74.36	76.99	77.10	76.15	76.01	78.08	78.19	77.42
Mean		74.20	76.85	76.96	76.00	75.87	77.94	78.05	77.29
N ₂	Zn ₁	78.94	80.99	81.08	80.33	80.03	82.08	82.17	81.42
	Zn ₂	79.22	81.27	81.36	80.61	80.31	82.36	82.45	81.70
Mean		79.08	81.13	81.22	80.47	80.17	82.22	82.31	81.56
N ₃	Zn ₁	80.15	81.36	81.44	80.98	81.24	82.45	82.53	82.07
	Zn ₂	80.43	81.64	81.72	81.26	81.52	82.73	82.78	82.34
Mean		80.29	81.50	81.58	81.12	81.38	82.59	82.65	82.20
Mean of the means		77.49	79.82	79.92	79.08	79.14	80.91	81.00	80.35
Absolute Control					60.05				60.89

N	SE (diff.)	1.05	CD (5%)	2.12	SE (diff.)	0.84	CD (5%)	1.70
S	SE (diff.)	1.05	CD (5%)	2.12	SE (diff.)	0.84	CD (5%)	1.70
Zn	SE (diff.)	0.84	CD (5%)	1.70	SE (diff.)	0.67	CD (5%)	1.36
N x S	SE (diff.)	1.80	CD (5%)	3.65	SE (diff.)	1.44	CD (5%)	N.S.
S x Zn	SE (diff.)	1.47	CD (5%)	2.98	SE (diff.)	1.17	CD (5%)	N.S.
N x Zn	SE (diff.)	1.47	CD (5%)	2.98	SE (diff.)	1.17	CD (5%)	N.S.
N x S x Zn	SE (diff.)	2.57	CD (5%)	5.21	SE (diff.)	2.04	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	1.84	CD (5%)	3.73	SE (diff.)	1.47	CD (5%)	2.99

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on the number of filled grains per panicle were non-significant. However, interactions have increasing trend on number of filled grains panicle⁻¹ and maximum values were noted at N₃S₃Zn₂ during both the years of investigation.

4.1.2.6 Weight of panicle (g)

It is obvious from the data presented in the Table 4.23 that application of graded doses of nitrogen significantly increased the weight of panicle upto its highest dose of application i.e. 180 kg N ha⁻¹ recording maximum weight 3.070 and 3.114 g panicle⁻¹ during 2003 and 2004, respectively. Sulphur application too increased the weight of panicle significantly upto 40 kg S ha⁻¹ and thereafter increased non-significantly during both the years. The weight of panicle at absolute control were recorded to be 1.812 and 1.839 g during 2003 and 2004, respectively. Application of graded doses of zinc also increased weight of panicle upto Zn₁ level noting down 2.826 and 2.778 g panicle⁻¹ during 2003 and 2004, respectively, and thereafter increased non-significantly during both the years.

Combined application of N x S, S x Zn, N x Zn and N x S x Zn have no effect on the weight of panicle during both the years. The interaction effects of were recorded to be non-significant on the weight of panicle but maximum values were noted at N₃S₃Zn₂ level during both the years of experimentation.

4.1.2.7 Test weight of grains (1000-grain weight)

Data portrayed in the Table 4.24 (Fig 4.1) reveal that the application of nitrogen significantly increased the test weight of grains upto 120 kg N ha⁻¹ and thereafter it decreased non-significantly at its highest dose (180 kg N ha⁻¹) during both the years. Application of sulphur significantly increased the test weight upto 40 kg S ha⁻¹ and thereafter it decreased non-significantly at its highest dose during both the years. Effect of Zn on test-weight of grains recorded increasing trend significantly upto 5 kg Zn ha⁻¹ and thereafter it

Table 4.23: Effect of N, S and Zn on weight of panicle (g) in rice

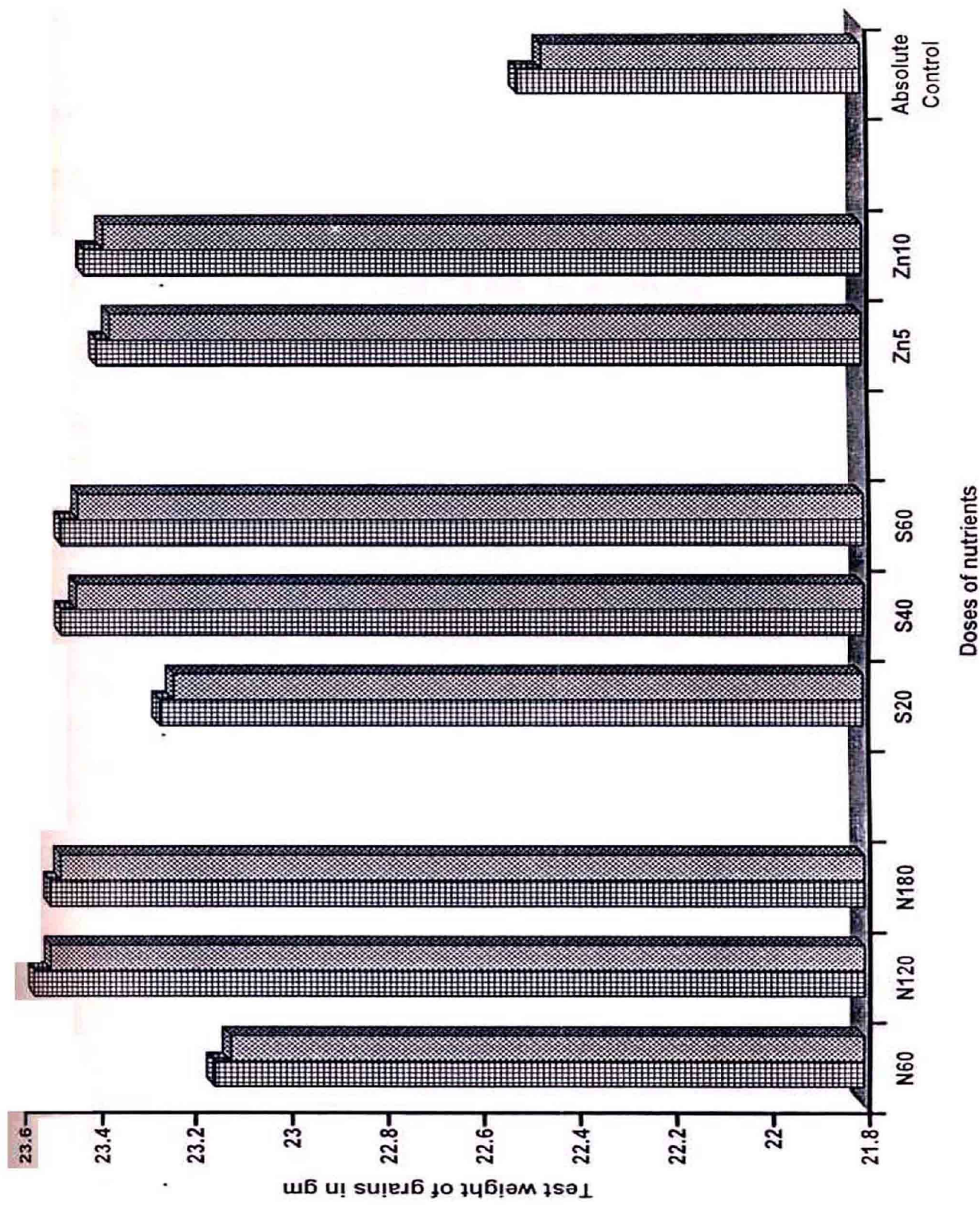
Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	2.203	2.412	2.419	2.344	2.239	2.448	2.455	2.380
	Zn ₂	2.247	2.456	2.464	2.389	2.283	2.482	3.501	2.422
Mean		2.225	2.434	2.441	2.366	2.261	2.465	2.478	2.501
N ₂	Zn ₁	2.183	2.393	2.399	2.825	2.719	2.929	3.935	2.861
	Zn ₂	2.227	2.437	2.443	2.869	2.763	2.973	3.979	2.905
Mean		2.705	2.915	2.921	2.847	2.741	2.951	3.957	2.883
N ₃	Zn ₁	2.906	3.109	3.104	3.039	2.942	3.165	3.170	3.092
	Zn ₂	2.951	3.173	3.178	3.100	2.987	3.209	3.214	3.136
Mean		2.928	3.141	3.141	3.070	2.964	3.187	3.192	3.114
Mean of the means		2.619	2.830	2.834	3.761	2.655	2.867	3.875	2.799
Absolute Control					1.812				1.839

N	SE (diff.)	0.095	CD (5%)	0.192	SE (diff.)	0.091	CD (5%)	0.184
S	SE (diff.)	0.095	CD (5%)	0.192	SE (diff.)	0.091	CD (5%)	0.184
Zn	SE (diff.)	0.076	CD (5%)	0.158	SE (diff.)	0.072	CD (5%)	0.147
N x S	SE (diff.)	0.163	CD (5%)	N.S.	SE (diff.)	0.156	CD (5%)	N.S.
S x Zn	SE (diff.)	0.133	CD (5%)	N.S.	SE (diff.)	0.127	CD (5%)	N.S.
N x Zn	SE (diff.)	0.133	CD (5%)	N.S.	SE (diff.)	0.127	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.231	CD (5%)	N.S.	SE (diff.)	0.222	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.168	CD (5%)	0.340	SE (diff.)	0.160	CD (5%)	0.324

Table 4.24: Effect of N, S and Zn on test weight(1000-grain weight) of grains (g) in rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	22.973	23.192	23.196	23.120	22.943	23.162	23.160	23.088
	Zn ₂	23.028	23.247	23.251	23.175	22.998	23.217	23.205	23.140
Mean		23.000	23.219	23.223	23.147	22.970	23.189	23.182	23.114
N ₂	Zn ₁	23.384	23.603	23.607	23.531	23.354	23.573	23.570	23.499
	Zn ₂	23.429	23.658	23.662	23.586	23.389	23.598	23.590	23.525
Mean		23.411	23.630	23.634	23.558	23.371	23.585	23.580	23.512
N ₃	Zn ₁	23.391	23.601	23.590	23.527	23.368	23.572	23.574	23.504
	Zn ₂	23.346	23.586	23.570	23.500	23.331	23.542	23.530	23.467
Mean		23.368	23.593	23.580	23.513	23.349	23.557	23.552	23.485
Mean of the means		23.259	23.480	23.479	23.406	23.230	23.443	23.438	23.370
Absolute Control					22.511				22.461

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	0.103	0.209	0.102	0.206
S	0.103	0.209	0.102	0.206
Zn	0.085	0.172	0.084	0.170
N x S	0.178	N.S.	0.176	N.S.
S x Zn	0.145	N.S.	0.143	N.S.
N x Zn	0.145	N.S.	0.143	N.S.
N x S x Zn	0.252	N.S.	0.250	N.S.
Absolute	0.183	0.371	0.181	0.367



■ 2003 ▨ 2004

Fig 4.1: Effect of N, S and Zn on test weight of grains

increased non-significantly upto 10 kg Zn ha⁻¹ during both the years. The minimum test weight of grains was recorded at absolute control.

Interaction effects of N x S, S x Zn, N x Zn and S x N x Zn on test weight of grains were non-significant during both the years of experimentation.

4.1.3 Effect of N, S & Zn on yield of grain and straw (q ha⁻¹)

Data on grain and straw yield of rice are presented in Tables 4.25 and 4.26 and depicted with Figs. 4.2&4.3, respectively.

4.1.3.1 Grain yield (q ha⁻¹)

Data presented in Table 4.25 clearly reveal that the grain yield of rice increased significantly with increasing level of nitrogen upto 120 kg Nha⁻¹ but yield differences at 120 and 180 kg Nha⁻¹ were noticed to be *at par* with each other during both the years of application. At application of nitrogen 120 kg Nha⁻¹ grain yield of rice were recorded 58.36 and 59.87 q ha⁻¹ during 2003 and 2004, respectively. With regards to S application, it was noticed that grain yield of rice increased significantly with increasing rates of sulphur application upto 40 kg S ha⁻¹ recording 56.57 and 57.90 q ha⁻¹ during 2003 and 2004, respectively. It was further observed that the grain yield of rice increased beyond 40 kg Sha⁻¹ but the yield differences at 40 and 60 kg S ha⁻¹ were recorded to be non-significant. The yield increased with increasing level of Zn significantly upto 5 kg Zn ha⁻¹ application but it was recorded to be non-significant at Zn₁ and Zn₂ levels during both the years. However, at all the levels of N, S and Zn the yield of grain increased significantly over absolute control recording 20.84 and 21.54 q ha⁻¹. during 2003 and 2004, respectively.

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on grain yield were non-significant. The grain yield of rice increased beyond 120 kg N, 40 kg S and 5 kg Zn ha⁻¹ but it could not touch the level of significance during both the years of experimentation. The N x S interaction affected favourably the grain yield and at highest levels of N and S interaction i.e. at N₃S₃ yield were noted 61.75 and 63.10 q ha⁻¹ during 2003 and 2004,

Table 4.25: Effect of N, S and Zn on grain yield of rice (qha⁻¹)

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	44.59	48.52	48.81	47.30	45.99	49.54	50.10	48.54
	Zn ₂	45.07	48.82	48.88	47.59	46.97	50.46	50.56	49.33
Mean		44.83	48.67	48.84	47.44	46.48	50.00	50.33	48.93
N ₂	Zn ₁	55.94	58.92	59.37	58.07	57.34	60.31	60.77	59.47
	Zn ₂	56.64	59.62	60.08	58.66	58.29	61.23	61.29	60.27
Mean		56.29	59.27	59.72	58.36	57.81	60.77	61.03	59.87
N ₃	Zn ₁	58.27	61.21	61.53	60.33	59.76	62.51	62.82	61.69
	Zn ₂	58.97	61.98	61.98	60.97	60.87	63.35	63.38	62.53
Mean		58.62	61.59	61.75	60.65	60.31	62.93	63.10	62.11
Mean of the means		53.24	56.51	56.77	55.50	54.87	57.90	58.15	56.97
Absolute Control					20.84				21.54

N	SE (diff.)	1.40	CD (5%)	2.83	SE (diff.)	1.41	CD (5%)	2.85
S	1.40	2.83	1.41	2.85				
Zn	1.12	2.27	1.13	2.29				
N x S	2.40	N.S.	2.42	N.S.				
S x Zn	1.96	N.S.	1.97	N.S.				
N x Zn	1.96	N.S.	1.97	N.S.				
N x S x Zn	3.41	N.S.	3.44	N.S.				
Absolute	2.46	4.98	2.48	5.02				
Control/Treatments								

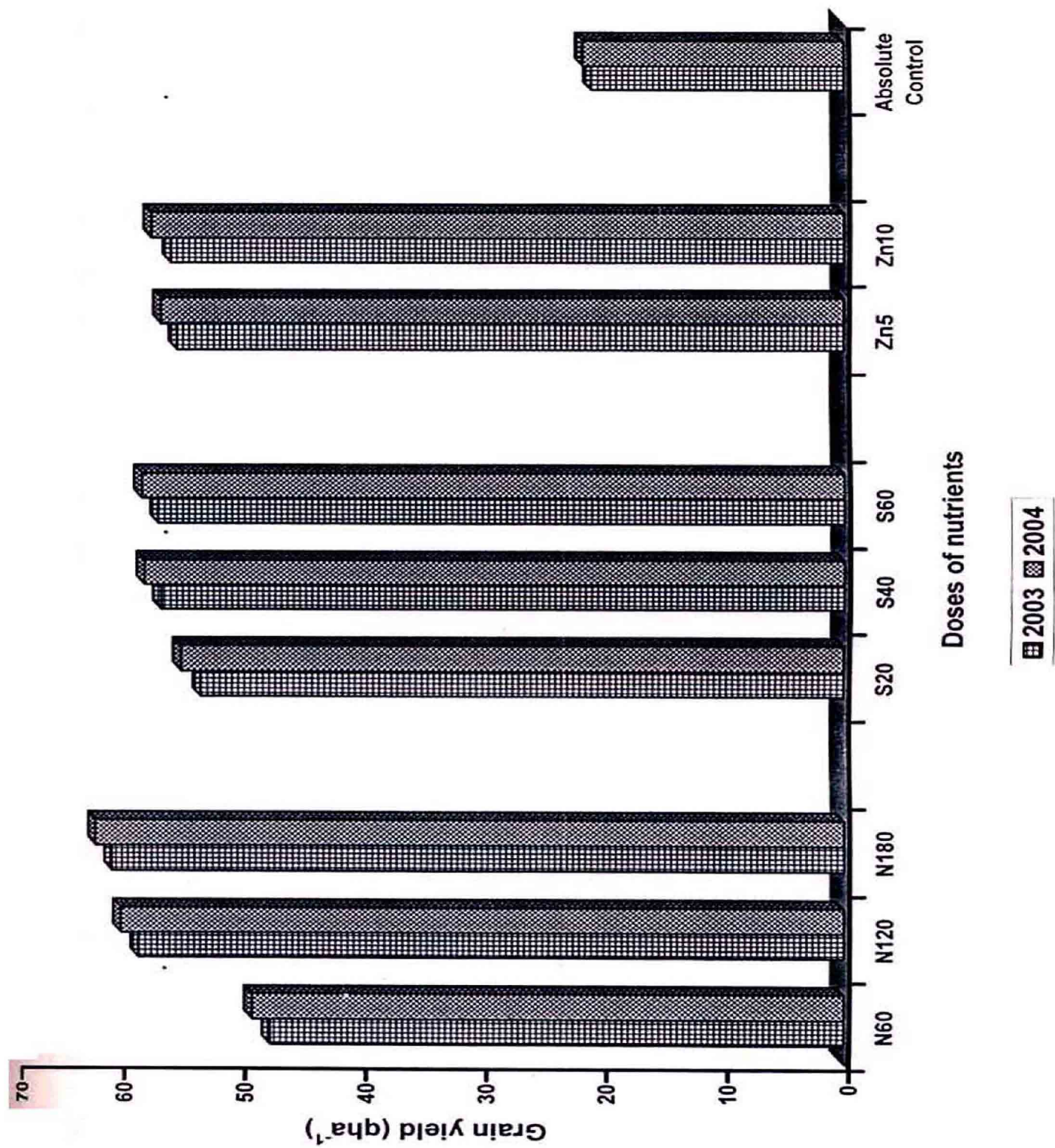


Fig 4.2: Effect of N, S and Zn on grain yield of rice

respectively which is not significantly higher than all other combinations, however, maximum grain yield was recorded at $N_3S_3Zn_2$ level during both the years of study.

4.1.3.2 Straw yield ($q\ ha^{-1}$)

Data portrayed in Table 4.26 (Fig 4.3) reveal that application of graded doses of nitrogen, sulphur and zinc significantly increased the straw yield of rice. Application of nitrogen significantly increased straw yield upto $120\ kg\ N\ ha^{-1}$ recording 85.90 and 87.26 $q\ ha^{-1}$ during 2003 and 2004, respectively. It was further observed that the straw yield of rice increased beyond $120\ kg\ N\ ha^{-1}$ but the yield differences at 120 and $180\ kg\ ha^{-1}$ were recorded to be non-significant. Application of sulphur significantly increased straw yield of rice upto $40\ kg\ S\ ha^{-1}$ noting down 79.04 and 80.42 $q\ ha^{-1}$ during 2003 and 2004, respectively and thereafter, increase was recorded to be non-significant. Graded doses of zinc also increased straw yield of rice significantly upto $5\ kg\ Zn\ ha^{-1}$ and thereafter the increase in respect of straw yield was observed to be non-significant.

However, the absolute control recorded the lowest straw yield during both the years. The interaction effects of $N \times S$, $S \times Zn$, $N \times Zn$ and $N \times S \times Zn$ on the straw yield of rice were non-significant during both the years of experimentation. However, the maximum yield was recorded at $N_3S_3Zn_2$ level during both the years of investigation.

4.2 EFFECT OF N, S AND Zn ON CONTENT AND UPTAKE OF NUTRIENTS

4.2.1 Effect of N, S and Zn on content of nutrients

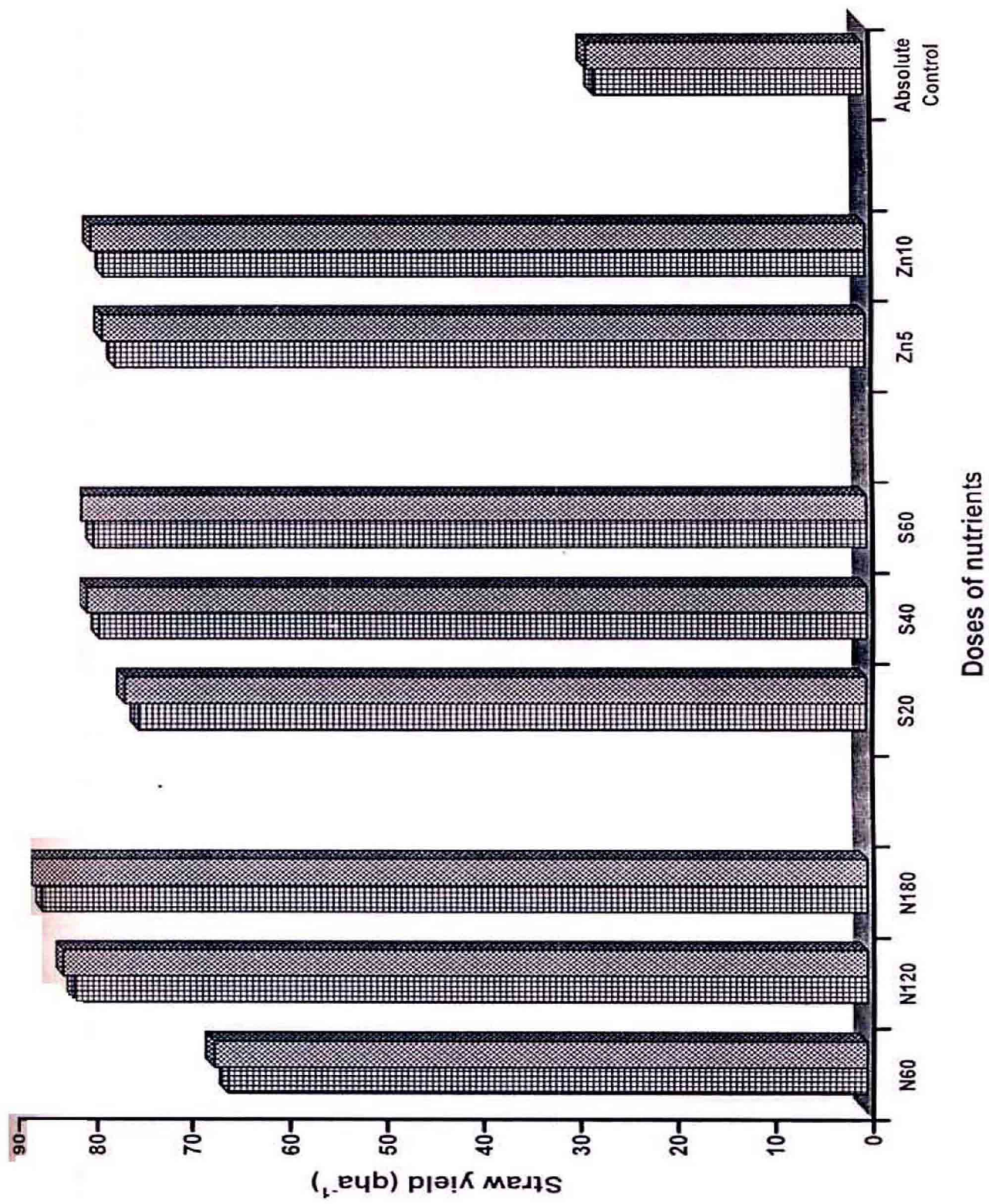
4.2.1.1 N content in rice plant

Data on N content at 30th and 60th day of transplanting are presented in Table 4.27 and 4.28, respectively during both the years.

Table 4.26: Effect of N, S and Zn on straw yield of rice (qha⁻¹)

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	61.53	66.40	67.21	65.04	63.00	67.86	68.63	66.49
	Zn ₂	62.88	67.70	68.46	66.34	64.34	69.13	69.87	67.78
Mean		62.20	67.05	67.83	65.69	63.67	68.49	69.25	67.13
N ₂	Zn ₁	78.31	82.48	83.11	81.30	79.70	83.83	84.47	82.66
	Zn ₂	79.64	83.76	84.35	82.58	81.02	85.10	85.67	83.93
Mean		78.97	83.12	83.72	81.94	80.36	84.46	85.07	83.29
N ₃	Zn ₁	82.74	86.35	86.81	85.30	84.12	87.72	88.16	86.66
	Zn ₂	84.02	87.56	87.94	86.50	85.40	88.91	89.30	87.87
Mean		83.38	86.95	87.37	85.90	84.76	88.31	88.73	87.26
Mean of the means		74.85	79.04	79.64	77.84	76.26	80.42	81.01	79.23
Absolute Control					27.71				28.49

N	SE (diff.)	2.05	CD (5%)	4.15	SE (diff.)	2.02	CD (5%)	4.09
S		2.05		4.15		2.02		4.09
Zn		1.64		3.32		1.61		3.27
N x S		3.52		N.S.		3.47		N.S.
S x Zn		2.87		N.S.		2.82		N.S.
N x Zn		2.87		N.S.		2.82		N.S.
N x S x Zn		5.00		N.S.		4.92		N.S.
Absolute		3.60		7.30		3.55		7.20
Control/Treatments								



■ 2003 ■ 2004

Fig 4.3: Effect of N, S and Zn on straw yield of rice

4.2.1.1.1 At 30th Day of transplanting

Data presented in the Table 4.27 reveal that N content (%) increased significantly by increasing the dose of nitrogen and maximum N content was recorded at N₃ level 37.61 and 37.97 percent higher over absolute control during 2003 and 2004, respectively. Application of sulphur increased nitrogen content upto its S₂ level and thereafter it was increased non-significantly upto 60 kg S ha⁻¹ during both the years. Application of zinc also increased nitrogen content upto its lower level (5 kg Zn ha⁻¹) and thereafter it was increased non-significantly upto 10 kg Znha⁻¹ during both the years. The minimum N content was noted at absolute control during both the years of study.

Effects of interactions of N x S, S x Zn, N x Zn and N x S x Zn on the N content at 30th day of transplanting were non significant but maximum content was noted at N₃S₃Zn₂ level during both the years of experimentation.

4.2.1.1.2 At 60th Day of transplanting

Data presented in the Table 4.28 clearly reveal that application of N significantly increased N content upto its highest level (180 kg Nha⁻¹) recording 41.84 and 41.65 percent higher over absolute control during 2003 and 2004, respectively. Application of sulphur increased N content significantly upto 40 kg S ha⁻¹ recording 37.18 and 37.04 percent higher over absolute control during 2003 and 2004, respectively. Application of zinc also increased nitrogen content upto 5 kg Zn ha⁻¹ 34.07 and 34.35 percent higher over absolute control during 2003 and 2004, respectively. Application of 60 kg S and 10 kg Znha⁻¹ increased N content of rice non-significantly during both the years.

Effects of interactions of N x S, S x Zn, N x Zn and N x S x Zn on the N content (per cent) were found to be non-significant although maximum values were recorded at N₃S₃Zn₂ level during both the years of study.

Table 4.27: Effect of N, S and Zn on N content (%) of rice at 30th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	1.953	2.042	2.044	2.013	1.986	2.087	2.090	2.054
	Zn ₂	1.984	2.073	2.076	2.044	1.996	2.104	2.106	2.068
Mean		1.968	2.057	2.060	2.028	1.991	2.095	2.098	2.061
N ₂	Zn ₁	2.274	2.355	2.358	2.329	2.305	2.396	2.399	2.366
	Zn ₂	2.305	2.386	2.389	2.360	2.338	2.429	2.431	2.399
Mean		2.289	2.370	2.373	2.344	2.321	2.412	2.415	2.383
N ₃	Zn ₁	2.346	2.421	2.422	2.396	2.386	2.468	2.471	2.441
	Zn ₂	2.377	2.451	2.453	2.427	2.407	2.480	2.482	2.456
Mean		2.361	2.436	2.437	2.411	2.396	2.474	2.476	2.449
Mean of the means		2.206	2.288	2.290	2.261	2.236	2.327	2.329	2.301
Absolute Control					1.752				1.775

N	SE (diff.)	0.032	CD (5%)	0.064	SE (diff.)	0.032	CD (5%)	0.064
S	0.032	0.064	0.032	0.064	0.032	0.064	0.032	0.064
Zn	0.025	0.050	0.027	0.050	0.027	0.050	0.027	0.050
N x S	0.056	N.S.	0.056	N.S.	0.056	N.S.	0.056	N.S.
S x Zn	0.045	N.S.	0.045	N.S.	0.045	N.S.	0.045	N.S.
N x Zn	0.045	N.S.	0.045	N.S.	0.045	N.S.	0.045	N.S.
N x S x Zn	0.081	N.S.	0.081	N.S.	0.081	N.S.	0.081	N.S.
Absolute Control/Treatments	0.060	0.121	0.060	0.121	0.060	0.121	0.060	0.121

Table 4.28: Effect of N, S and Zn on N content (%) of rice at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	1.242	1.293	1.295	1.276	1.263	1.314	1.316	1.297
	Zn ₂	1.261	1.310	1.312	1.294	1.284	1.333	1.334	1.317
Mean		1.251	1.301	1.303	1.285	1.273	1.323	1.325	1.307
N ₂	Zn ₁	1.355	1.446	1.448	1.416	1.396	1.457	1.459	1.437
	Zn ₂	1.375	1.465	1.467	1.435	1.417	1.476	1.477	1.456
Mean		1.365	1.455	1.457	1.426	1.406	1.466	1.468	1.447
N ₃	Zn ₁	1.409	1.473	1.475	1.452	1.430	1.484	1.486	1.466
	Zn ₂	1.429	1.492	1.493	1.471	1.448	1.504	1.505	1.485
Mean		1.419	1.482	1.484	1.461	1.439	1.494	1.495	1.476
Mean of the means		1.345	1.413	1.415	1.391	1.373	1.428	1.429	1.410
Absolute Control					1.030				1.042

N	SE (diff.)	0.016	CD (5%)	0.032	SE (diff.)	0.014	CD (5%)	0.028
S	SE (diff.)	0.016	CD (5%)	0.032	SE (diff.)	0.014	CD (5%)	0.028
Zn	SE (diff.)	0.012	CD (5%)	0.024	SE (diff.)	0.011	CD (5%)	0.022
N x S	SE (diff.)	0.027	CD (5%)	N.S.	SE (diff.)	0.024	CD (5%)	N.S.
S x Zn	SE (diff.)	0.022	CD (5%)	N.S.	SE (diff.)	0.019	CD (5%)	N.S.
N x Zn	SE (diff.)	0.022	CD (5%)	N.S.	SE (diff.)	0.019	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.040	CD (5%)	N.S.	SE (diff.)	0.034	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.028	CD (5%)	0.057	SE (diff.)	0.024	CD (5%)	0.049

4.2.1.1.3 N content in rice grain

The data presented in Table 4.29 and depicted with Fig 4.4 reveal that N content significantly increased by increasing doses of nitrogen upto 120 kg N ha⁻¹ recording 17.56 and 19.08 percent higher over absolute control during 2003 and 2004, respectively. Application of sulphur increased nitrogen content significantly upto 40 kg S ha⁻¹ recording 1.495 and 1.504 per cent during 2003 and 2004, respectively. N content also increased upto 180 kg N and 60 kg S ha⁻¹ which were at par with 120 kg N and 40 kg S ha⁻¹ during both the years, respectively. Effect of zinc also significantly increased nitrogen content upto 5 kg Zn ha⁻¹ recording 15.37 and 17.53 percent higher over absolute control during 2003 and 2004, respectively and thereafter, there was a increase in N content at 10 kg Zn ha⁻¹ application but it was noticed to be non-significant.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on N content were non significant. However, interactions have increasing trend on N content and maximum content was recorded at N₃S₃Zn₂ level during both the years.

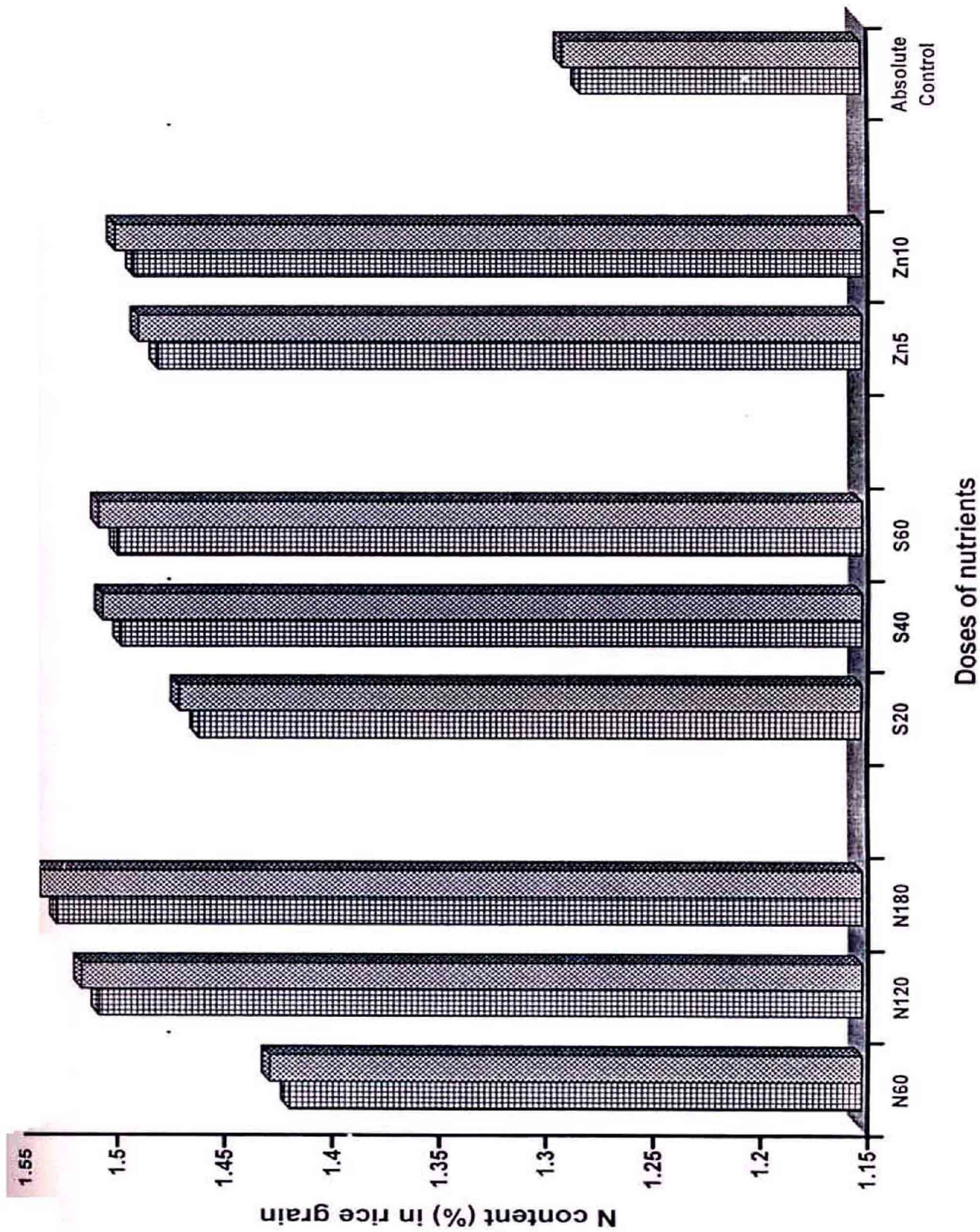
4.2.1.1.4 N content in rice straw

It is obvious from the data presented in Table 4.30 and depicted with Fig 4.5 that application of nitrogen significantly increased nitrogen content in straw of rice upto 120 kg N ha⁻¹ recording 17.14 and 17.64 percent higher over lowest values (absolute control) during 2003 and 2004, respectively. Sulphur application increased N content upto 40 kg S ha⁻¹ recording 0.528 and 0.535 per cent during 2003 and 2004, respectively. Application of zinc also increased nitrogen content significantly upto 5 kg Zn ha⁻¹ and N contents were noted to be 0.521 and 0.528 per cent during 2003 and 2004, respectively. N content further increased upto highest doses of N, S and Zn but these were at par with lower levels of nutrients during both the years.

Table 4.29: Effect of N, S and Zn on N content (%) in grain of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	1.382	1.425	1.428	1.411	1.391	1.434	1.437	1.420
	Zn ₂	1.394	1.436	1.438	1.422	1.403	1.445	1.447	1.431
Mean		1.388	1.430	1.433	1.417	1.397	1.439	1.442	1.426
N ₂	Zn ₁	1.472	1.515	1.517	1.501	1.481	1.524	1.526	1.510
	Zn ₂	1.484	1.526	1.527	1.512	1.493	1.535	1.536	1.521
Mean		1.478	1.520	1.522	1.506	1.487	1.529	1.531	1.515
N ₃	Zn ₁	1.505	1.531	1.532	1.522	1.514	1.540	1.541	1.531
	Zn ₂	1.517	1.542	1.542	1.533	1.526	1.551	1.552	1.543
Mean		1.511	1.536	1.537	1.528	1.520	1.545	1.546	1.537
Mean of the means		1.459	1.495	1.497	1.484	1.468	1.504	1.506	1.493
Absolute Control					1.281				1.289

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	0.015	0.030	0.016	0.032
S	0.015	0.030	0.016	0.032
Zn	0.012	0.024	0.012	0.024
N x S	0.025	N.S.	0.027	N.S.
S x Zn	0.021	N.S.	0.022	N.S.
N x Zn	0.021	N.S.	0.022	N.S.
N x S x Zn	0.037	N.S.	0.039	N.S.
Absolute	0.026	0.052	0.028	0.056



■ 2003 ■ 2004

Fig 4.4: Effect of N, S and Zn on N content (%) in rice grain

Table 4.30: Effect of N, S and Zn on N content (%) in straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.477	0.496	0.498	0.490	0.484	0.503	0.505	0.497
	Zn ₂	0.482	0.500	0.501	0.494	0.489	0.507	0.508	0.501
Mean		0.479	0.498	0.499	0.492	0.486	0.505	0.506	0.499
N ₂	Zn ₁	0.519	0.537	0.538	0.531	0.526	0.544	0.546	0.538
	Zn ₂	0.524	0.541	0.542	0.535	0.531	0.548	0.549	0.542
Mean		0.521	0.539	0.540	0.533	0.528	0.546	0.547	0.540
N ₃	Zn ₁	0.532	0.545	0.547	0.541	0.539	0.552	0.554	0.548
	Zn ₂	0.537	0.549	0.549	0.545	0.544	0.556	0.557	0.552
Mean		0.534	0.547	0.548	0.543	0.541	0.554	0.555	0.550
Mean of the means		0.511	0.528	0.529	0.523	0.518	0.535	0.536	0.530
Absolute Control					0.455				0.459

N	SE (diff.)	0.006	CD (5%)	0.012	SE (diff.)	0.006	CD (5%)	0.012
S	SE (diff.)	0.006	CD (5%)	0.012	SE (diff.)	0.006	CD (5%)	0.012
Zn	SE (diff.)	0.004	CD (5%)	0.009	SE (diff.)	0.004	CD (5%)	0.009
N x S	SE (diff.)	0.010	CD (5%)	N.S.	SE (diff.)	0.010	CD (5%)	N.S.
S x Zn	SE (diff.)	0.008	CD (5%)	N.S.	SE (diff.)	0.008	CD (5%)	N.S.
N x Zn	SE (diff.)	0.008	CD (5%)	N.S.	SE (diff.)	0.008	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.014	CD (5%)	N.S.	SE (diff.)	0.014	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.010	CD (5%)	0.021	SE (diff.)	0.010	CD (5%)	0.021

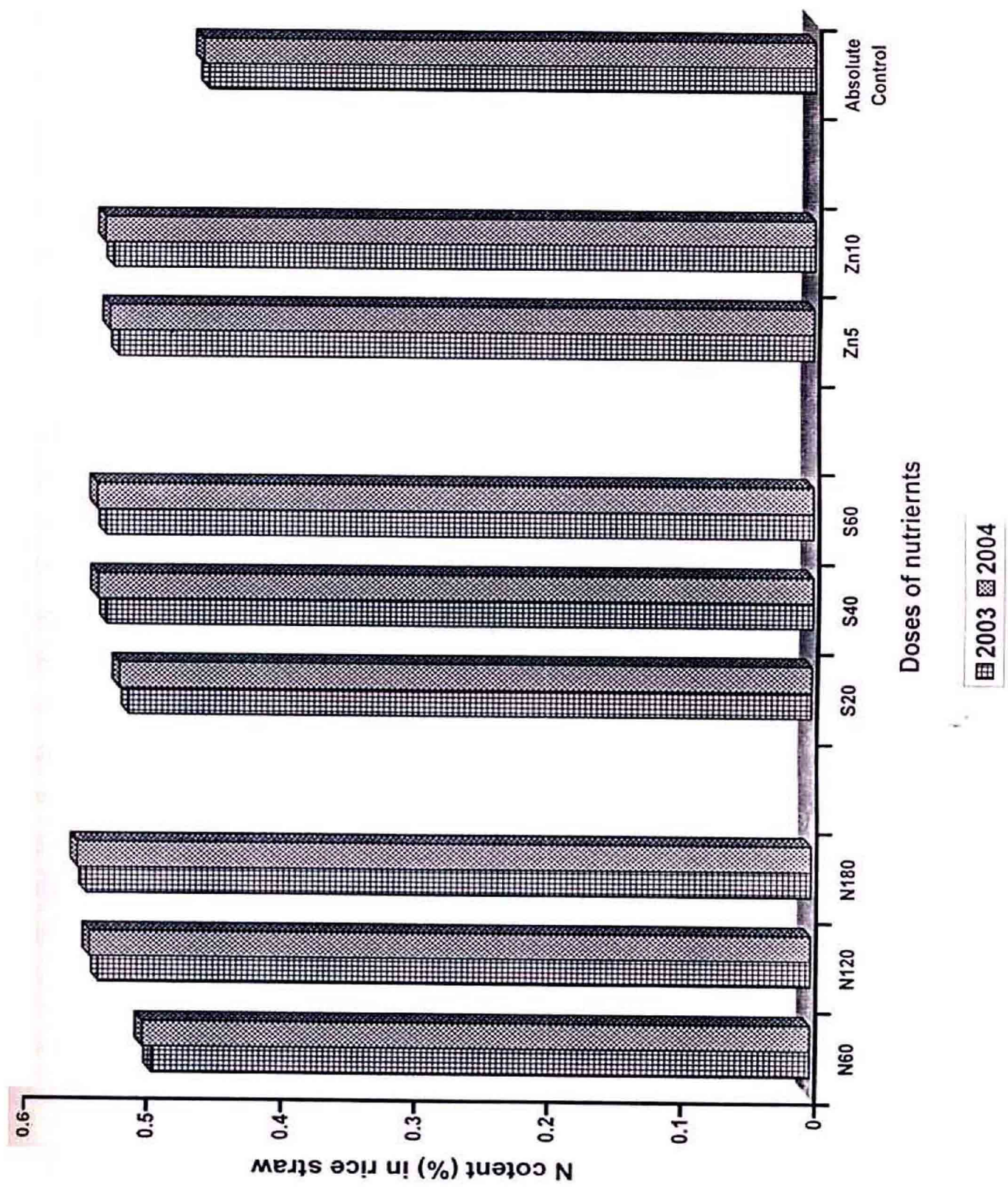


Fig 4.5: Effect of N, S & Zn on N content (%) in rice straw

Combined application of N x S, S x Zn, N x Zn and N x S x Zn did not increase nitrogen content (%) significantly in rice straw. All the interactions were noted to be non-significant. However, maximum values were noted at $N_3S_3Zn_2$ level during both the years of investigation.

4.2.1.2 P content in rice plant

The data in respect of P contents are presented in Tables 4.31 and 4.32 at 30th and 60th day of transplanting during both the years, respectively.

4.2.1.2.1 At 30th day of transplanting

Data presented in Table 4.31 show that the application of nitrogen significantly increased P content (%) in rice at 30th day of transplanting upto 120 kg N ha⁻¹ and thereafter P content increased but it was noted to be non-significant. At 120 kg N ha⁻¹ application phosphorus contents were recorded 27.16 and 27.50 percent higher over absolute control during 2003 and 2004, respectively. Application of sulphur significantly increased P content upto 40 kg S ha⁻¹ and thereafter it decreased non-significantly upto 60 kg S ha⁻¹. P contents at 40 kg S ha⁻¹ were recorded 26.41 and 26.39 percent higher over absolute control during 2003 and 2004, respectively. Application of zinc also increased P content upto 5 kg Zn ha⁻¹ and thereafter it decreased significantly upto 10 kg Zn ha⁻¹ due to antagonistic relationship of P and Zn at their higher levels of application. The minimum P content was noted at absolute control during both the years.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were recorded to be non-significant on P content (%). However, maximum values of P were noted at $N_3S_2Zn_1$ during both the years of investigation.

4.2.1.2.2 At 60th day of transplanting

Data presented in Table 4.32 show that the application of nitrogen significantly increased P content upto 120 kg N ha⁻¹ and thereafter it increased upto 180kg N ha⁻¹ but the increase was noted to be non-significant. Application of sulphur increased phosphorus contents upto 40 kg S ha⁻¹ and

Table 4.31: Effect of N, S and Zn on P content (%) of rice at 30th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.292	0.314	0.311	0.305	0.297	0.319	0.316	0.310
	Zn ₂	0.284	0.306	0.302	0.297	0.290	0.311	0.308	0.303
Mean		0.288	0.310	0.306	0.301	0.293	0.315	0.312	0.306
N ₂	Zn ₁	0.329	0.350	0.346	0.341	0.334	0.355	0.351	0.346
	Zn ₂	0.321	0.342	0.338	0.333	0.327	0.347	0.344	0.339
Mean		0.325	0.348	0.342	0.337	0.330	0.351	0.347	0.343
N ₃	Zn ₁	0.341	0.354	0.350	0.348	0.346	0.358	0.353	0.352
	Zn ₂	0.333	0.346	0.341	0.340	0.339	0.350	0.346	0.345
Mean		0.337	0.350	0.345	0.344	0.342	0.354	0.349	0.348
Mean of the means		0.316	0.335	0.331	0.327	0.322	0.340	0.336	0.332
Absolute Control					0.265				0.269

N	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.004	CD (5%)	0.008
S	0.005	0.010	0.004	0.008	0.004	0.008	0.006	0.008
Zn	0.004	0.008	N.S.	N.S.	0.003	0.007	N.S.	N.S.
N x S	0.008	0.007	N.S.	N.S.	0.006	0.006	N.S.	N.S.
S x Zn	0.007	0.012	N.S.	N.S.	0.010	0.007	N.S.	N.S.
N x Zn	0.007	0.009	0.018	0.014				
N x S x Zn								
Absolute Control/Treatments								

Table 4.32: Effect of N, S and Zn on P content (%) of rice at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.231	0.261	0.248	0.243	0.240	0.259	0.255	0.251
	Zn ₂	0.224	0.243	0.240	0.235	0.233	0.251	0.247	0.243
Mean		0.227	0.247	0.244	0.239	0.236	0.255	0.251	0.247
N ₂	Zn ₁	0.273	0.292	0.288	0.284	0.281	0.300	0.297	0.292
	Zn ₂	0.266	0.284	0.281	0.277	0.275	0.292	0.288	0.285
Mean		0.269	0.288	0.284	0.280	0.278	0.296	0.292	0.288
N ₃	Zn ₁	0.285	0.295	0.293	0.291	0.294	0.304	0.301	0.299
	Zn ₂	0.278	0.288	0.284	0.283	0.287	0.296	0.292	0.291
Mean		0.281	0.292	0.288	0.287	0.290	0.300	0.296	0.295
Mean of the means		0.259	0.275	0.272	0.269	0.268	0.283	0.280	0.277
Absolute Control					0.208				0.215

N	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
S	0.005	0.010	0.005	0.010	0.005	0.010	0.008	N.S.
Zn	0.004	0.008	0.009	N.S.	0.007	0.007	N.S.	N.S.
N x S	0.007	N.S.	0.012	N.S.	0.012	0.012	N.S.	0.018
S x Zn	0.007	N.S.	0.009	0.009	0.009	0.009	0.018	
N x Zn	0.007	N.S.	0.009	0.009	0.009	0.009	0.018	
N x S x Zn	0.012	N.S.	0.012	0.012	0.012	0.012	0.018	
Absolute Control/Treatments	0.009	0.018	0.009	0.018	0.009	0.018	0.018	

thereafter it decreased but the decline was non-significant. Application of zinc also increased P content upto 5 kg Zn ha⁻¹ and thereafter it decreased significantly. Minimum P content was recorded at absolute control recording 0.208 and 0.215 per cent during 2003 and 2004, respectively.

The interaction effect of N x S, S x Zn, N x Zn and N x S x Zn on the P content of rice at 60th day of transplanting were non-significant. However, maximum values were noted at N₃S₂Zn₁ level during both the years of experimentation.

4.2.1.2.3 P content in rice grain

The data pertaining to P contents in grain are presented in Table 4.33 and depicted in Fig 4.6. The data reveal that P content in rice grain increased by the application of graded doses of nitrogen significantly upto 120 kg N ha⁻¹ and thereafter it increased non significantly. At 120 kg N ha⁻¹ P content was recorded 12.50 and 12.25 per cent higher over absolute control during 2003 and 2004, respectively. Application of sulphur increased P content significantly upto 40 kg S ha⁻¹ recording 0.342 and 0.345 per cent during 2003 and 2004, respectively. Beyond 40 kg S ha⁻¹ P content was decreased non significantly due to antagonistic relationship between P and S at their higher levels. Zinc application also increased P content significantly upto 5 kg Zn ha⁻¹ and thereafter decreased it significantly. However, the minimum P contents were noted at absolute control during both the years of study.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on P content in rice grain were non-significant but maximum values were noted at N₃S₂Zn₁ level, during both the years of experimentation.

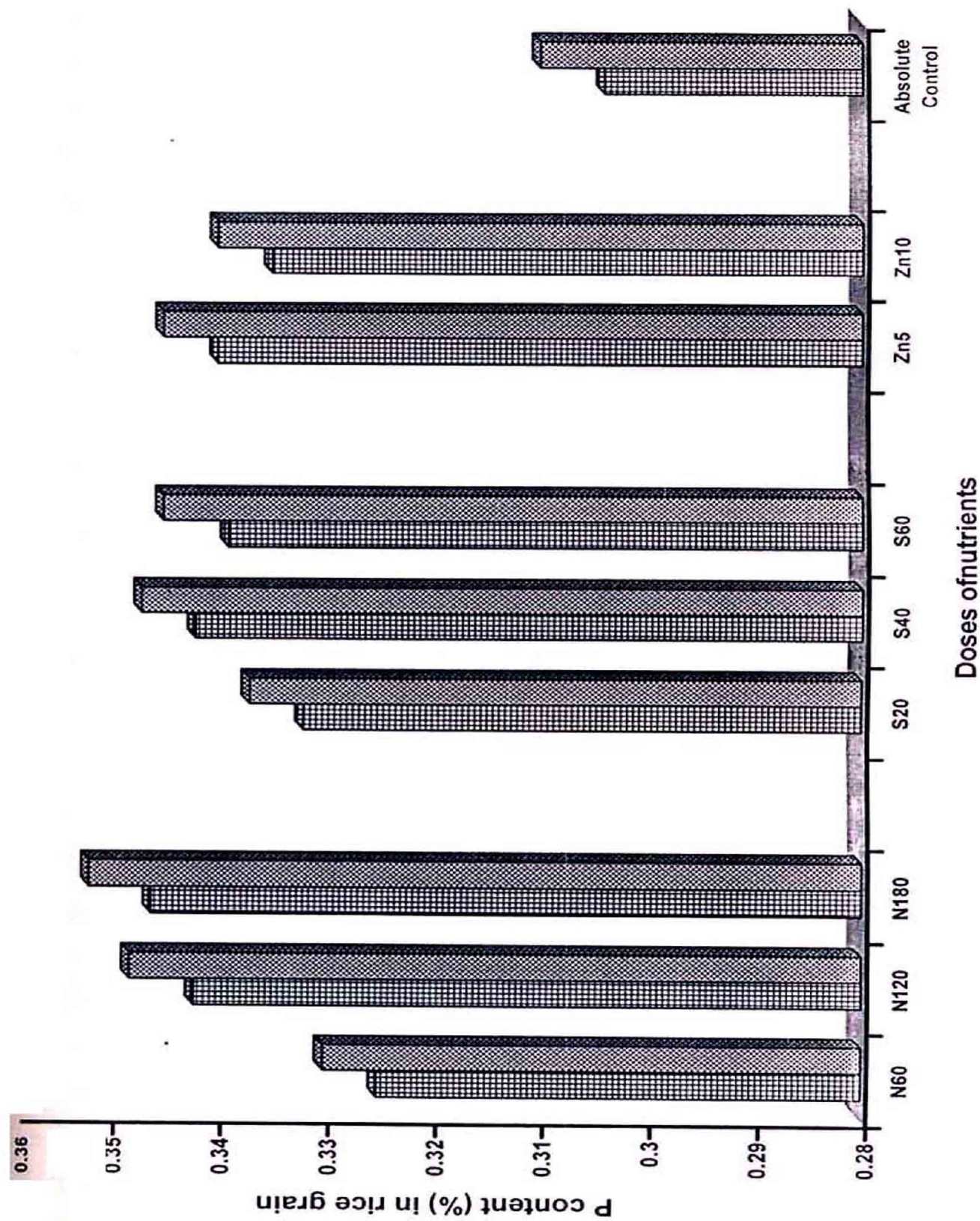
4.2.1.2.4 P content in rice straw

The data on P content in straw are presented in Table 4.34 and depicted with Fig 4.7. It is obvious from the data that application of nitrogen significantly increased P content in rice straw upto 120 kg N ha⁻¹ and thereafter it increased non significantly upto 180 kg N ha⁻¹ recording 0.119

Table 4.33: Effect of N, S and Zn on P content (%) in rice grain

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.322	0.332	0.330	0.328	0.326	0.337	0.335	0.332
	Zn ₂	0.317	0.327	0.325	0.323	0.321	0.332	0.330	0.327
Mean		0.319	0.329	0.227	0.325	0.323	0.334	0.332	0.330
N ₂	Zn ₁	0.339	0.350	0.347	0.345	0.344	0.356	0.353	0.351
	Zn ₂	0.334	0.345	0.342	0.340	0.339	0.351	0.348	0.346
Mean		0.336	0.347	0.344	0.342	0.341	0.353	0.350	0.348
N ₃	Zn ₁	0.345	0.352	0.349	0.348	0.351	0.358	0.355	0.354
	Zn ₂	0.340	0.347	0.344	0.343	0.346	0.353	0.350	0.349
Mean		0.342	0.349	0.346	0.346	0.348	0.355	0.352	0.352
Mean of the means		0.332	0.342	0.339	0.338	0.337	0.347	0.345	0.343
Absolute Control					0.304				0.310

N	SE (diff.)	0.003	CD (5%)	0.007	SE (diff.)	0.003	CD (5%)	0.007
S	SE (diff.)	0.003	CD (5%)	0.007	SE (diff.)	0.003	CD (5%)	0.007
Zn	SE (diff.)	0.002	CD (5%)	0.005	SE (diff.)	0.002	CD (5%)	0.005
N x S	SE (diff.)	0.006	CD (5%)	N.S.	SE (diff.)	0.006	CD (5%)	N.S.
S x Zn	SE (diff.)	0.005	CD (5%)	N.S.	SE (diff.)	0.005	CD (5%)	N.S.
N x Zn	SE (diff.)	0.005	CD (5%)	N.S.	SE (diff.)	0.005	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.008	CD (5%)	N.S.	SE (diff.)	0.008	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.006	CD (5%)	0.012	SE (diff.)	0.006	CD (5%)	0.012



■ 2003 ■ 2004

Fig 4.6: Effect of N, S & Zn on P content (%) in rice grain

and 0.124 percent during 2003 and 2004, respectively. S application increased P content upto 40 kg S ha⁻¹ and thereafter it decreased non-significantly. The minimum P contents were recorded at absolute control during both the years. Application of zinc also increased P content significantly upto 5 kg Zn ha⁻¹ recording 0.117 and 0.122 per cent during 2003 and 2004, respectively and thereafter it decreased significantly showing antagonistic relationship between P and Zn at their higher levels of application.

The interaction effect of N x S, S x Zn, N x Zn and N x S x Zn on P content in rice straw were observed to be non-significant during both the years of experimentation.

4.2.1.3 K content in rice plant

The data on K content at 30th and 60th day of transplanting are presented in Tables 4.35 and 4.36, respectively.

4.2.1.3.1 At 30th day of Transplanting

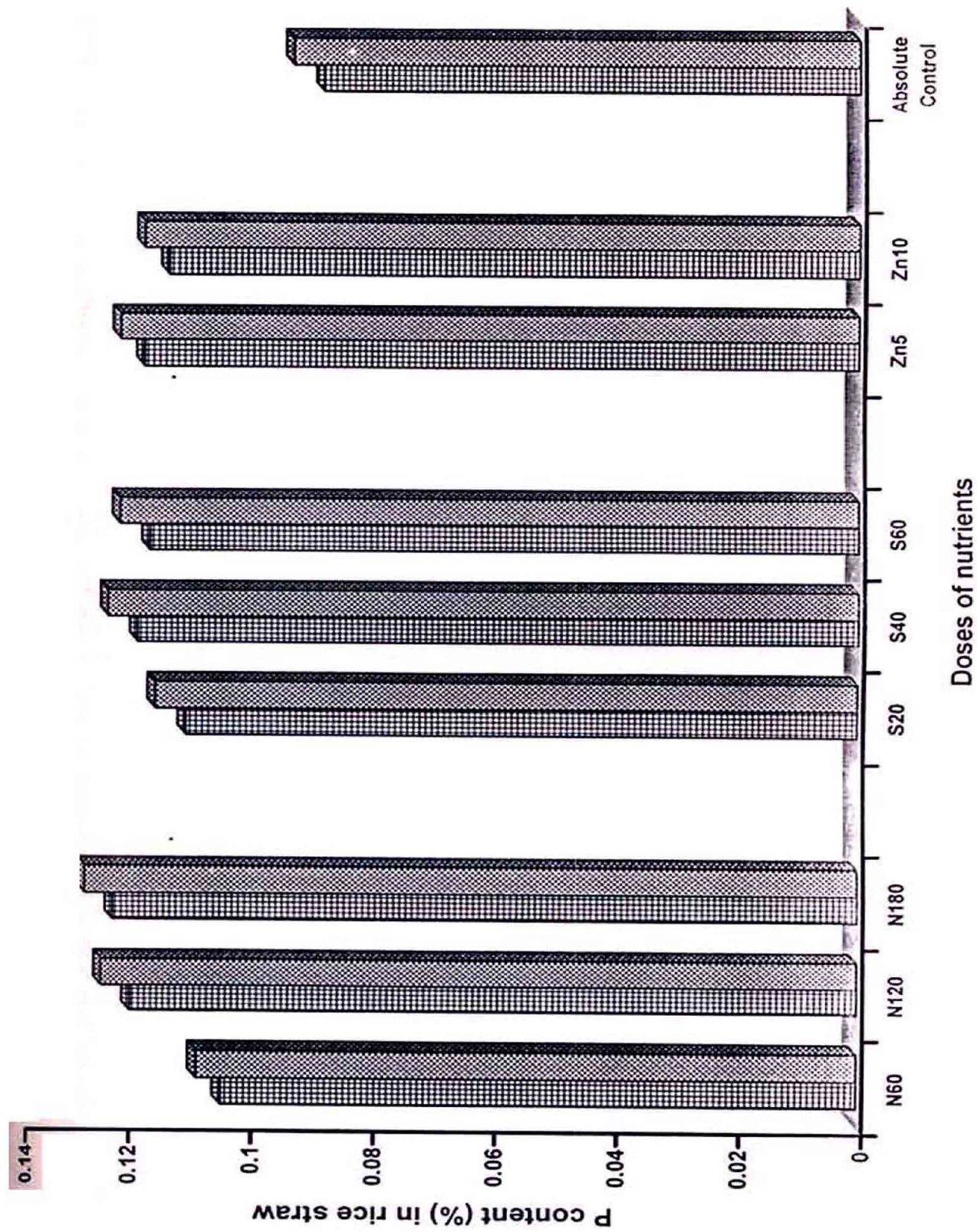
The effect of different doses of N, S & Zn on K content at 30th day of transplanting (Table 4.35) clearly reveal that application of different doses of nitrogen accelerated the absorption of K at 30th day of crop growth during both the years. Application of nitrogen significantly increased K content upto 120 Kg N ha⁻¹ recording 24.95 and 25.08 percent higher over absolute control and thereafter it was increased non-significantly upto 180 kg N ha⁻¹ during both the years. However, minimum K contents were recorded at absolute control during both the years. Application of sulphur increased K content significantly upto 40Kg S ha⁻¹ whereas zinc dressings increased K content significantly upto 5 kg Zn ha⁻¹ during both the years, respectively. Application of 60 kg S and 10 kg Zn ha⁻¹ increased K content non-significantly during both the years.

However, the interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on K content were non-significant but maximum values were noted at N₃S₃Zn₂ level during both the years of experimentation.

Table 4.34: Effect of N, S and Zn on P content (%) in straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.101	0.109	0.108	0.106	0.106	0.114	0.112	0.110
	Zn ₂	0.097	0.105	0.104	0.102	0.102	0.110	0.108	0.106
Mean		0.099	0.107	0.106	0.104	0.104	0.112	0.110	0.108
N ₂	Zn ₁	0.116	0.125	0.123	0.121	0.121	0.130	0.128	0.126
	Zn ₂	0.112	0.121	0.119	0.117	0.117	0.126	0.124	0.122
Mean		0.114	0.123	0.121	0.119	0.119	0.128	0.126	0.124
N ₃	Zn ₁	0.121	0.127	0.125	0.124	0.126	0.132	0.130	0.129
	Zn ₂	0.117	0.123	0.121	0.120	0.122	0.128	0.126	0.125
Mean		0.119	0.125	0.123	0.122	0.124	0.130	0.128	0.127
Mean of the means		0.110	0.118	0.116	0.115	0.115	0.123	0.121	0.120
Absolute Control					0.088				0.093

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	0.003	0.006	0.003	0.006
S	0.003	0.006	0.003	0.006
Zn	0.002	0.004	0.002	0.004
N x S	0.005	N.S.	0.005	N.S.
S x Zn	0.004	N.S.	0.004	N.S.
N x Zn	0.004	N.S.	0.004	N.S.
N x S x Zn	0.007	N.S.	0.007	N.S.
Absolute Control/Treatments	0.005	0.010	0.005	0.010



■ 2003 ■ 2004

Fig 4.7: Effect of N, S & Zn on P content (%) in rice straw

Table 4.35: Effect of N, S and Zn on K content (%) of rice at 30th day of transplanting .

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	2.207	2.217	2.218	2.214	2.211	2.220	2.221	2.217
	Zn ₂	2.210	2.219	2.220	2.216	2.214	2.223	2.224	2.220
Mean		2.208	2.218	2.219	2.215	2.212	2.221	2.222	2.218
N ₂	Zn ₁	2.221	2.230	2.231	2.227	2.226	2.236	2.237	2.233
	Zn ₂	2.224	2.232	2.233	2.229	2.229	2.238	2.239	2.235
Mean		2.222	2.231	2.232	2.228	2.227	2.237	2.238	2.234
N ₃	Zn ₁	2.226	2.233	2.234	2.231	2.231	2.239	2.240	2.236
	Zn ₂	2.229	2.236	2.236	2.233	2.234	2.241	2.242	2.239
Mean		2.227	2.234	2.235	2.232	2.232	2.240	2.241	2.237
Mean of the means		2.219	2.227	2.228	2.225	2.224	2.232	2.233	2.230
Absolute Control					1.783				1.786

N	SE (diff.)	0.003	CD (5%)	0.006	SE (diff.)	0.003	CD (5%)	0.006
S	SE (diff.)	0.003	CD (5%)	0.006	SE (diff.)	0.003	CD (5%)	0.006
Zn	SE (diff.)	0.002	CD (5%)	0.005	SE (diff.)	0.002	CD (5%)	0.005
N x S	SE (diff.)	0.005	CD (5%)	N.S.	SE (diff.)	0.005	CD (5%)	N.S.
S x Zn	SE (diff.)	0.004	CD (5%)	N.S.	SE (diff.)	0.004	CD (5%)	N.S.
N x Zn	SE (diff.)	0.004	CD (5%)	N.S.	SE (diff.)	0.004	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010

4.2.1.3.2 At 60th day of transplanting

It is apparent from the data presented in Table 4.36 that application of nitrogen significantly increased K content upto 120 Kg Nha⁻¹ recording 18.61 and 17.05 percent higher over absolute control during 2003 and 2004, respectively, and thereafter it increased non-significantly. However, minimum K contents were recorded at absolute control, during both the years. Similarly, application of sulphur increased K content significantly upto 40 Kg Sha⁻¹ whereas zinc dressings significantly enhanced K content upto 5 Kg Znha⁻¹ and thereafter it was increased non-significantly during both the years.

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were noted to be non-significant on K content during both the years of experimentation.

4.2.1.3.3 In rice grain

The data on K content in grain of rice are presented in Table 4.37 and depicted with Fig 4.8. The data clearly reveal that application of nitrogen increased K content significantly upto 120 Kg Nha⁻¹ recording 0.409 and 0.416 percent which were computed for 22.45 and 22.71 percent higher over absolute control during 2003 and 2004, respectively, however, K content increased upto 180 kg N ha⁻¹ but it was at par with its lower dose of N application. The minimum K contents were recorded at absolute control during both the years. Similarly, application of sulphur increased K content significantly upto 40 kg Sha⁻¹ whereas zinc application increased K content significantly upto 5Kg Znha⁻¹ and thereafter it was increased non significantly upto 60 kg S and 10 kg Znha⁻¹ during both the years.

However, effects of all the interactions of N x S, S x Zn, N x Zn and N x S x Zn were found to be non-significant on K content but maximum values were noted at N₃S₃Zn₂ level during both the years of experimentation.

4.2.1.3.4 In rice straw

The data on K content in rice straw are presented in Table 4.38 and depicted with Fig 4.9. It is obvious from the data that the application of

Table 4.36: Effect of N, S and Zn on K content (%) of rice at 60th day of transplanting

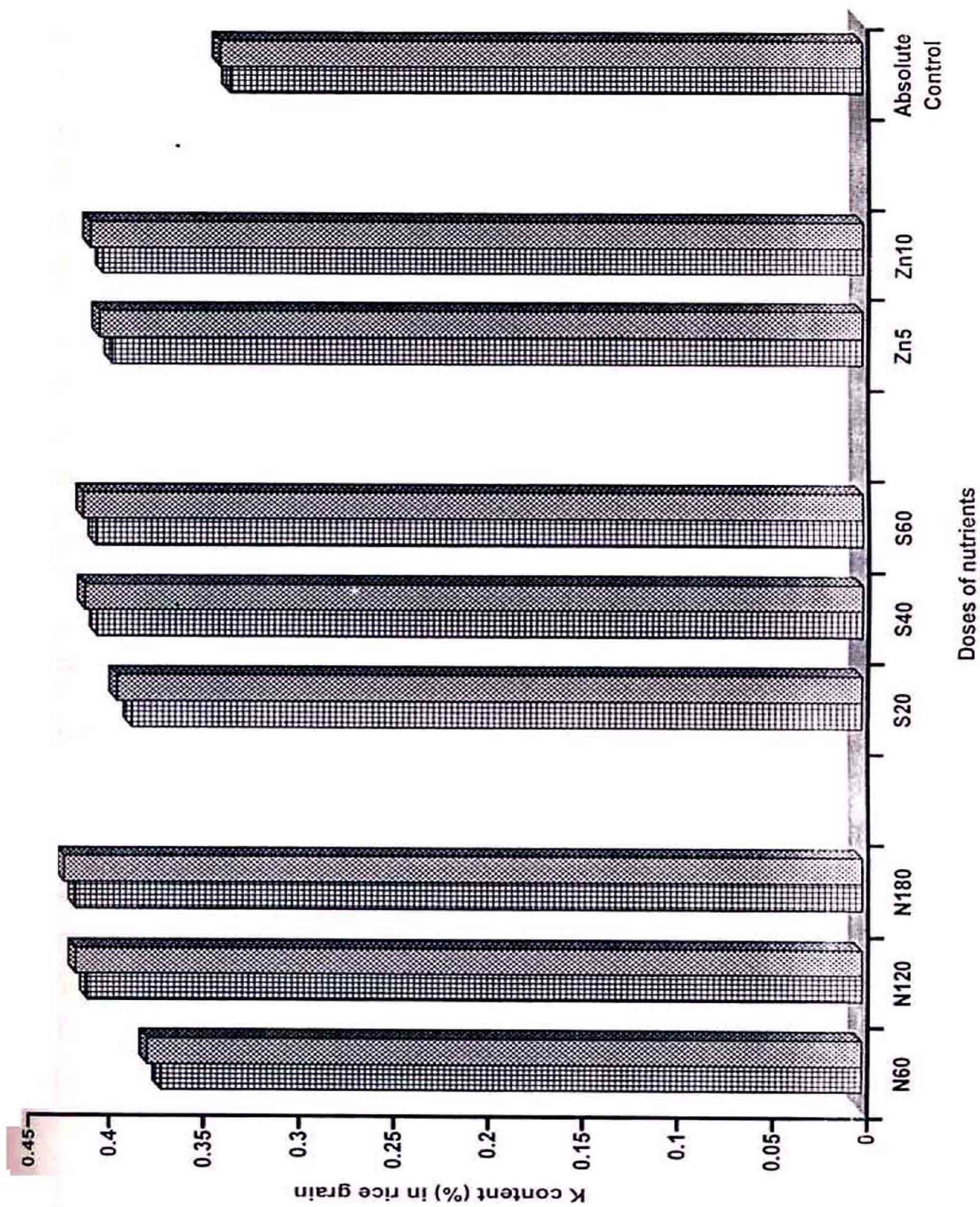
Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	1.744	1.795	1.797	1.778	1.780	1.804	1.806	1.796
	Zn ₂	1.755	1.804	1.806	1.788	1.787	1.809	1.811	1.802
Mean		1.749	1.799	1.801	1.783	1.783	1.806	1.808	1.799
N ₂	Zn ₁	1.834	1.874	1.876	1.861	1.844	1.888	1.891	1.874
	Zn ₂	1.847	1.881	1.884	1.870	1.851	1.894	1.896	1.880
Mean		1.840	1.877	1.880	1.866	1.847	1.891	1.893	1.877
N ₃	Zn ₁	1.859	1.884	1.886	1.876	1.869	1.894	1.896	1.886
	Zn ₂	1.869	1.893	1.895	1.885	1.875	1.901	1.902	1.892
Mean		1.864	1.888	1.890	1.880	1.872	1.897	1.899	1.889
Mean of the means		1.818	1.855	1.857	1.843	1.834	1.865	1.867	1.855
Absolute Control					1.590				1.612

N	SE (diff.)	0.011	CD (5%)	0.026	SE (diff.)	0.010	CD (5%)	0.020
S	SE (diff.)	0.011	CD (5%)	0.026	SE (diff.)	0.010	CD (5%)	0.020
Zn	SE (diff.)	0.009	CD (5%)	0.018	SE (diff.)	0.008	CD (5%)	0.016
N x S	SE (diff.)	0.019	CD (5%)	N.S.	SE (diff.)	0.017	CD (5%)	N.S.
S x Zn	SE (diff.)	0.015	CD (5%)	N.S.	SE (diff.)	0.014	CD (5%)	N.S.
N x Zn	SE (diff.)	0.015	CD (5%)	N.S.	SE (diff.)	0.014	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.026	CD (5%)	N.S.	SE (diff.)	0.024	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.019	CD (5%)	0.039	SE (diff.)	0.018	CD (5%)	0.036

Table 4.37: Effect of N, S and Zn on K content (%) in grain of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.352	0.374	0.376	0.367	0.360	0.381	0.382	0.374
	Zn ₂	0.357	0.379	0.380	0.372	0.365	0.386	0.387	0.379
Mean		0.354	0.376	0.378	0.369	0.362	0.383	0.384	0.376
N ₂	Zn ₁	0.392	0.414	0.416	0.407	0.400	0.421	0.422	0.414
	Zn ₂	0.397	0.419	0.421	0.412	0.405	0.426	0.427	0.419
Mean		0.394	0.416	0.418	0.409	0.402	0.423	0.424	0.416
N ₃	Zn ₁	0.406	0.418	0.419	0.414	0.412	0.425	0.426	0.421
	Zn ₂	0.411	0.423	0.423	0.419	0.417	0.430	0.431	0.426
Mean		0.408	0.420	0.421	0.416	0.414	0.427	0.428	0.423
Mean of the means		0.385	0.404	0.405	0.398	0.393	0.411	0.412	0.405
Absolute Control					0.334				0.339

N	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
S	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
Zn	SE (diff.)	0.004	CD (5%)	0.008	SE (diff.)	0.004	CD (5%)	0.008
N x S	SE (diff.)	0.009	CD (5%)	N.S.	SE (diff.)	0.009	CD (5%)	N.S.
S x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
N x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.012	CD (5%)	N.S.	SE (diff.)	0.012	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.009	CD (5%)	0.018	SE (diff.)	0.009	CD (5%)	0.018



■ 2003 ■ 2004

Fig 4.8: Effect of N, S & Zn on K content (%) in rice grain

nitrogen significantly increased K content upto 120 kg N ha⁻¹ recording 1.426 and 1.431 per cent during 2003 and 2004, respectively, However, K content was increased upto 180 kg N ha⁻¹ which was at par with its lower level of N application. However, minimum K contents were recorded at absolute control during both the years of study. Application of sulphur increased K content significantly upto 40 kg S ha⁻¹ whereas zinc application significantly increased K content upto 5 kg Zn ha⁻¹ and thereafter it was increased non-significantly upto 60 kg S and 10 kg Znha⁻¹ during both the years.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on K content in rice straw were non-significant but showed increasing trend and maximum values were noted at N₃S₃Zn₂ level during both the years of experimentation.

4.2.1.4 S content in rice plant

The data on S content at 30th and 60th day of transplanting are presented in Tables 4.39 and 4.40 during both the years, respectively.

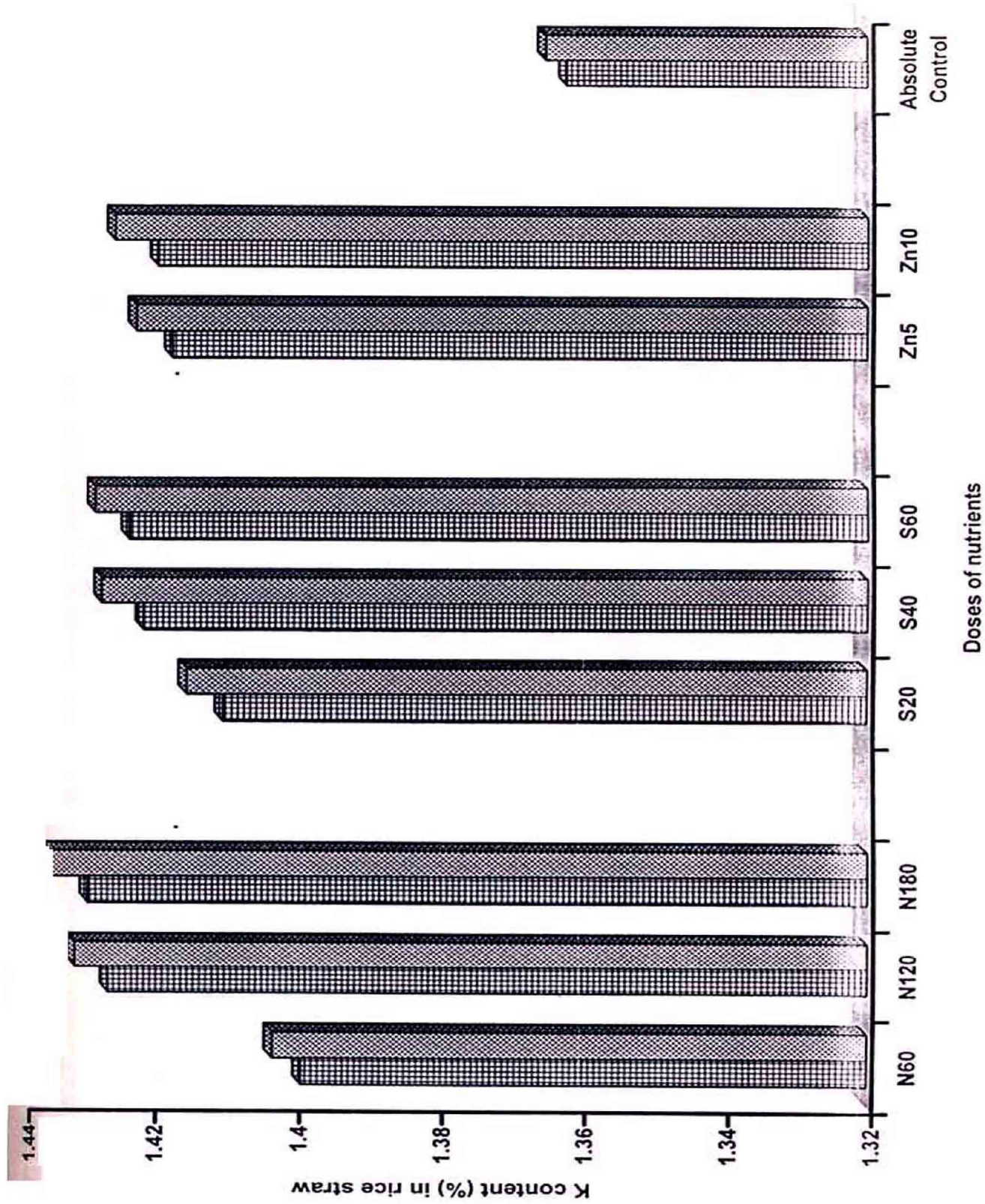
4.2.1.4.1 At 30th day of transplanting

It is obvious from the data presented in Table 4.39 that application of different doses of nitrogen increased S content significantly upto 120 kg Nha⁻¹ recording 0.298 and 0.301 percent which were found to be 21.63 and 21.86 per cent higher over absolute control during 2003 and 2004, respectively. Similarly, application of sulphur increased S content upto 40 kg S ha⁻¹ and were computed to be 20.81 and 21.25 per cent higher over absolute control during 2003 and 2004, respectively and thereafter it was increased non-significantly whereas zinc dressings increased S content significantly upto 5 kg Znha⁻¹ and thereafter it declined significantly upto 10 kg Znha⁻¹ during both the years showing antagonistic relationship between S and Zn at their higher levels of application. However, minimum S contents were recorded at absolute control, during both the years. The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were noticed to be non-significant on S content at 30th day of transplanting during both the years of experimentation.

Table 4.38: Effect of N, S and Zn on K content (%) in straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	1.389	1.402	1.403	1.398	1.393	1.407	1.408	1.402
	Zn ₂	1.391	1.404	1.405	1.400	1.396	1.410	1.411	1.405
Mean		1.390	1.403	1.404	1.399	1.394	1.408	1.409	1.403
N ₂	Zn ₁	1.415	1.429	1.431	1.425	1.421	1.434	1.435	1.430
	Zn ₂	1.417	1.431	1.433	1.427	1.424	1.437	1.438	1.433
Mean		1.416	1.430	1.432	1.426	1.422	1.435	1.436	1.431
N ₃	Zn ₁	1.423	1.431	1.432	1.428	1.429	1.437	1.438	1.434
	Zn ₂	1.425	1.433	1.434	1.430	1.432	1.440	1.441	1.437
Mean		1.424	1.432	1.433	1.429	1.430	1.438	1.439	1.435
Mean of the means		1.410	1.421	1.423	1.418	1.415	1.427	1.428	1.423
Absolute Control					1.362				1.365

N	SE (diff.)	0.003	CD (5%)	0.006	SE (diff.)	0.003	CD (5%)	0.006
S	SE (diff.)	0.003	CD (5%)	0.006	SE (diff.)	0.003	CD (5%)	0.006
Zn	SE (diff.)	0.002	CD (5%)	0.005	SE (diff.)	0.002	CD (5%)	0.005
N x S	SE (diff.)	0.005	CD (5%)	N.S.	SE (diff.)	0.005	CD (5%)	N.S.
S x Zn	SE (diff.)	0.004	CD (5%)	N.S.	SE (diff.)	0.004	CD (5%)	N.S.
N x Zn	SE (diff.)	0.004	CD (5%)	N.S.	SE (diff.)	0.004	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010



■ 2003 ▨ 2004

Fig 4.9: Effect of N, S & Zn on K content (%) in rice straw

Table 4.39: Effect of N, S and Zn on S content (%) of rice at 30th day of transplanting

Treatments		2003			Mean		2004			Mean
		S ₁	S ₂	S ₃			S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.267	0.284	0.295	0.282		0.269	0.286	0.299	0.285
	Zn ₂	0.263	0.280	0.279	0.274		0.265	0.282	0.281	0.276
Mean		0.265	0.282	0.287	0.278		0.267	0.284	0.290	0.280
N ₂	Zn ₁	0.289	0.305	0.311	0.301		0.291	0.310	0.315	0.305
	Zn ₂	0.285	0.299	0.299	0.294		0.287	0.302	0.301	0.297
Mean		0.287	0.302	0.305	0.298		0.289	0.306	0.308	0.301
N ₃	Zn ₁	0.290	0.306	0.311	0.302		0.292	0.312	0.316	0.307
	Zn ₂	0.286	0.300	0.299	0.295		0.288	0.302	0.300	0.297
Mean		0.288	0.303	0.305	0.299		0.290	0.307	0.308	0.302
Mean of the means		0.280	0.296	0.299	0.292		0.282	0.299	0.302	0.294
Absolute Control					0.245					0.247

N	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
S	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
Zn	SE (diff.)	0.004	CD (5%)	0.008	SE (diff.)	0.004	CD (5%)	0.008
N x S	SE (diff.)	0.008	CD (5%)	N.S.	SE (diff.)	0.008	CD (5%)	N.S.
S x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
N x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.012	CD (5%)	N.S.	SE (diff.)	0.012	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.009	CD (5%)	0.018	SE (diff.)	0.009	CD (5%)	0.018

4.2.1.4.2 At 60th day of transplanting

Data presented in Table 4.40 clearly indicate that application of nitrogen significantly increased S content upto 120 kg Nha⁻¹ application recording 0.251 and 0.252 per cent during 2003 and 2004, respectively whereas minimum S contents were recorded at absolute control during both the years. Application of sulphur increased S content significantly upto 40 kg Sha⁻¹ showing 26.39 and 26.26 per cent higher over absolute control during 2003 and 2004, respectively and thereafter it increased non-significantly. The application of zinc significantly increased S content upto 5kg Znha⁻¹ and thereafter it decreased significantly upto 10 kg Znha⁻¹ during both the years showing antagonistic relationship between S and Zn at their higher levels of application.

Effects of all the interactions of N x S, S x Zn, N x Zn and N x S x Zn were noticed to be non-significant on S content (%) at 60th day of transplanting during both the years of experimentation.

4.2.1.4.3 In rice grain

The data on S content (%) in rice grain are presented in Table 4.41 and depicted with Fig 4.10, respectively during both the years. It is obvious from the data that application of nitrogen significantly increased S concentration upto 120 kg Nha⁻¹ and thereafter the increase was noticed to be non-significant recording 0.191 and 0.193 per cent during 2003 and 2004, respectively. The minimum S contents were recorded at absolute control during both the years. Application of sulphur increased S concentration significantly upto 40 kg Sha⁻¹ noting down 37.95 and 37.41 percent higher over absolute control during 2003 and 2004, respectively and thereafter it did not increased significantly whereas zinc dressings increased S content significantly upto 5 kg Znha⁻¹ application and thereafter it decreased significantly during both the years showing antagonistic relationship between S and Zn at their higher levels of application.

However, effects of all the interactions have been noticed to be non-significant on S content (%) during both the years of experimentation.

Table 4.40: Effect of N, S and Zn on S content (%) of rice at 60th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.219	0.236	0.249	0.235	0.220	0.237	0.250	0.236
	Zn ₂	0.215	0.232	0.231	0.226	0.216	0.233	0.232	0.227
Mean		0.217	0.234	0.240	0.230	0.218	0.235	0.241	0.231
N ₂	Zn ₁	0.241	0.260	0.265	0.255	0.242	0.261	0.266	0.256
	Zn ₂	0.237	0.252	0.251	0.247	0.238	0.253	0.252	0.248
Mean		0.239	0.256	0.258	0.251	0.240	0.257	0.259	0.252
N ₃	Zn ₁	0.242	0.261	0.266	0.256	0.243	0.262	0.267	0.257
	Zn ₂	0.238	0.253	0.252	0.248	0.239	0.254	0.253	0.249
Mean		0.240	0.257	0.259	0.252	0.241	0.258	0.260	0.253
Mean of the means		0.232	0.249	0.252	0.244	0.233	0.250	0.253	0.245
Absolute Control					0.197				0.198

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	0.005	0.010	0.004	0.008
S	0.005	0.010	0.004	0.008
Zn	0.004	0.008	0.003	0.006
N x S	0.008	N.S.	0.007	N.S.
S x Zn	0.007	N.S.	0.006	N.S.
N x Zn	0.007	N.S.	0.006	N.S.
N x S x Zn	0.012	N.S.	0.010	N.S.
Absolute Control/Treatments	0.009	0.018	0.007	0.014

Table 4.41: Effect of N, S and Zn on S content (%) in rice grain

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.159	0.176	0.189	0.175	0.161	0.178	0.191	0.177
	Zn ₂	0.155	0.172	0.171	0.166	0.157	0.174	0.173	0.168
Mean		0.157	0.174	0.180	0.170	0.159	0.176	0.182	0.172
N ₂	Zn ₁	0.181	0.200	0.205	0.195	0.183	0.202	0.207	0.197
	Zn ₂	0.177	0.192	0.191	0.187	0.179	0.194	0.193	0.189
Mean		0.179	0.196	0.198	0.191	0.181	0.198	0.200	0.193
N ₃	Zn ₁	0.182	0.201	0.206	0.196	0.184	0.203	0.208	0.198
	Zn ₂	0.178	0.193	0.192	0.188	0.180	0.195	0.194	0.190
Mean		0.180	0.197	0.199	0.192	0.182	0.199	0.201	0.194
Mean of the means		0.172	0.189	0.192	0.184	0.174	0.191	0.194	0.186
Absolute Control					0.137				0.139

N	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
S	SE (diff.)	0.005	CD (5%)	0.010	SE (diff.)	0.005	CD (5%)	0.010
Zn	SE (diff.)	0.004	CD (5%)	0.008	SE (diff.)	0.004	CD (5%)	0.008
N x S	SE (diff.)	0.008	CD (5%)	N.S.	SE (diff.)	0.008	CD (5%)	N.S.
S x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
N x Zn	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.012	CD (5%)	N.S.	SE (diff.)	0.012	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.009	CD (5%)	0.018	SE (diff.)	0.009	CD (5%)	0.018

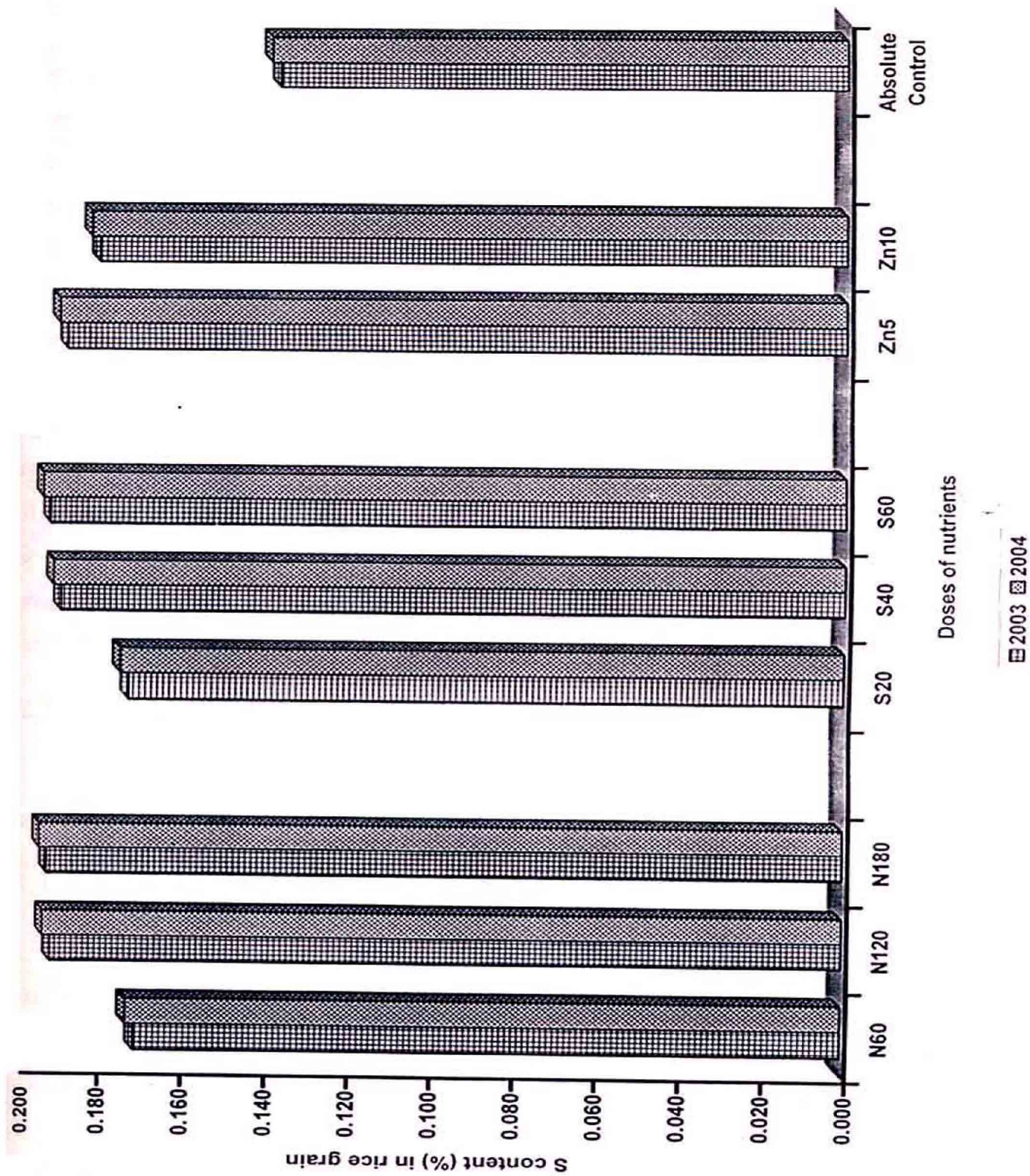


Fig 4.10: Effect of N, S & Zn on S content (%) in rice grain

4.2.1.4.4 In rice straw

Data on S content (%) in straw of rice are presented in Table 4.42 and depicted with Fig 4.11. The data clearly reveal that the effects of N, S and Zn and their interactions on S content in straw of rice have shown the same results as in grain of rice during both the years. Application of nitrogen significantly increased S content upto 120 kg Nha⁻¹ recording 0.086 and 0.089 per cent during 2003 and 2004, respectively and thereafter it increased non-significantly whereas minimum S contents were recorded at absolute control during both the years. Effect of sulphur recorded increase significantly upto 40 kg Sha⁻¹ on S content in straw of rice during both the years showing 20.0 and 21.56 per cent higher over absolute control during 2003 and 2004, respectively. Zn application increased S content significantly upto 5 kg Znha⁻¹ and thereafter declined significantly upto 10 kg Znha⁻¹ during both the years. The interaction effects have been found to be non-significant on S content during both the years of experimentation, however maximum S contents were noted at N₃S₃Zn₁ level.

4.2.1.5 Zn content in rice plant

The data pertaining to Zn contents at 30th and 60th day of transplanting are presented in Tables 4.43 and 4.44, respectively during both the year.

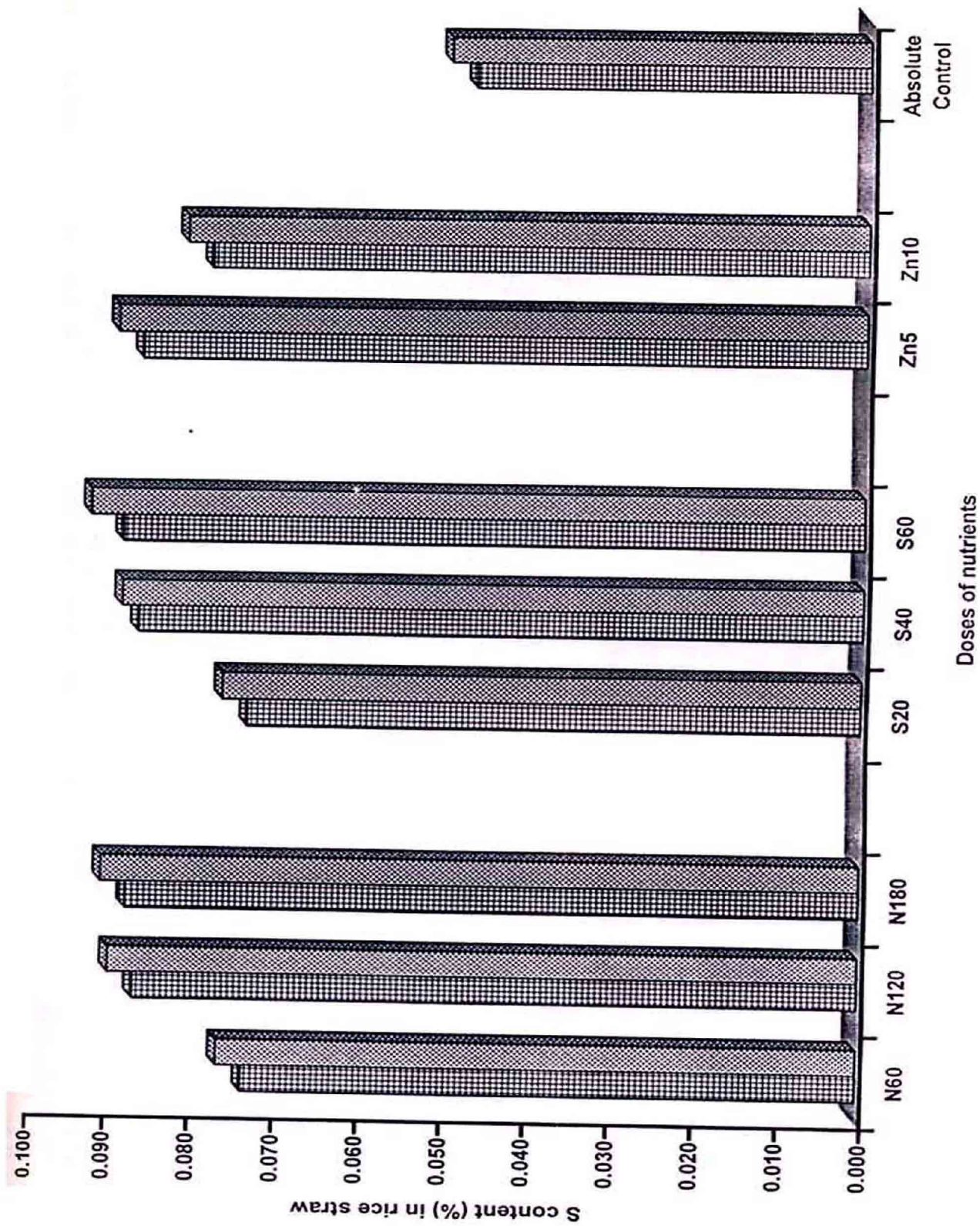
4.2.1.5.1 At 30th day of transplanting

Data presented in Table 4.43 clearly reveal that application of nitrogen significantly increased zinc content upto 120 kg Nha⁻¹ recording 46.78 and 47.28 ppm during 2003 and 2004, respectively. However, minimum zinc content was recorded at absolute control during both the years. Application of sulphur increased Zn content significantly upto 40 kg Sha⁻¹ and thereafter, a sharp significant decrease was noted upto 60 kg Sha⁻¹ because of antagonistic relationship between S and Zn at their higher levels of application whereas zinc dressings increased Zn content significantly upto 10 kg Znha⁻¹ application during both the years. At Zn₂ level Zn contents were recoded 45.85 and 46.35 ppm during 2003 and 2004, respectively.

Table 4.42: Effect of N, S and Zn on S content (%) in straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	0.067	0.080	0.086	0.077	0.069	0.082	0.089	0.080
	Zn ₂	0.061	0.074	0.072	0.069	0.064	0.076	0.075	0.072
Mean		0.064	0.077	0.079	0.073	0.066	0.079	0.082	0.076
N ₂	Zn ₁	0.080	0.093	0.099	0.090	0.083	0.095	0.103	0.094
	Zn ₂	0.074	0.087	0.085	0.082	0.077	0.089	0.089	0.085
Mean		0.077	0.090	0.092	0.086	0.080	0.092	0.096	0.089
N ₃	Zn ₁	0.081	0.094	0.100	0.091	0.084	0.096	0.104	0.095
	Zn ₂	0.075	0.088	0.086	0.083	0.078	0.090	0.090	0.086
Mean		0.078	0.091	0.093	0.087	0.081	0.093	0.097	0.090
Mean of the means		0.073	0.086	0.088	0.082	0.076	0.088	0.092	0.085
Absolute Control					0.047				0.050

N	SE (diff.)	0.004	CD (5%)	0.008	SE (diff.)	0.004	CD (5%)	0.008
S	SE (diff.)	0.004	CD (5%)	0.008	SE (diff.)	0.004	CD (5%)	0.008
Zn	SE (diff.)	0.003	CD (5%)	0.006	SE (diff.)	0.003	CD (5%)	0.006
N x S	SE (diff.)	0.007	CD (5%)	N.S.	SE (diff.)	0.007	CD (5%)	N.S.
S x Zn	SE (diff.)	0.006	CD (5%)	N.S.	SE (diff.)	0.006	CD (5%)	N.S.
N x Zn	SE (diff.)	0.006	CD (5%)	N.S.	SE (diff.)	0.006	CD (5%)	N.S.
N x S x Zn	SE (diff.)	0.010	CD (5%)	N.S.	SE (diff.)	0.010	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	0.007	CD (5%)	0.014	SE (diff.)	0.007	CD (5%)	0.014



2003 2004

Fig 4.11: Effect of N, S & Zn on S content (%) in rice straw

Table 4.43: Effect of N, S and Zn on Zn content (mg kg⁻¹) in rice at 30th day of transplanting

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	31.30	38.20	36.90	35.46	31.80	38.70	37.40	35.96
	Zn ₂	38.40	45.10	35.90	39.80	38.90	45.60	36.40	40.30
Mean		34.85	41.65	36.40	37.63	35.35	42.15	36.90	38.13
N ₂	Zn ₁	41.20	48.30	45.90	45.13	41.70	48.80	46.40	45.63
	Zn ₂	48.10	55.40	44.80	48.43	48.60	55.90	45.30	48.93
Mean		44.65	51.85	45.35	46.78	45.15	52.35	45.85	47.28
N ₃	Zn ₁	42.10	49.20	46.80	46.03	42.60	49.70	47.30	46.53
	Zn ₂	49.00	56.30	45.70	49.33	49.50	56.80	46.20	49.83
Mean		45.55	52.75	46.25	47.68	46.05	53.25	46.75	48.18
Mean of the means		41.68	48.75	42.66	44.03	42.18	49.25	43.16	44.53
Absolute Control					24.60				25.10

N	SE (diff.)	1.80	CD (5%)	3.65	SE (diff.)	1.85	CD (5%)	3.75
S	1.80	3.65	1.85	3.75				
Zn	1.44	2.92	1.48	3.00				
N x S	3.09	N.S.	3.18	N.S.				
S x Zn	2.52	N.S.	2.59	N.S.				
N x Zn	2.52	N.S.	2.59	N.S.				
N x S x Zn	4.39	N.S.	4.51	N.S.				
Absolute	3.17	6.42	3.25	6.60				
Control/Treatments								

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were noticed to be non-significant on Zn content at 30th day of transplanting during both the years but maximum Zn content was noted at N₃S₂Zn₂ level.

4.2.1.5.2 At 60th day of transplanting

Data presented in Table 4.44 clearly indicate that application of nitrogen significantly increased Zn content upto 120 kg Nha⁻¹ and thereafter it increased non-significantly upto 180 kg Nha⁻¹ during both the years. Application of S increased Zn content significantly upto 40 kg Sha⁻¹ and thereafter it decreased significantly upto 60 kg Sha⁻¹ during both the years showing antagonistic effects between Zn and S at their higher levels of application. Zn application significantly increased Zn content upto 10 kg Znha⁻¹ and at this level magnitude of responses was 86.38 and 84.66 per cent during 2003 and 2004, respectively. The minimum Zn content was noted at absolute control and all the data were significantly higher than absolute control during both the years.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were non-significant on Zn content but maximum contents were noted at N₃S₂Zn₁ level during both the years of experimentation.

4.2.1.5.3 In rice grain

The data on Zn content in rice grain are presented in Table 4.45 and depicted with Fig 4.12. The data reveal that application of nitrogen increased Zn content significantly upto 120 kg Nha⁻¹ and, thereafter, it increased non-significantly whereas minimum content was recorded at absolute control during both the years of experimentation. Application of sulphur increased Zn content significantly upto 40 kg Sha⁻¹ and thereafter it decreased significantly during both the years. Application of zinc also increased Zn content

Table 4.44: Effect of N, S and Zn on Zn content (mg kg⁻¹) in rice at 60th day of transplanting

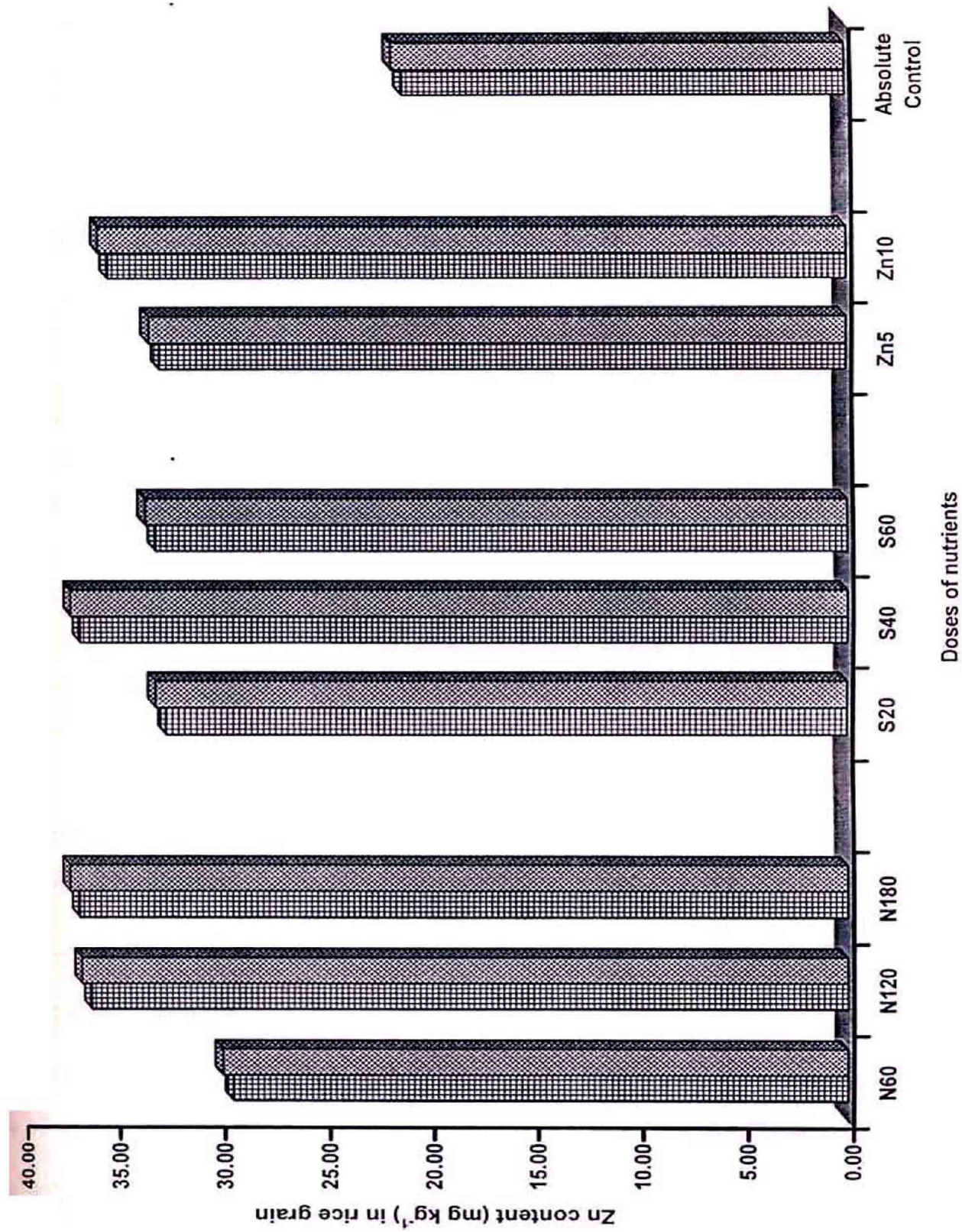
Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	26.90	30.20	29.10	28.73	27.40	30.70	29.60	29.23
	Zn ₂	30.60	33.90	28.20	30.90	31.10	34.40	28.70	31.40
Mean		28.75	32.05	28.65	29.81	29.25	32.55	29.15	30.31
N ₂	Zn ₁	31.10	34.50	33.90	33.16	31.60	35.00	34.40	33.66
	Zn ₂	35.10	37.50	32.80	35.13	35.60	38.00	33.30	35.63
Mean		33.10	36.00	33.35	34.15	33.60	36.50	33.85	34.65
N ₃	Zn ₁	31.60	35.00	34.40	33.66	32.10	35.40	34.90	34.16
	Zn ₂	35.60	38.00	33.30	35.63	36.10	38.50	33.80	36.13
Mean		33.60	36.50	33.85	34.65	34.10	37.00	34.35	35.15
Mean of the means		31.82	34.85	31.95	32.87	32.32	35.35	32.45	33.37
Absolute Control					22.00				22.50

N	SE (diff.)	1.25	CD (5%)	2.53	SE (diff.)	1.25	CD (5%)	2.53
S	1.25	2.53	1.25	2.53	1.25	2.53	1.25	2.53
Zn	1.00	2.00	1.00	2.00	1.00	2.00	1.00	2.00
N x S	2.15	N.S.	2.15	N.S.	2.15	N.S.	2.15	N.S.
S x Zn	1.75	N.S.	1.75	N.S.	1.75	N.S.	1.75	N.S.
N x Zn	1.75	N.S.	1.75	N.S.	1.75	N.S.	1.75	N.S.
N x S x Zn	3.05	N.S.	3.05	N.S.	3.05	N.S.	3.05	N.S.
Absolute Control/Treatments	2.20	4.46	2.20	4.46	2.20	4.46	2.20	4.46

Table 4.45: Effect of N, S and Zn on Zn content (mg kg⁻¹) in rice grain

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	25.90	29.90	28.80	28.20	26.40	30.40	29.30	28.70
	Zn ₂	29.80	33.80	27.70	30.43	30.30	34.30	28.20	30.83
Mean		27.85	31.85	28.25	29.31	28.35	32.35	28.75	29.81
N ₂	Zn ₁	32.10	36.70	35.60	34.80	32.60	37.20	36.10	35.30
	Zn ₂	36.90	40.90	34.50	37.43	37.40	41.40	35.00	37.93
Mean		34.50	38.80	35.05	36.11	35.00	39.30	35.55	36.61
N ₃	Zn ₁	32.70	37.30	36.20	35.40	33.20	37.80	36.70	35.90
	Zn ₂	37.50	41.50	35.10	38.03	38.00	42.00	35.60	38.53
Mean		35.10	39.40	35.65	36.71	35.60	39.90	36.15	37.21
Mean of the means		32.48	36.68	32.98	34.04	32.98	37.18	33.48	34.54
Absolute Control					21.20				21.70

N	SE (diff.)	1.30	CD (5%)	2.63	SE (diff.)	1.30	CD (5%)	2.63
S	SE (diff.)	1.30	CD (5%)	2.63	SE (diff.)	1.30	CD (5%)	2.63
Zn	SE (diff.)	1.04	CD (5%)	2.10	SE (diff.)	1.04	CD (5%)	2.10
N x S	SE (diff.)	2.23	CD (5%)	N.S.	SE (diff.)	2.23	CD (5%)	N.S.
S x Zn	SE (diff.)	1.82	CD (5%)	N.S.	SE (diff.)	1.82	CD (5%)	N.S.
N x Zn	SE (diff.)	1.82	CD (5%)	N.S.	SE (diff.)	1.82	CD (5%)	N.S.
N x S x Zn	SE (diff.)	3.17	CD (5%)	N.S.	SE (diff.)	3.17	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	2.29	CD (5%)	4.64	SE (diff.)	2.29	CD (5%)	4.64



2003 2004

Fig 4.12: Effect of N, S & Zn on Zn content (%) in rice grain

significantly upto 10 kg Zn ha⁻¹ during both the years and were computed for 66.46 and 64.79 per cent higher over absolute control during 2003 and 2004, respectively.

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were observed to be non-significant on Zn content in rice grain and maximum contents were noted at N₃S₂Zn₁ level during both the years.

4.2.1.5.4 In rice straw

The data on Zn content in rice straw are presented in Table 4.46 and depicted with Fig 4.13. The data reveal that application of N significantly increased Zn content upto 120 kg N ha⁻¹ and thereafter it increased but the increase was noted to be at par with higher level of N during both the years. S application enhanced Zn content significantly upto 40 kg S ha⁻¹ and thereafter it decreased significantly upto 60 kg S ha⁻¹ during both the years. Application of Zn increased Zn content significantly upto 10 kg Zn ha⁻¹, however, minimum Zn content was noted at absolute control during both the years of study.

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on Zn content in rice straw was non-significant for both the years of experimentation.

4.2.2. EFFECT OF N, S & Zn ON UPTAKE OF NUTRIENTS

4.2.2.1 N uptake

The data on N uptake by rice grain and straw are presented in Tables 4.47 and 4.48 and depicted with Fig 4.14 & 4.15, respectively.

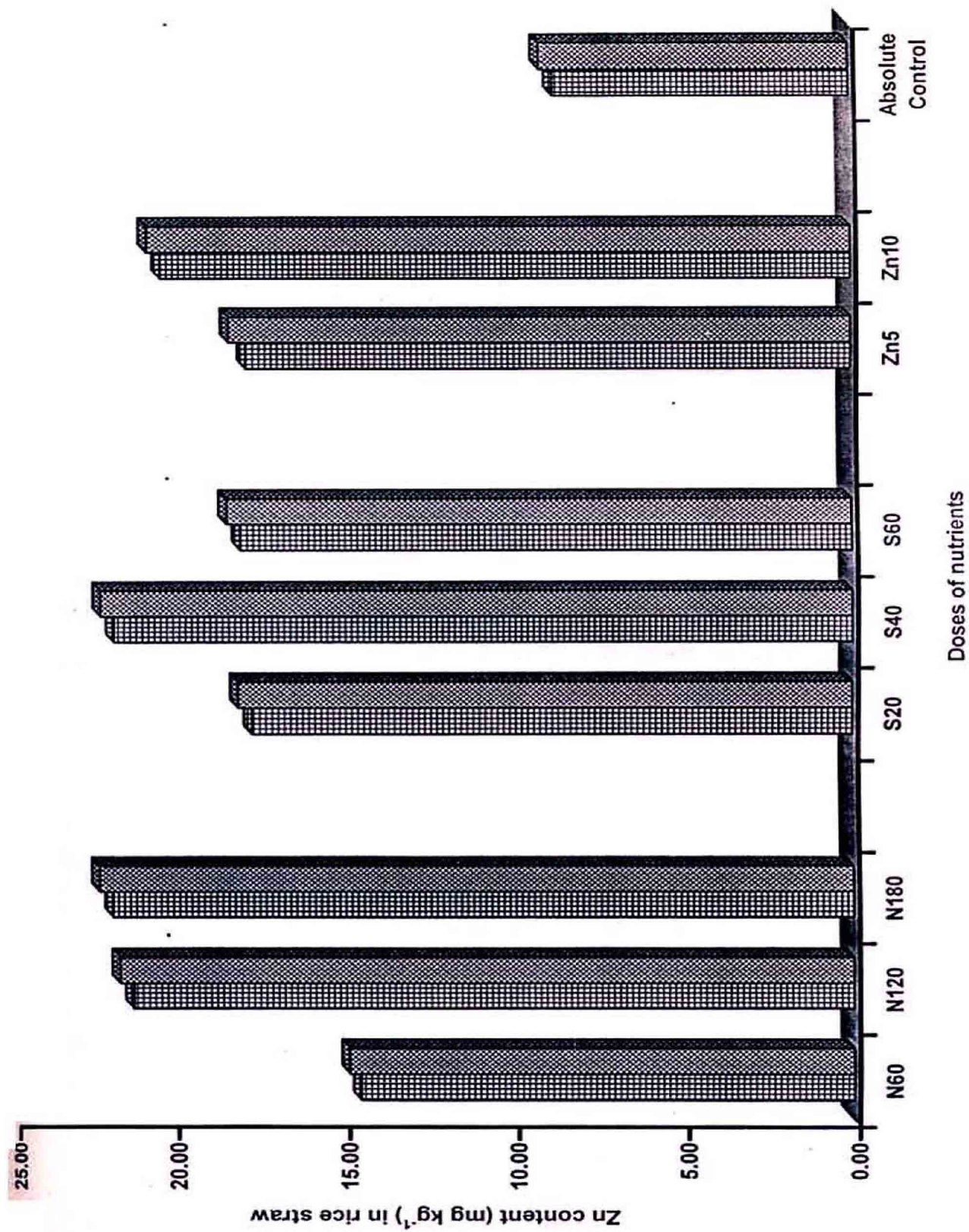
4.2.2.1.1 In rice grain

The data on N uptake by rice grain are presented in Table 4.47 and depicted with Fig 4.14 reveal that application of nitrogen significantly increased N uptake in rice grain upto 120 kg N ha⁻¹ application and thereafter it increased non-significantly upto 180 kg N ha⁻¹ recording 88.22 and 90.73 kg ha⁻¹ which were computed to be 148.50 and 147.08 per cent higher than

Table 4.46: Effect of N, S and Zn on Zn content (mg kg⁻¹) in rice straw

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	11.90	14.90	13.80	13.20	12.30	15.30	14.20	13.90
	Zn ₂	14.80	18.80	12.70	15.43	15.20	19.20	13.10	15.83
Mean		13.35	16.85	13.25	14.48	13.75	17.25	13.65	14.81
N ₂	Zn ₁	17.10	21.70	20.60	19.80	17.50	22.10	21.00	20.20
	Zn ₂	21.90	25.90	19.50	22.43	22.30	26.30	19.90	22.83
Mean		19.50	23.80	20.05	21.11	19.90	24.20	20.45	21.51
N ₃	Zn ₁	17.70	22.30	21.20	20.40	18.10	22.70	21.60	20.80
	Zn ₂	22.50	26.50	20.10	23.03	22.90	26.90	20.50	23.43
Mean		20.10	24.40	20.65	21.71	20.50	24.80	21.05	22.11
Mean of the means		17.65	21.68	17.98	19.10	18.05	22.08	18.38	19.50
Absolute Control					8.70				9.10

N	SE (diff.)	0.86	CD (5%)	1.74	SE (diff.)	0.84	CD (5%)	1.70
S	SE (diff.)	0.86	CD (5%)	1.74	SE (diff.)	0.84	CD (5%)	1.70
Zn	SE (diff.)	0.69	CD (5%)	1.40	SE (diff.)	0.67	CD (5%)	1.36
N x S	SE (diff.)	1.47	CD (5%)	N.S.	SE (diff.)	1.44	CD (5%)	N.S.
S x Zn	SE (diff.)	1.20	CD (5%)	N.S.	SE (diff.)	1.17	CD (5%)	N.S.
N x Zn	SE (diff.)	1.20	CD (5%)	N.S.	SE (diff.)	1.17	CD (5%)	N.S.
N x S x Zn	SE (diff.)	2.09	CD (5%)	N.S.	SE (diff.)	2.04	CD (5%)	N.S.
Absolute Control/Treatments	SE (diff.)	1.52	CD (5%)	3.10	SE (diff.)	1.47	CD (5%)	2.99



2003 2004

Fig 4.13: Effect of N, S & Zn on Zn content (%) in rice straw

Table 4.47: Effect of N, S and Zn on N uptake (kg ha⁻¹) in grain of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	61.62	69.14	69.70	66.82	63.97	71.04	71.99	69.00
	Zn ₂	63.10	70.67	70.86	68.21	65.89	72.91	73.16	70.65
Mean		62.36	69.90	70.28	67.51	64.93	71.97	72.57	69.82
N ₂	Zn ₁	82.34	89.26	90.06	87.22	84.92	91.91	92.73	89.85
	Zn ₂	84.05	90.98	92.65	89.22	87.02	93.98	94.14	91.71
Mean		83.19	90.12	91.35	88.22	85.97	92.94	93.43	90.73
N ₃	Zn ₁	87.69	93.71	94.26	91.88	90.47	96.26	96.80	94.51
	Zn ₂	89.45	95.46	95.57	93.49	92.88	98.25	98.36	96.49
Mean		88.57	94.58	94.91	92.69	91.67	97.25	97.58	95.50
Mean of the means		78.04	84.87	85.51	82.80	80.85	87.39	87.86	85.37
Absolute Control					35.50				36.72

N	SE (diff.)	2.71	CD (5%)	5.48	SE (diff.)	2.74	CD (5%)	5.59
S		2.71		5.48		2.74		5.59
Zn		2.16		4.39		2.19		4.44
N x S		4.66		N.S.		4.70		N.S.
S x Zn		3.79		N.S.		3.85		N.S.
N x Zn		3.79		N.S.		3.85		N.S.
N x S x Zn		6.61		N.S.		6.69		N.S.
Absolute Control/Treatments		4.76		9.67		4.86		9.85

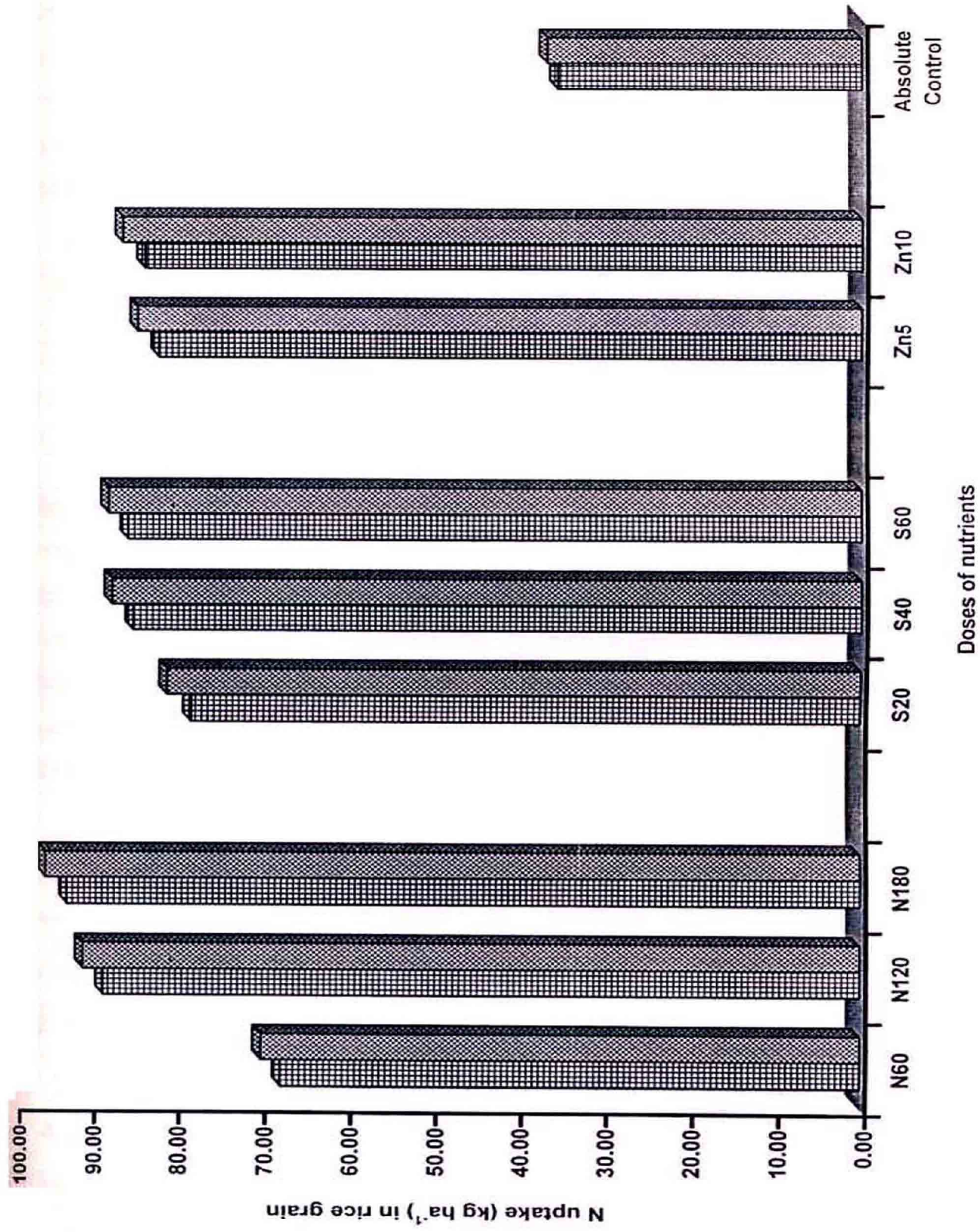


Fig 4.14: Effect of N, S & Zn on N uptake (kg ha⁻¹) in rice grain

absolute control during 2003 and 2004, respectively. However, minimum uptake was recorded at absolute control during both the years. Application of sulphur increased N-uptake significantly upto 40 Kg Sha⁻¹ and thereafter it increased non-significantly whereas zinc dressings increased N uptake significantly upto 5Kg Zn ha⁻¹ but beyond it increased non-significantly during both the years of investigation.

However, interactions effects of N x S, S x Zn, N x Zn and N x S x Zn were found to be non-significant on N uptake but maximum uptake was noted at N₃S₃Zn₂ level during both the years of experimentation.

4.2.2.1.2 In rice straw

It is obvious from the data presented in Table 4.48 (Fig 4.15) that uptake of nitrogen significantly increased by N application upto 120 Kg Nha⁻¹. Maximum uptake recorded at this level was 247.14 and 245.37 per cent higher over absolute control during 2003 and 2004, respectively. Similarly, application of sulphur enhanced N uptake significantly upto 40 kg Sha⁻¹ whereas zinc dressings increased N uptake significantly upto 5 kg Zn ha⁻¹ and thereafter it increased non-significantly during both the years. Minimum N uptake was recorded at absolute control during both the years.

However, effects of all the interactions N x S, S x Zn, N x Zn and N x S x Zn were found to be non-significant on N uptake in straw of rice but maximum uptake was noted at 180 kg N, 60 kg S and 10 kg Znha⁻¹ applied together during both the years of investigation.

4.2.2.2 P uptake

Data on P uptake in grain and straw of rice are presented in Tables 4.49 and 4.50 and depicted with Figs. 4.16&4.17, respectively, during both the years.

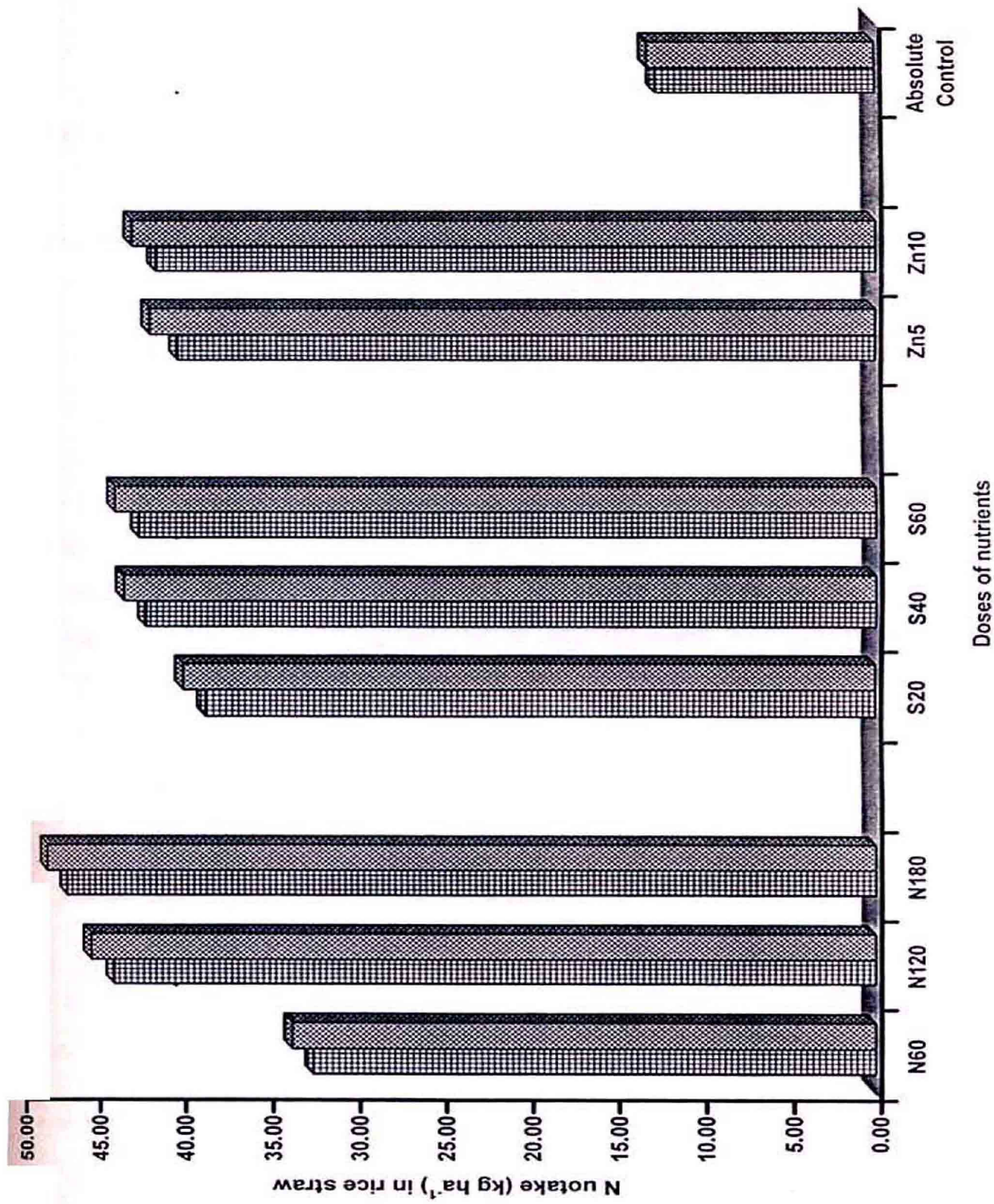
4.2.2.2.1 In rice grain

It is obvious from the data given in Table 4.49 that application of nitrogen significantly increased P uptake in rice grain upto 120 kg Nha⁻¹ recording 20.45 and 20.87 kg ha⁻¹ during 2003 and 2004, respectively and thereafter it increased non-significantly during both the years whereas

Table 4.48: Effect of N, S and Zn on N uptake (kg ha⁻¹) in straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	29.34	32.93	33.47	31.91	30.49	34.13	34.65	33.09
	Zn ₂	30.30	33.85	34.29	32.81	31.46	35.04	35.49	33.99
Mean		29.82	33.39	33.89	32.36	30.97	34.58	35.07	33.54
N ₂	Zn ₁	40.64	44.29	44.79	42.24	41.92	45.60	46.12	44.54
	Zn ₂	41.73	45.31	45.71	44.25	43.02	46.63	47.58	45.74
Mean		41.18	44.80	45.25	43.74	42.47	46.11	46.85	45.14
N ₃	Zn ₁	44.01	47.06	47.48	46.18	45.34	48.42	48.84	47.53
	Zn ₂	45.11	48.07	48.27	47.15	46.45	49.43	49.74	48.54
Mean		44.56	47.56	47.87	46.66	45.89	48.92	49.29	48.03
Mean of the means		38.52	41.91	42.33	40.92	39.79	43.20	43.73	42.24
Absolute Control					12.60				13.07

N	SE (diff.)	1.47	CD (5%)	2.98	SE (diff.)	1.45	CD (5%)	2.94
S	1.47	2.98	1.45	2.94				
Zn	1.17	2.39	1.05	2.32				
N x S	2.52	N.S.	2.49	N.S.				
S x Zn	2.06	N.S.	2.03	N.S.				
N x Zn	2.06	N.S.	2.03	N.S.				
N x S x Zn	3.58	N.S.	3.53	N.S.				
Absolute	2.57	5.22	2.54	5.15				
Control/Treatments								



2003 2004

Fig 4.15: Effect of N, S & Zn on N uptake (kg ha⁻¹) in rice straw

minimum P uptake was noticed at absolute control during both the years. Similarly, application of sulphur significantly increased P uptake upto 40 kg Sha^{-1} and thereafter it decreased non-significantly upto 60 kg Sha^{-1} . The zinc dressings increased P uptake significantly upto 5kg Znha^{-1} and thereafter it decreased non-significantly upto 10 kg Zn ha^{-1} during both the years.

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on P uptake in rice grain were observed to be non-significant but maximum values were noted at $\text{N}_3\text{S}_2\text{Zn}_1$ level during both the years of experimentation.

4.2.2.2 In rice straw

The data presented in Table 4.50 clearly reveal that significant effect of nitrogen was recorded upto 120 kg Nha^{-1} on P uptake in rice straw whereas, minimum P uptake was noticed at absolute control during both the years. Similarly, application of sulphur significantly increased P uptake upto 40 kg Sha^{-1} and thereafter it decreased non-significantly upto 60 kg Sha^{-1} . The zinc dressings too increased P uptake significantly upto 5kg Zn ha^{-1} and thereafter it decreased non-significantly during both the years.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were recorded to be non-significant on P uptake in straw of rice but maximum uptake was noted at $\text{N}_3\text{S}_2\text{Zn}_1$ during both the years of experimentation.

4.2.2.3 K uptake

Data on K uptake by rice grain and straw are presented in Tables 4.51 and 4.52 and depicted with Figs. 4.18 & 4.19, respectively during both the years.

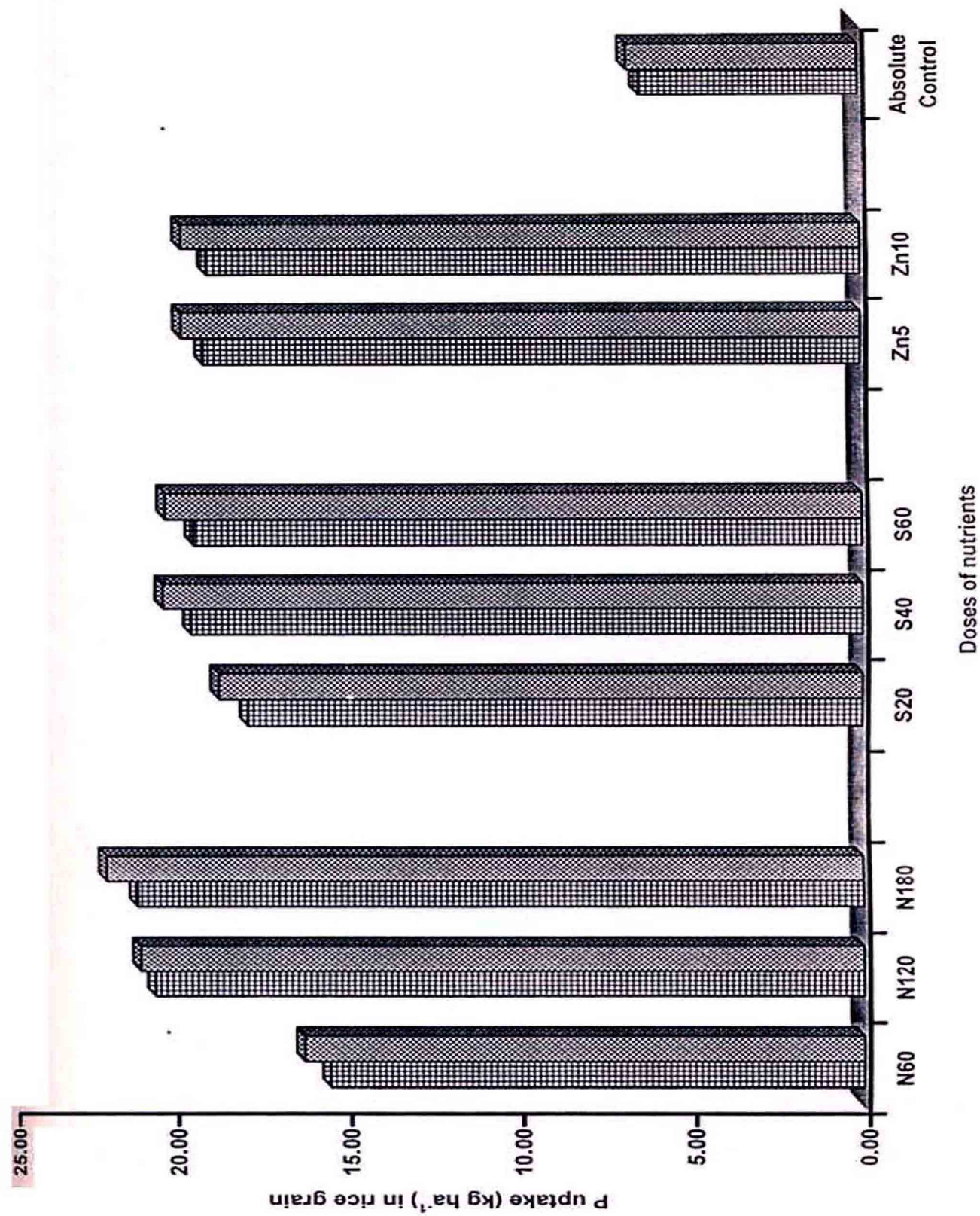
4.2.2.3.1 In rice grain

It is visualized from the data (Table 4.51) that application of nitrogen significantly increased K uptake upto 120 kg Nha^{-1} and thereafter it increased non-significantly during both the years. At N_2 level K uptake were recorded 24.00 and 24.99 kg ha^{-1} during 2003 and 2004, respectively and minimum K uptake was recorded at absolute control during both the years. Similarly, application of sulphur increased K uptake significantly upto 40 kg Sha^{-1}

Table 4.49: Effect of N, S, Zn on P uptake (Kg ha⁻¹) in grain of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	14.35	16.10	16.10	15.51	14.99	16.69	16.78	16.15
	Zn ₂	14.28	15.96	15.88	15.34	15.07	16.75	16.68	16.17
Mean		14.30	16.01	15.98	15.41	15.03	16.72	16.73	16.16
N ₂	Zn ₁	18.96	20.62	20.60	20.48	19.72	21.47	21.45	20.88
	Zn ₂	18.91	20.56	20.54	20.42	19.76	21.49	21.32	20.86
Mean		18.93	20.59	20.57	20.45	19.74	21.48	21.38	20.87
N ₃	Zn ₁	20.10	21.54	21.47	20.99	20.97	22.37	22.30	21.88
	Zn ₂	20.04	21.50	21.32	20.91	21.06	22.36	22.18	21.86
Mean		20.07	21.52	21.36	20.95	21.01	22.36	22.24	21.87
Mean of the means		17.76	19.37	19.30	18.94	18.59	20.18	20.11	19.63
Absolute Control					6.33				6.67

N	SE (diff.)	0.66	CD (5%)	1.33	SE (diff.)	0.60	CD (5%)	1.21
S	0.66	1.33	0.60	1.21				
Zn	0.52	1.07	0.48	0.97				
N x S	1.13	N.S.	1.03	N.S.				
S x Zn	0.92	N.S.	0.84	N.S.				
N x Zn	0.92	N.S.	0.84	N.S.				
N x S x Zn	1.61	N.S.	1.46	N.S.				
Absolute	1.16	2.35	1.05	2.14				
Control/Treatments								



2003 2004

Fig 4.16: Effect of N, S & Zn on P uptake (kg ha⁻¹) in rice grain

Table 4.50: Effect of N, S & Zn on P uptake (Kg ha⁻¹) in straw of rice.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	6.21	7.24	7.25	6.90	6.68	7.74	7.68	7.36
	Zn ₂	6.10	7.11	7.12	6.77	6.56	7.60	7.55	7.23
Mean		6.15	7.17	7.18	6.83	6.62	7.67	7.61	7.30
N ₂	Zn ₁	9.08	10.31	10.22	9.87	9.64	10.90	10.81	10.45
	Zn ₂	8.92	10.13	10.03	9.69	9.48	10.72	10.62	10.27
Mean		9.00	10.22	10.12	9.78	9.56	10.81	10.71	10.36
N ₃	Zn ₁	10.01	10.96	10.85	10.60	10.59	11.57	11.46	11.20
	Zn ₂	9.83	10.76	10.81	10.46	10.42	11.38	11.25	11.01
Mean		9.92	10.86	10.83	10.53	10.50	11.47	11.35	11.11
Mean of the means		8.35	9.41	9.38	9.05	8.89	9.98	9.89	9.59
Absolute Control					2.43				2.64

N	SE (diff.)	0.39	CD (5%)	0.79	SE (diff.)	0.38	CD (5%)	0.77
S	0.39	0.79	0.38	0.77				
Zn	0.31	0.63	0.30	0.61				
N x S	0.67	N.S.	0.65	N.S.				
S x Zn	0.54	N.S.	0.53	N.S.				
N x Zn	0.54	N.S.	0.53	N.S.				
N x S x Zn	0.95	N.S.	0.92	N.S.				
Absolute	0.68	1.39	0.66	1.35				
Control/Treatments								

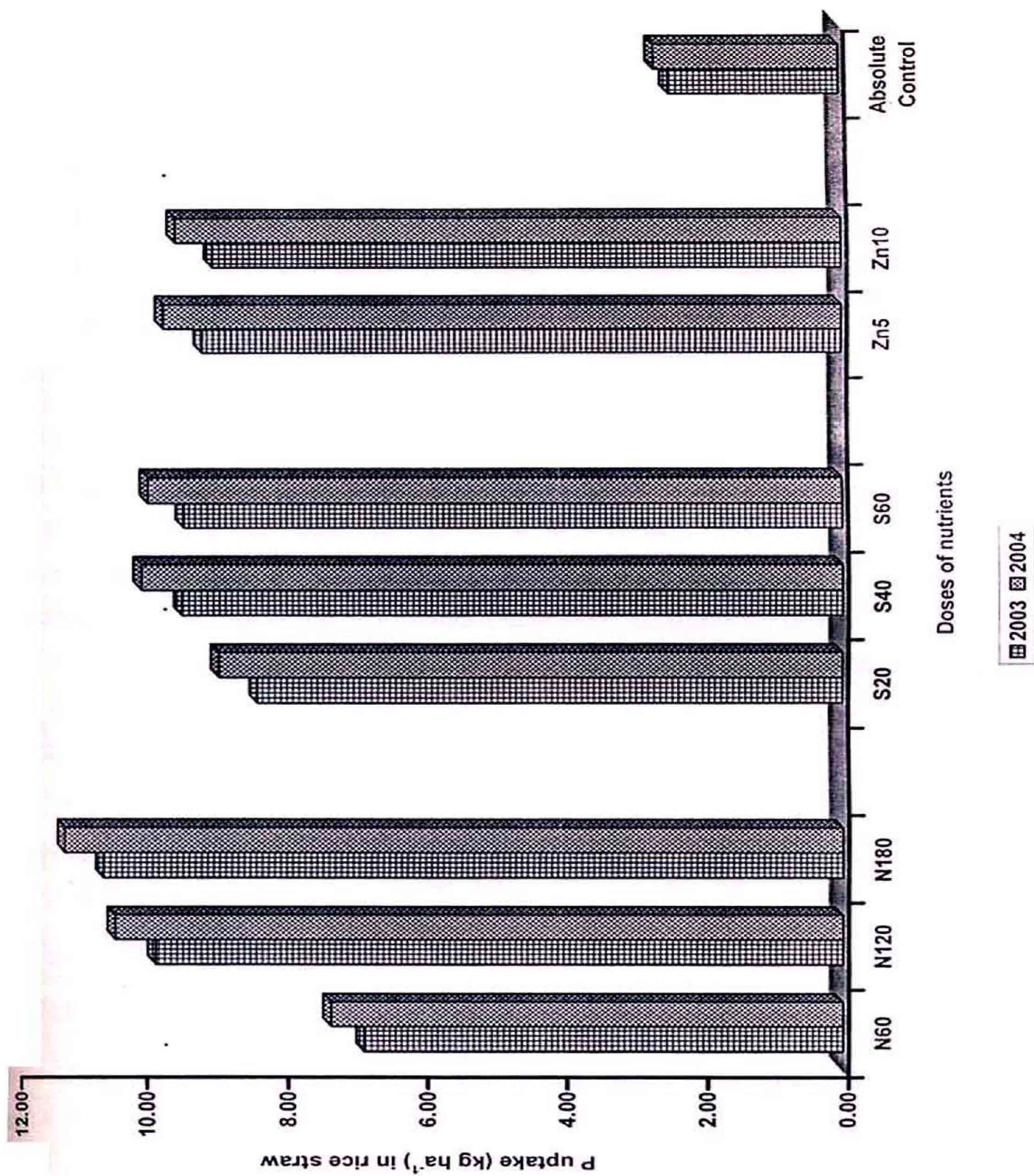


Fig 4.17: Effect of N, S & Zn on P uptake (kg ha⁻¹) in rice straw

recording 22.97 and 23.93 kg ha⁻¹ during 2003 and 2004, respectively and thereafter it increased non-significantly during both the years. Zinc application also increased K uptake upto 5 kg Zn ha⁻¹ significantly and thereafter it increased non-significantly during both the years.

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on K uptake in rice grain were found to be non-significant but maximum values were obtained at N₃S₃Zn₂ level during both the years of experimentation.

4.2.2.3.2 In rice straw

The data presented in Table 4.52 (Fig 4.19) obviously revealed that application of nitrogen significantly increased K uptake upto 120 kg N ha⁻¹ recording 116.85 and 119.32 kg ha⁻¹ during 2003 and 2004, respectively and thereafter, it increased non-significantly. Application of sulphur increased K uptake significantly upto 40 kg S ha⁻¹ and thereafter it increased non-significantly whereas zinc dressings increased K uptake significantly upto 5 kg Zn ha⁻¹ application and thereafter it increased non-significantly during both the years. The minimum K uptake was recorded with absolute control during both the years of study.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were observed to be non-significant on K uptake but maximum uptake was noted where 180 kg N, 60 kg S and 10 kg Zn ha⁻¹ were applied together during both the years of experimentation.

4.2.2.4 S uptake

Data on S uptake in rice grain and straw are presented in Tables 4.53 and 4.54 and depicted with Figs. 4.20 & 4.21, respectively during both the years.

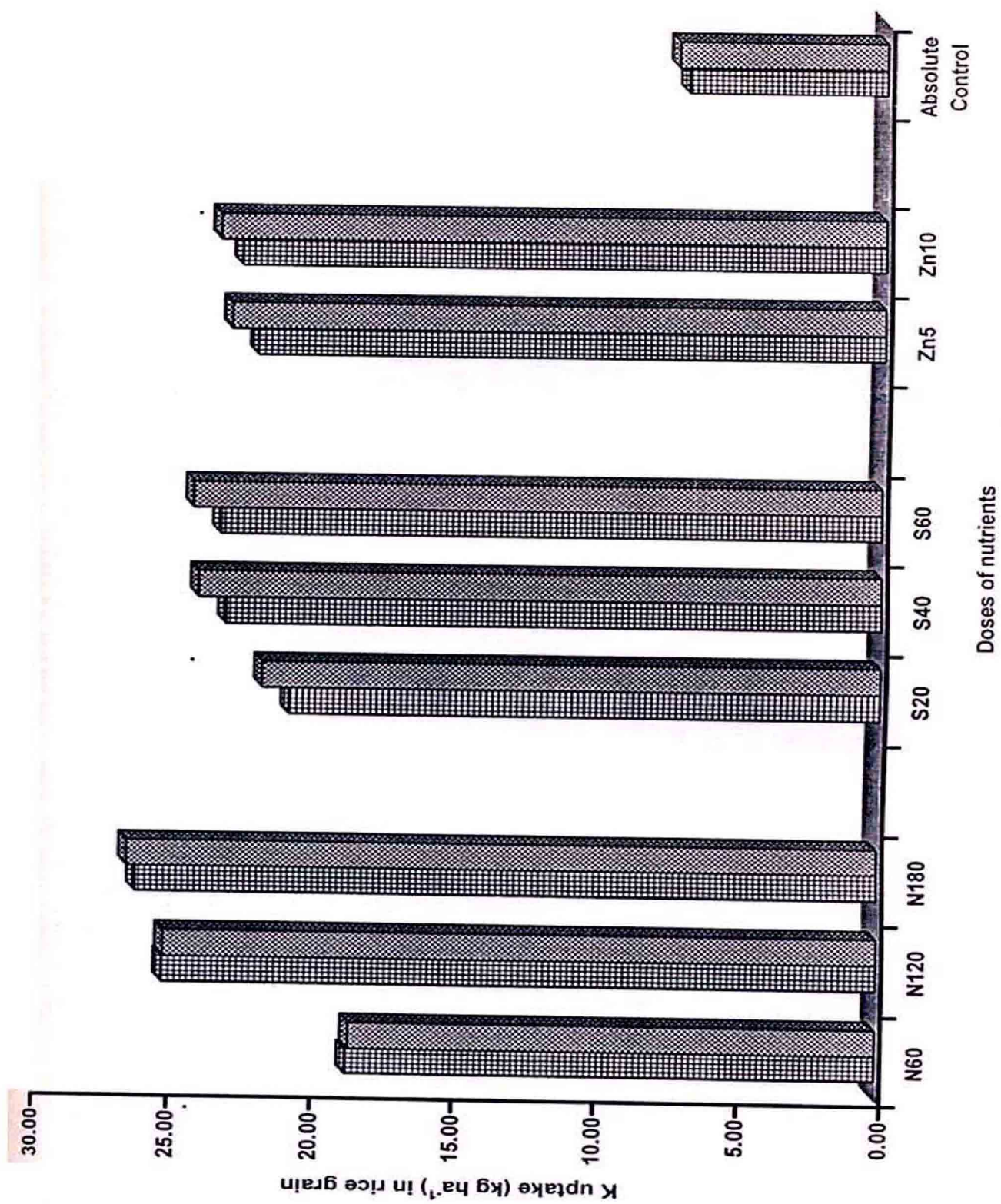
4.2.2.4.1 In rice grain

The data (Table 4.53) reveal that application of nitrogen significantly increased S uptake in rice grain upto 120 kg N ha⁻¹ recording 11.14 and 11.55 kg ha⁻¹ during 2003 and 2004, respectively and thereafter it increased non-

Table 4.51: Effect of N, S & Zn on K uptake (Kg ha⁻¹) in grain of rice.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	15.69	17.99	18.31	17.33	16.57	18.87	19.14	18.19
	Zn ₂	16.27	18.60	18.85	17.90	17.13	19.48	19.74	18.78
Mean		15.98	18.29	18.58	17.61	16.85	19.17	19.44	18.48
N ₂	Zn ₁	21.92	24.40	24.70	23.67	22.94	25.39	25.64	24.65
	Zn ₂	22.58	25.07	25.30	24.33	23.60	26.26	26.32	25.33
Mean		22.25	24.73	25.03	24.00	23.27	25.73	25.98	24.99
N ₃	Zn ₁	23.60	25.58	25.78	25.00	24.62	26.56	26.76	25.98
	Zn ₂	24.32	26.18	26.21	25.57	25.26	27.24	27.31	26.60
Mean		23.99	25.88	25.99	25.28	24.94	26.90	27.03	26.29
Mean of the means		20.74	22.97	23.20	22.30	21.68	23.93	24.15	23.25
Absolute Control					6.96				7.30

N	SE (diff.)	0.81	CD (5%)	1.64	SE (diff.)	0.75	CD (5%)	1.52
S	0.81	1.64	0.75	1.52				
Zn	0.66	1.33	0.62	1.25				
N x S	1.40	N.S.	1.33	N.S.				
S x Zn	1.14	N.S.	1.07	N.S.				
N x Zn	1.14	N.S.	1.07	N.S.				
N x S x Zn	1.98	N.S.	1.87	N.S.				
Absolute	1.44	2.92	1.36	2.75				



■ 2003 ■ 2004

Fig 4.18: Effect of N, S & Zn on K uptake (kg ha⁻¹) in rice grain

Table 4.52: Effect of N, S & Zn on K uptake (Kg ha⁻¹) in straw of rice.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	85.46	93.09	94.29	90.94	87.76	95.48	96.63	93.29
	Zn ₂	87.59	95.25	96.39	93.07	89.88	97.61	98.72	95.40
Mean		86.52	94.17	95.34	92.01	88.82	96.54	97.67	94.34
N ₂	Zn ₁	110.80	117.86	118.93	115.86	113.25	120.21	121.21	118.22
	Zn ₂	112.75	119.94	120.87	117.85	115.45	122.45	123.36	120.42
Mean		111.77	118.90	119.90	116.85	114.35	121.33	122.28	119.32
N ₃	Zn ₁	117.73	123.56	124.31	121.86	120.20	126.05	126.77	124.34
	Zn ₂	119.89	125.64	125.73	123.75	122.37	128.11	128.77	126.41
Mean		118.81	124.60	125.02	122.81	121.28	127.08	127.77	125.37
Mean of the means		105.70	112.56	113.42	110.56	108.15	114.98	115.91	113.01
Absolute Control					37.74				38.88

N	SE (diff.)	2.98	CD (5%)	6.04	SE (diff.)	3.00	CD (5%)	6.08
S	2.98	6.04	3.00	6.08				
Zn	2.38	4.83	2.40	4.86				
N x S	5.12	N.S.	5.16	N.S.				
S x Zn	4.17	N.S.	4.20	N.S.				
N x Zn	4.17	N.S.	4.20	N.S.				
N x S x Zn	7.27	N.S.	7.32	N.S.				
Absolute	5.24	10.65	5.28	10.70				
Control/Treatments								

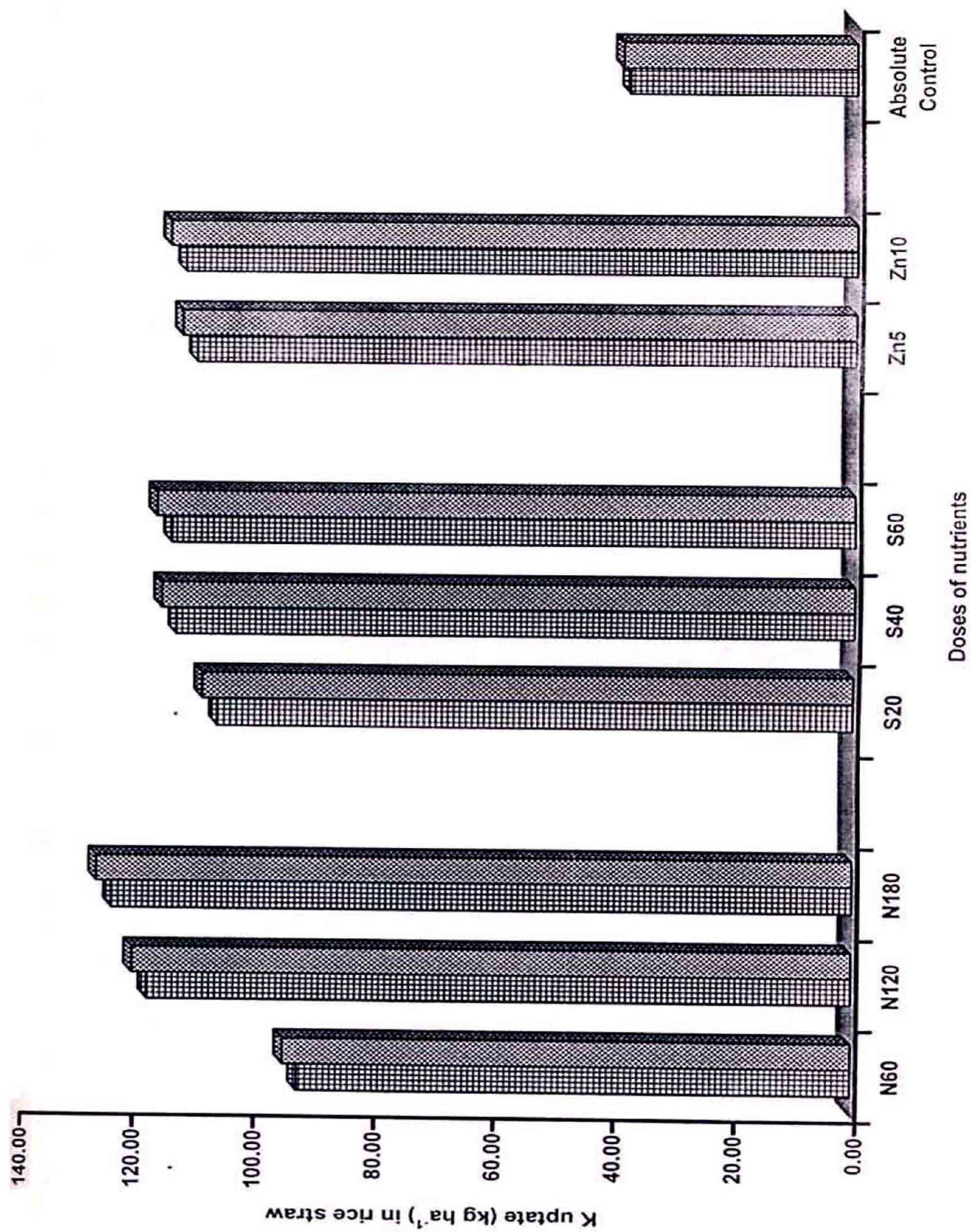


Fig 4.19: Effect of N, S & Zn on K uptake (kg ha⁻¹) in rice straw

significantly. Minimum S uptake was recorded at absolute control during both the years. Application of sulphur significantly increased S uptake upto 40 kg S ha⁻¹ and thereafter it increased non-significantly during both the years. Application of zinc also increased S uptake upto 5 kg Zn ha⁻¹ significantly and thereafter it decreased non-significantly during both the years.

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on S uptake in rice grain were found to be non-significant but maximum values were obtained at N₃S₃Zn₁ during both the years of experimentation.

4.2.2.4.2 In rice straw

The data presented in Table 4.54 (Fig 4.21) reveal that application of nitrogen significantly increased S uptake upto 120 kg N ha⁻¹ and thereafter it increased non-significantly during both the years and minimum S uptake was recorded at absolute control. Application of sulphur significantly increased S uptake upto 40 kg S ha⁻¹ and thereafter it increased non-significantly whereas zinc dressings increased S uptake significantly upto 5 kg Zn ha⁻¹ application and thereafter it decreased non significantly during both the years of investigation.

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on S uptake in rice straw were non-significant but maximum values were noted at N₃S₃Zn₁ during both the years of study.

4.2.2.5 Zn uptake

The data on Zn uptake are presented in Tables 4.55 and 4.56 and depicted with Figs. 4.22&4.23 in rice grain and straw, respectively for both the years.

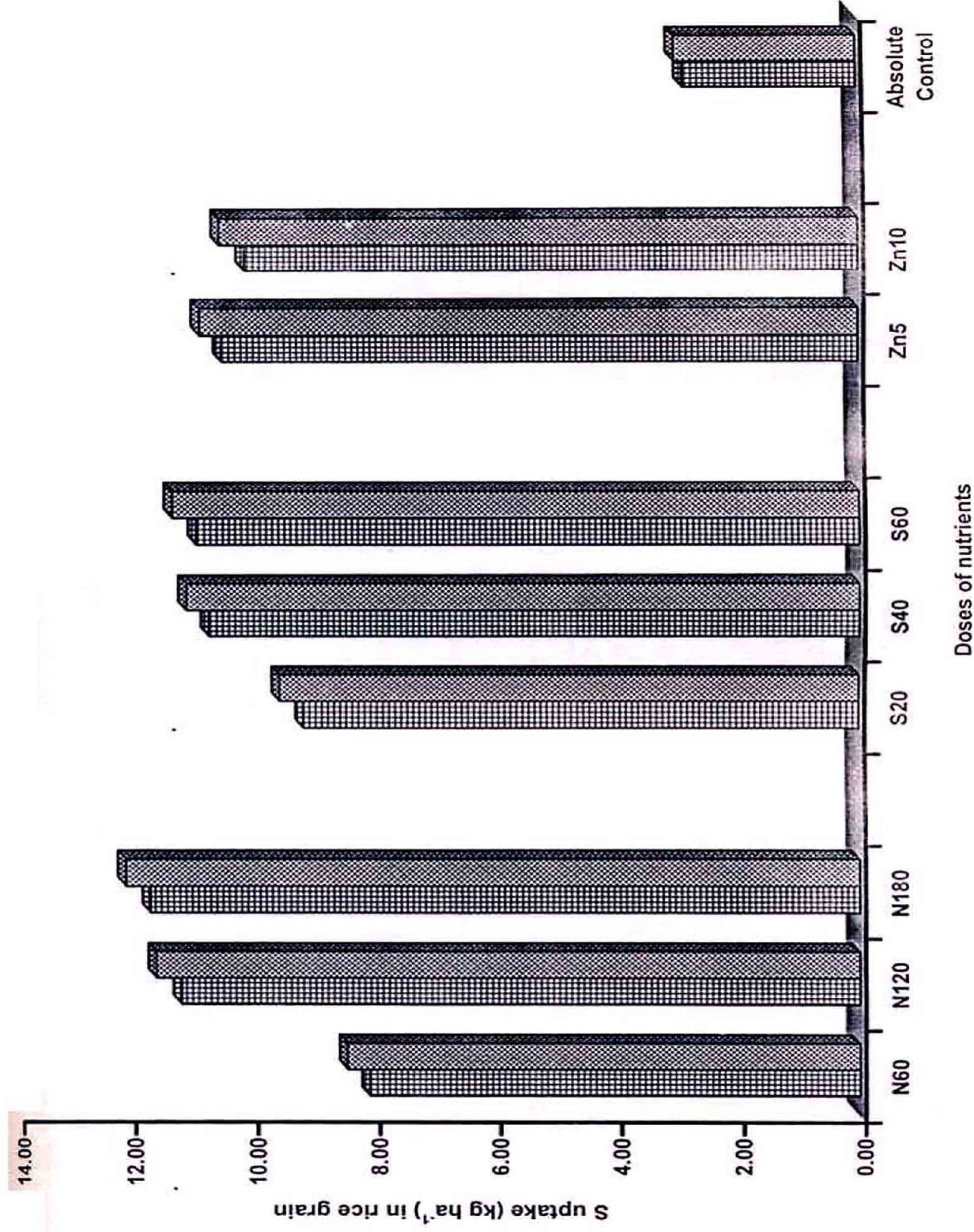
4.2.2.5.1 In rice grain

The data (Table 4.55) reveal that application of nitrogen linearly and significantly increased Zn uptake in rice grain upto 120 kg N ha⁻¹ and thereafter it increased non-significantly upto 180 kg N ha⁻¹ recording 210.73 and 219.18 kg ha⁻¹ during 2003 and 2004, respectively. The minimum Zn uptake was recorded at absolute control during both the years. Application of

Table 4.53: Effect of N, S and Zn on sulphur uptake (kg ha^{-1}) in rice grain

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	7.09	8.54	9.22	8.27	7.40	8.81	9.56	8.59
	Zn ₂	6.98	8.39	8.35	7.89	7.37	8.78	8.74	8.28
Mean		7.03	8.46	8.79	8.06	7.39	8.80	9.16	8.43
N ₂	Zn ₁	10.12	11.78	12.17	11.32	10.49	12.18	12.58	11.71
	Zn ₂	10.02	11.44	11.47	10.96	10.43	11.87	11.82	11.39
Mean		10.07	11.61	11.82	11.14	10.46	12.03	12.20	11.55
N ₃	Zn ₁	10.60	12.30	12.67	11.82	10.99	12.68	13.06	12.21
	Zn ₂	10.50	11.96	11.90	11.46	10.95	12.35	12.29	11.88
Mean		10.55	12.13	12.28	11.64	10.97	12.52	12.68	12.04
Mean of the means		9.15	10.68	10.89	10.21	9.54	11.05	11.28	10.59
Absolute Control					2.85				2.99

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	0.45	0.91	0.40	0.81
S	0.45	0.91	0.40	0.81
Zn	0.36	0.73	0.32	0.64
N x S	0.77	N.S.	0.68	N.S.
S x Zn	0.63	N.S.	0.56	N.S.
N x Zn	0.63	N.S.	0.56	N.S.
N x S x Zn	1.09	N.S.	0.97	N.S.
Absolute	0.79	1.60	0.70	1.44

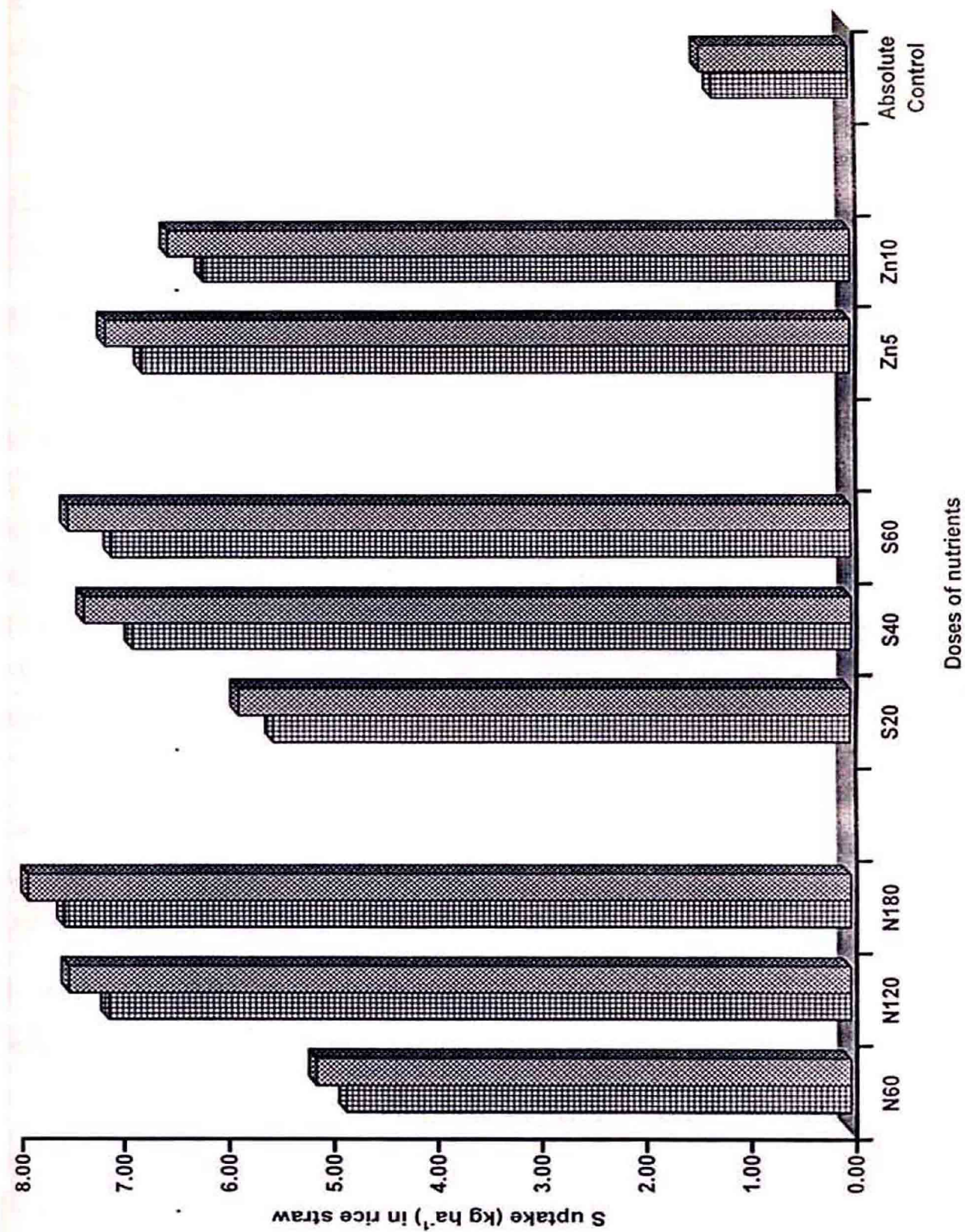


2003 2004

Fig 4.20: Effect of N, S & Zn on S uptake (kg ha⁻¹) in rice grain

Table 4.54: Effect of N, S and Zn on S uptake (kg ha⁻¹) by straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	4.12	5.31	5.78	5.07	4.34	5.57	6.10	5.34
	Zn ₂	3.83	5.00	4.92	4.58	4.11	5.25	5.26	4.88
Mean		3.98	5.16	5.35	4.82	4.22	5.42	5.68	5.11
N ₂	Zn ₁	6.30	7.67	8.22	7.39	6.74	7.96	8.71	7.80
	Zn ₂	5.89	7.28	7.17	6.78	6.23	7.57	7.62	7.14
Mean		6.08	7.48	7.70	7.09	6.48	7.76	8.16	7.47
N ₃	Zn ₁	6.70	8.11	8.68	7.84	7.06	8.42	9.16	8.21
	Zn ₂	6.30	7.70	7.56	7.18	6.66	8.00	8.03	7.56
Mean		6.50	7.91	8.12	7.51	6.86	8.21	8.59	7.88
Mean of the means		5.52	6.85	7.05	6.47	5.85	7.31	7.47	6.87
Absolute Control					1.30				1.42
		SE (diff.)			CD (5%)			SE (diff.)	
N		0.45			0.91			0.44	
S		0.45			0.91			0.44	
Zn		0.36			0.73			0.35	
N x S		0.77			N.S.			0.75	
S x Zn		0.63			N.S.			0.61	
N x Zn		0.63			N.S.			0.61	
N x S x Zn		1.09			N.S.			1.07	
Absolute Control/Treatments		0.79			1.60			0.77	
								CD (5%)	
N								0.88	
S								0.88	
Zn								0.71	
N x S								N.S.	
S x Zn								N.S.	
N x Zn								N.S.	
N x S x Zn								N.S.	
Absolute Control/Treatments								1.57	



2003 2004

Fig 4.21: Effect of N, S & Zn on S uptake (kg ha⁻¹) in rice straw

graded doses of sulphur increased Zn uptake upto 40 kg S ha⁻¹ significantly and thereafter it decreased significantly. The application of zinc significantly increased Zn uptake upto 10 kg Zn ha⁻¹ during both the years of experimentation.

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn on Zn uptake in rice grain were non-significant although maximum uptake was recorded at N₃S₂Zn₂ level during both the years of investigation.

4.2.2.5.2 In rice straw

The data presented in Table 4.56 (Fig 4.23) clearly reveal that application of graded doses of nitrogen significantly increased Zn uptake upto 120 kg N ha⁻¹ recording 172.97 and 179.15 g ha⁻¹ during 2003 and 2004, respectively and thereafter it increased non-significantly whereas minimum uptake was recorded at absolute control during both the years. Similarly application of sulphur increased Zn uptake upto 40 kg S ha⁻¹ and thereafter it decreased significantly whereas application of zinc increased Zn-uptake significantly upto 10 kg Zn ha⁻¹ during both the years of study.

However, all the interaction effects N x S, S x Zn, N x Zn and N x S x Zn on Zn uptake in rice straw were found to be non significant whereas maximum values were observed at N₃S₂Zn₂ level during both the years of experimentation.

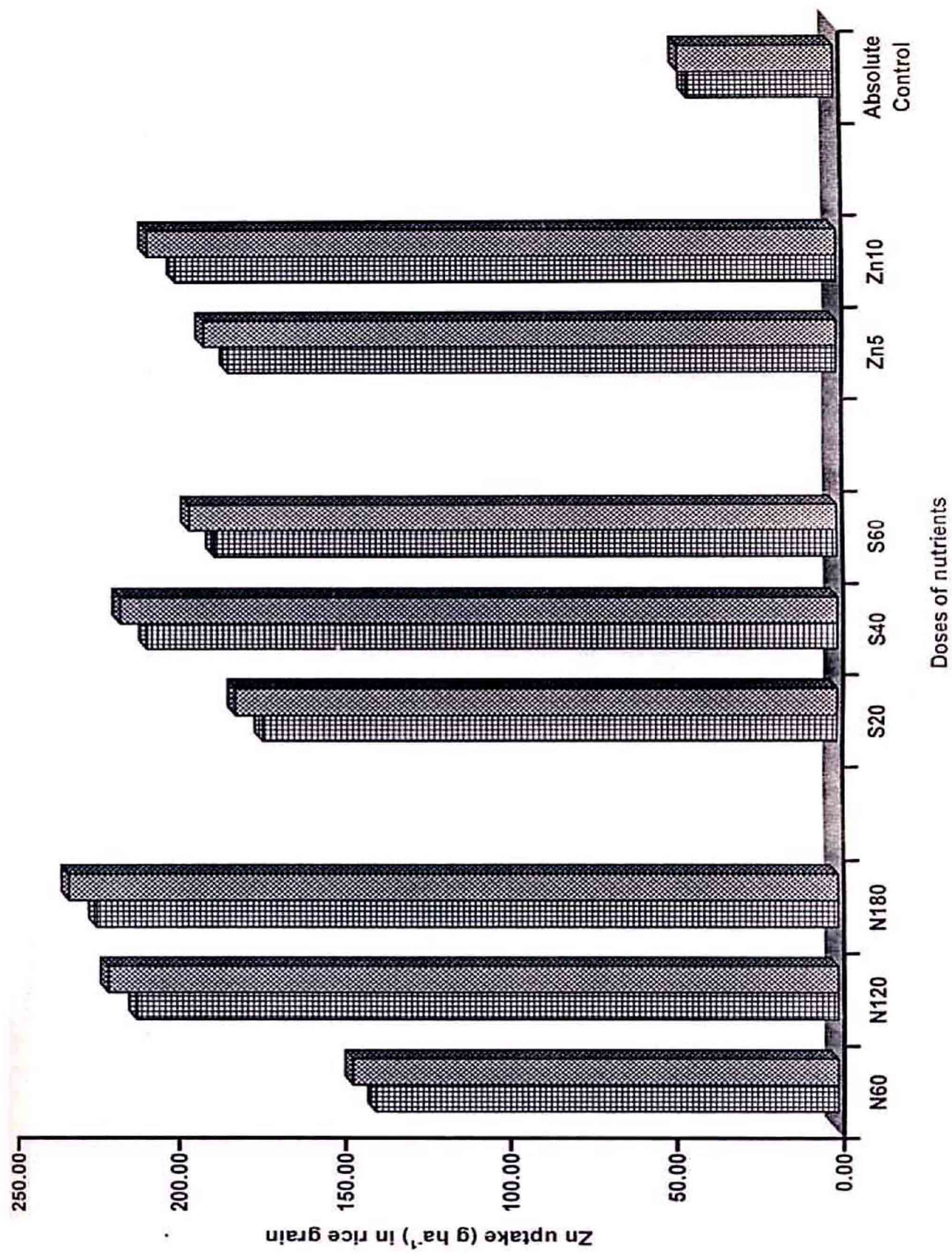
4.3 OPTIMUM REQUIREMENT OF N, S AND Zn FOR MAXIMUM GRAIN YIELD

From the data on grain yield presented in Table 4.57, it is apparent that rice crop responded curvilinearly to the application of nitrogen, sulphur and zinc during 2003 and 2004. Therefore, it is inevitable to find out the optimum requirement of nitrogen, sulphur and zinc for maximum economic grain yield. For this purpose, average grain yield of both the years obtained at different doses of nitrogen, sulphur and zinc and with the help of response curves (Fig 4.24) and response equations (Table 4.57) optimum requirements of nitrogen, sulphur and zinc were calculated.

Table 4.55: Effect of N, S and Zn on Zn uptake (g ha^{-1}) by rice grain

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	115.48	145.07	140.57	133.38	121.41	150.60	146.79	139.30
	Zn ₂	134.30	165.01	135.39	144.60	142.31	173.07	142.57	152.08
Mean		124.84	155.04	137.97	139.04	131.77	161.75	144.69	145.86
N ₂	Zn ₁	179.56	216.23	211.35	202.08	186.92	224.35	219.37	209.92
	Zn ₂	209.00	243.84	207.27	219.56	218.00	253.49	214.51	228.60
Mean		194.20	229.96	209.31	210.73	202.33	238.82	216.96	219.18
N ₃	Zn ₁	190.54	228.31	222.73	213.56	198.40	236.28	230.54	221.46
	Zn ₂	221.13	257.21	217.54	231.86	231.30	266.07	225.63	240.92
Mean		205.75	242.66	220.13	222.64	214.70	251.09	228.10	231.11
Mean of the means		172.92	207.27	187.22	188.92	180.96	215.27	194.68	196.77
Absolute Control					44.18				46.74

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	9.90	20.00	10.30	20.90
S	9.90	20.00	10.30	20.90
Zn	8.25	16.73	8.58	17.42
N x S	17.02	N.S.	17.71	N.S.
S x Zn	13.86	N.S.	14.43	N.S.
N x Zn	13.86	N.S.	14.43	N.S.
N x S x Zn	24.15	N.S.	25.13	N.S.
Absolute	17.42	35.33	18.12	36.76



2003 2004

Fig 4.22: Effect of N, S & Zn on Zn uptake (g ha⁻¹) in rice grain

Table 4.56: Effect of N, S and Zn on zinc uptake (g ha^{-1}) by straw of rice

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	78.06	98.93	92.74	89.85	79.19	103.82	97.45	93.42
	Zn ₂	93.06	127.27	86.94	102.36	100.83	132.72	91.52	107.29
Mean		85.56	112.97	89.87	96.13	90.01	118.14	94.52	100.74
N ₂	Zn ₁	133.91	178.98	171.20	160.97	139.47	185.26	177.38	166.97
	Zn ₂	174.41	216.93	164.48	185.22	180.67	223.81	170.48	191.61
Mean		153.99	197.82	167.85	172.97	159.91	119.93	173.96	179.15
N ₃	Zn ₁	146.44	192.56	184.03	174.01	152.25	199.12	190.42	180.25
	Zn ₂	189.04	232.03	176.75	199.20	195.56	239.16	183.06	205.87
Mean		167.59	212.15	180.41	186.48	173.75	219.00	186.77	192.93
Mean of the means		135.71	171.35	143.19	151.86	141.35	177.56	148.89	155.82
Absolute Control					24.10				25.92

N	SE (diff.)	12.60	CD (5%)	25.55	SE (diff.)	12.72	CD (5%)	25.79
S		12.60		25.55		12.72		25.79
Zn		10.50		21.29		10.60		21.49
N x S		20.67		N.S.		21.87		N.S.
S x Zn		17.64		N.S.		17.80		N.S.
N x Zn		17.64		N.S.		17.80		N.S.
N x S x Zn		30.74		N.S.		31.04		N.S.
Absolute		21.07		42.67		21.80		43.12

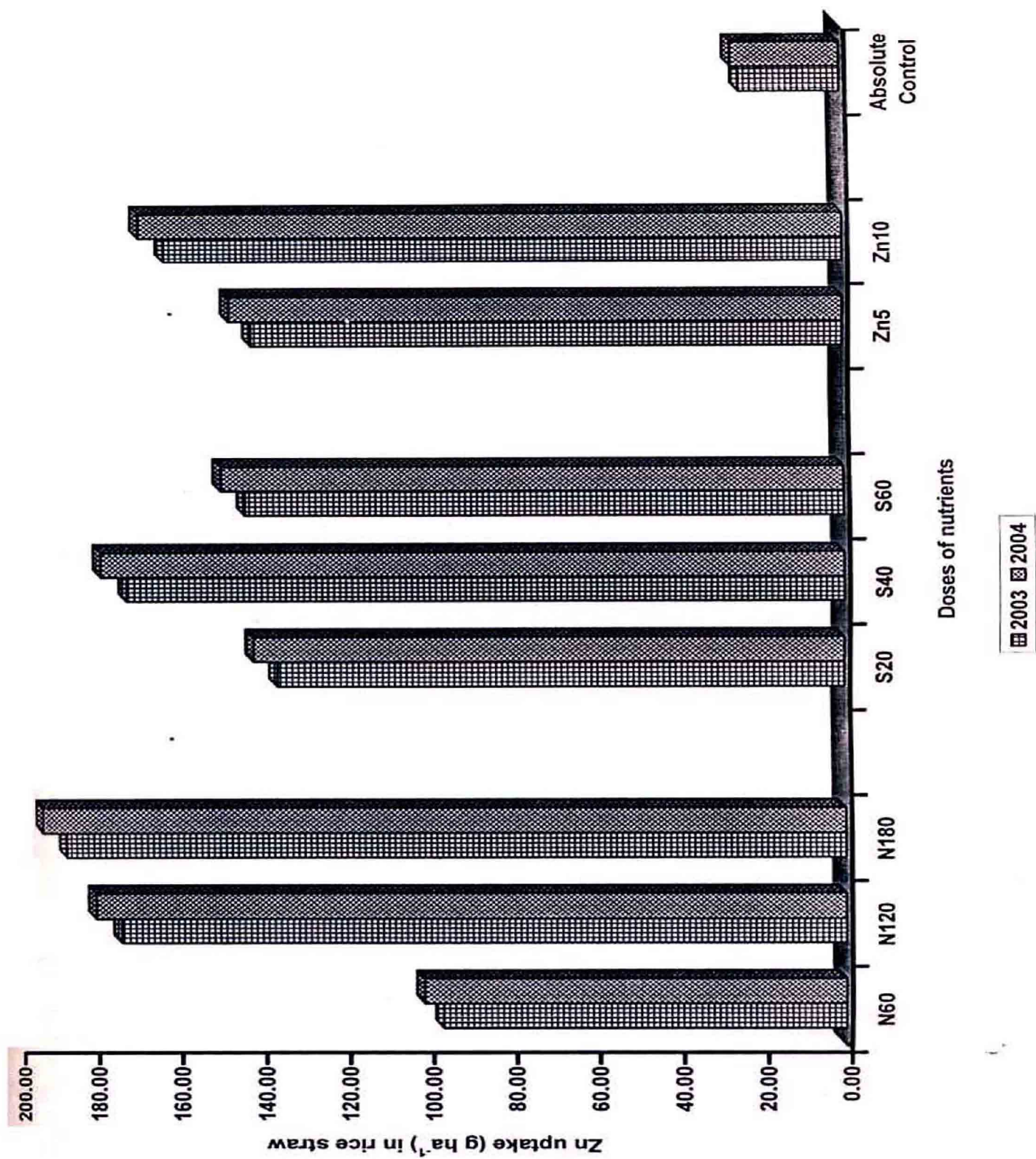


Fig 4.23: Effect of N, S & Zn on Zn uptake (g ha^{-1}) in rice straw

It is evident from the response curves and response equations for the maximum economic grain yield of 62.61 q, 61.48 q and 60.66 q ha⁻¹, the optimum doses of nitrogen, sulphur and zinc in present study would be 156 kg N, 43.69 kg S and 7.24 kg Zn ha⁻¹, respectively.

Table 4.57: Optimum doses of N, S and Zn for maximum grain yield.

Nutrient applied	Optimum dose (kg/ha) (x)	Maximum economic yield (qha ⁻¹) (y)	Response equations
N	156	62.61	$21.5595 + 0.5284 x - 0.0017 x^2$
S	43.69	61.48	$22.5310 + 1.7827 x - 0.0204 x^2$
Zn	7.24	60.66	$22.8810 + 10.4410 x - 0.7212 x^2$

4.4 EFFECT OF N, S, & ZN ON QUALITY CHARACTERISTICS OF RICE

4.4.1 Effect of N, S, & Zn on crude protein content (%) in rice

The data on crude protein contents in grain and straw are presented in Tables 4.58 and 4.59, respectively during both the years.

4.4.1.1 In rice grain

The data presented in Table 4.58 and depicted with Fig 4.25 reveal that application of graded doses of nitrogen significantly increased crude protein content upto 120 kg N ha⁻¹ recording 8.96 and 9.01 percent which were computed for 19.46 and 19.33 percent higher than absolute control during 2003 and 2004, respectively and thereafter it increased non-significantly upto 180 kg N ha⁻¹ during both the years. The minimum protein content was recorded at absolute control during both the years. Application of sulphur increased crude protein content significantly upto 40 kg S ha⁻¹ and thereafter it increased non-significantly. The zinc dressings also increased crude protein content significantly upto 5 kg Zn ha⁻¹ but it was recorded *at par* at 10 kg Zn ha⁻¹ during both the years of experimentation.

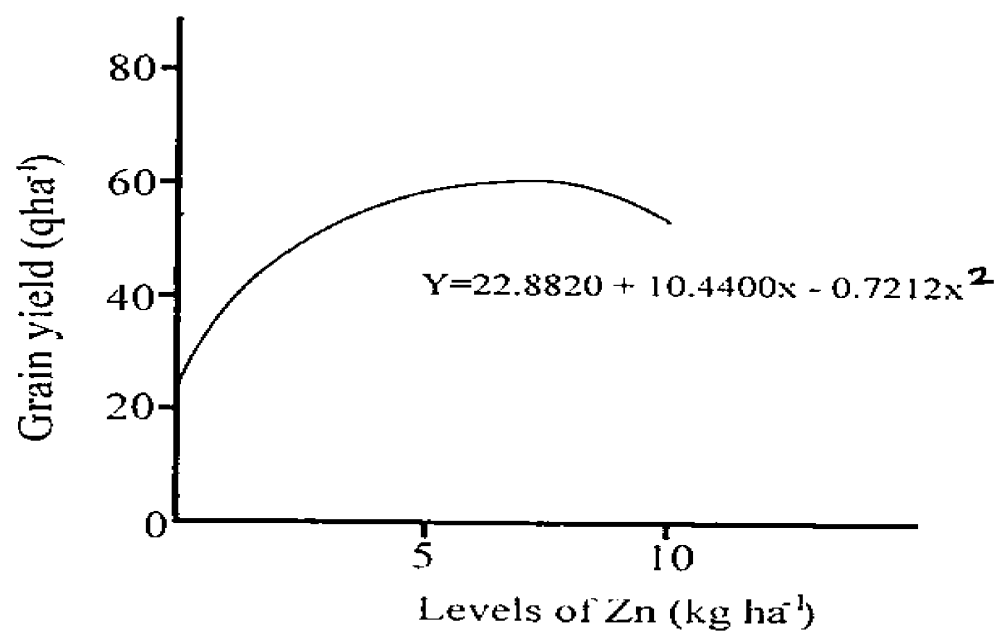
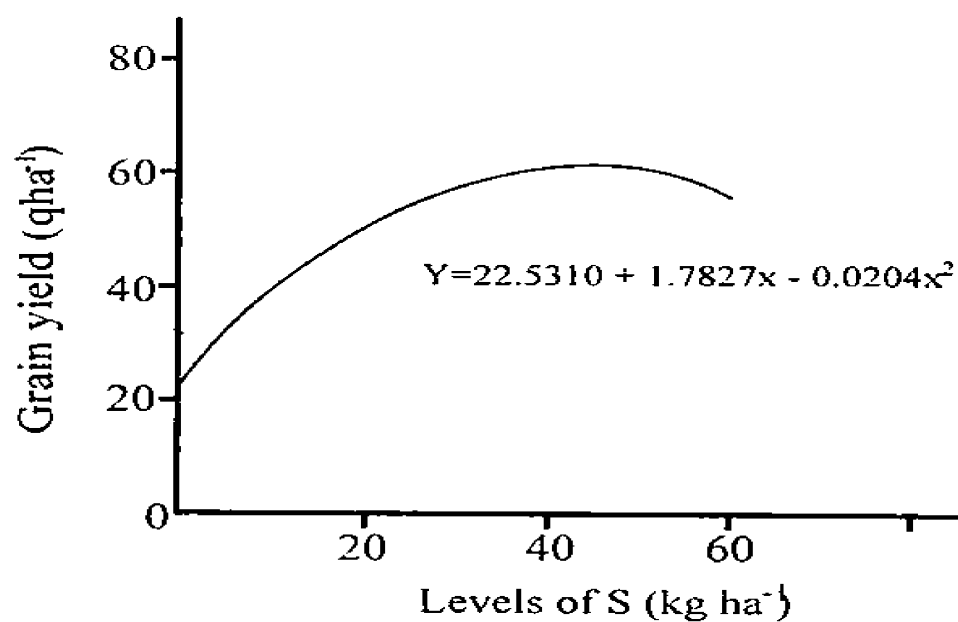
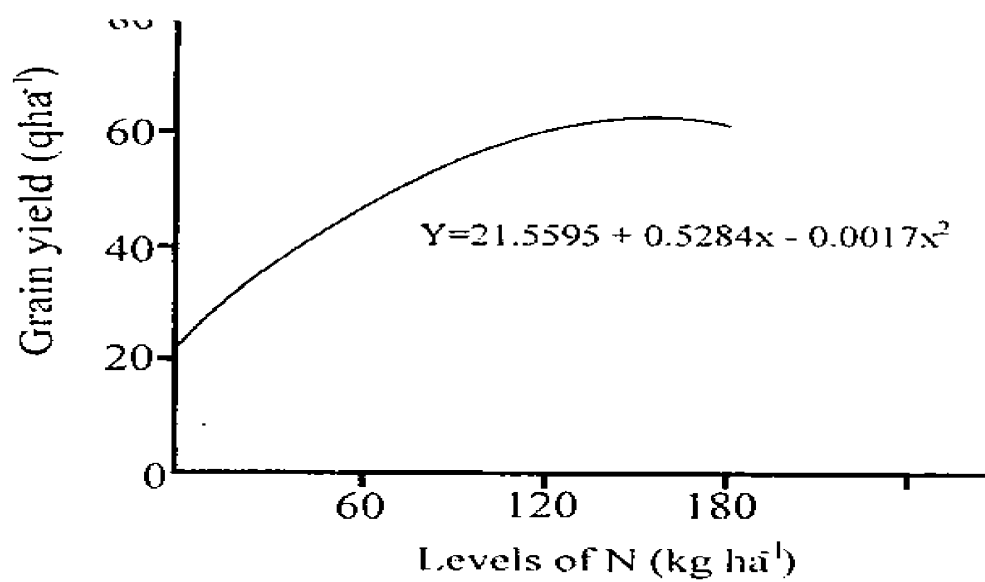


Fig 4.24: Response curves of rice to applied N, S & Zn

Table 4.58: Effect of N, S & Zn on crude protein content (%) in rice grain.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	8.22	8.47	8.49	8.39	8.27	8.53	8.55	8.45
	Zn ₂	8.30	8.54	8.55	8.46	8.34	8.59	8.60	8.51
Mean		8.26	8.50	8.52	8.42	8.30	8.56	8.57	8.48
N ₂	Zn ₁	8.75	9.01	9.02	8.92	8.81	9.06	9.07	8.98
	Zn ₂	8.83	9.07	9.08	8.99	8.88	9.13	9.14	9.05
Mean		8.79	9.04	9.05	8.96	8.84	9.09	9.10	9.01
N ₃	Zn ₁	8.91	9.06	9.07	9.01	8.96	9.12	9.12	9.06
	Zn ₂	8.98	9.13	9.13	9.08	9.03	9.18	9.19	9.13
Mean		8.94	9.09	9.10	9.04	8.99	9.15	9.15	9.10
Mean of the means		8.66	8.88	8.89	8.81	8.71	8.93	8.94	8.86
Absolute Control					7.50				7.55

N	SE (diff.)	0.09	CD (5%)	0.18	SE (diff.)	0.09	CD (5%)	0.18
S	0.09	0.18	0.18	0.09	0.18	0.18		
Zn	0.07	0.14	0.14	0.07	0.14	0.14		
N x S	0.15	N.S.	N.S.	0.15	N.S.	N.S.		
S x Zn	0.13	N.S.	N.S.	0.13	N.S.	N.S.		
N x Zn	0.13	N.S.	N.S.	0.13	N.S.	N.S.		
N x S x Zn	0.22	N.S.	N.S.	0.22	N.S.	N.S.		
Absolute	0.16	0.32	0.32	0.16	0.32	0.32		
Control/Treatments								

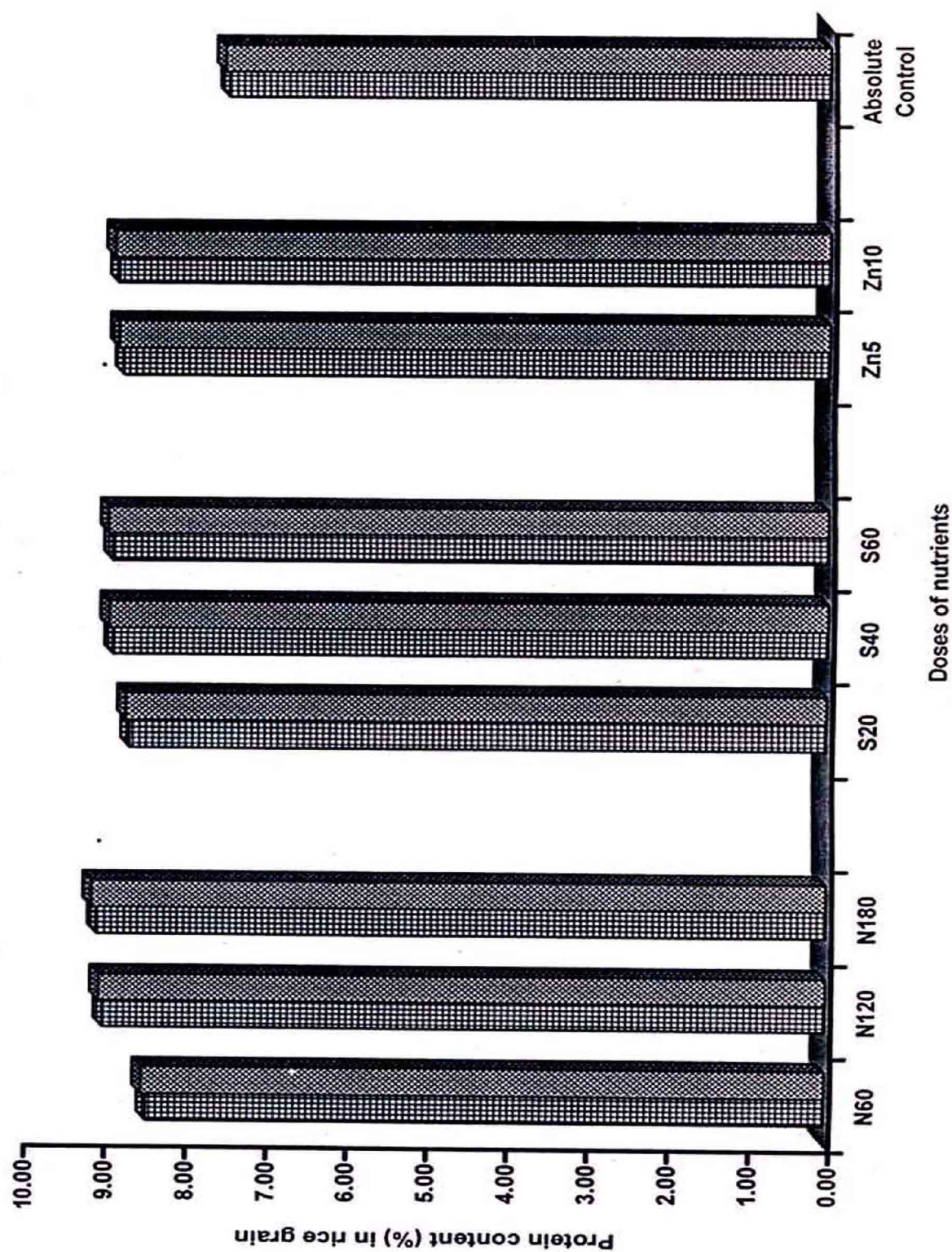


Fig 4.25: Effect of N, S & Zn on Protein content (%) in rice grain

The interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were noted to be non-significant on crude protein content in rice grain recording the maximum value at $N_3S_3Zn_2$ level during both the years of study.

4.4.1.2 In rice straw

The data presented in Table 4.59 (Fig 4.26) clearly showed that application of graded doses of nitrogen significantly increased crude protein content in straw of rice upto 120 kg N ha^{-1} recording 3.33 and 3.37 percent during 2003 and 2004, respectively. The protein content increased non significantly after 120 kg N ha^{-1} . However, minimum protein contents (2.78 & 2.80 %) were recorded at absolute control during both the years. Application of sulphur significantly increased protein content upto 40 kg S ha^{-1} recording 17.98 and 18.92 percent higher over absolute control. The zinc dressing's increased crude protein content significantly upto 5 kg Zn ha^{-1} and thereafter it increased non-significantly during both the years.

However, effects of all the interactions of NxS, SxZn, NxZn and NxSxZn were noted to be non-significant but maximum protein content was noted at $N_3S_3Zn_2$ level during both the years of experimentation.

4.4.2. Effect of N, S & Zn on Crude protein production (kg ha^{-1}) by Rice

The data on crude protein production are presented in Tables 4.60 and 4.61 and depicted with Fig 4.27 & 4.28 in grain and straw, respectively during the both years.

4.4.2.1 By Rice grain

The data presented in Table 4.60 (Fig 4.27) revealed that application of graded doses of nitrogen significantly increased crude protein production by rice grain upto 120 kg N ha^{-1} and thereafter it increased non-significantly. The crude protein production at 120 kg N ha^{-1} were recorded 524.61 and 539.93 kg ha^{-1} during 2003 and 2004, respectively. However, minimum crude protein production was noted at absolute control during both the years. Application of

Table 4.59: Effect of N, S & Zn on crude protein content (%) in straw of rice.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	2.98	3.10	3.11	3.06	3.02	3.14	3.15	3.10
	Zn ₂	3.01	3.12	3.13	3.08	3.05	3.16	3.17	3.12
Mean		2.99	3.11	3.12	3.07	3.03	3.15	3.16	3.11
N ₂	Zn ₁	3.24	3.35	3.36	3.31	3.28	3.40	3.41	3.36
	Zn ₂	3.27	3.38	3.39	3.34	3.31	3.42	3.43	3.38
Mean		3.25	3.36	3.37	3.33	3.29	3.41	3.42	3.37
N ₃	Zn ₁	3.30	3.38	3.39	3.35	3.34	3.42	3.43	3.39
	Zn ₂	3.33	3.40	3.40	3.38	3.37	3.45	3.45	3.42
Mean		3.31	3.39	3.39	3.36	3.35	3.43	3.44	3.41
Mean of the means		3.18	3.28	3.29	3.25	3.22	3.33	3.34	3.30
Absolute Control					2.78				2.80

N	SE (diff.)	0.04	CD (5%)	0.08	SE (diff.)	0.04	CD (5%)	0.08
S	0.04	0.08	0.04	0.08	0.04	0.08	0.08	0.08
Zn	0.02	0.06	0.03	0.06	0.03	0.06	0.06	0.06
N x S	0.07	N.S.	0.07	N.S.	0.07	N.S.	N.S.	N.S.
S x Zn	0.06	N.S.	0.06	N.S.	0.06	N.S.	N.S.	N.S.
N x Zn	0.06	N.S.	0.06	N.S.	0.06	N.S.	N.S.	N.S.
N x S x Zn	0.10	N.S.	0.10	N.S.	0.10	N.S.	N.S.	N.S.
Absolute Control/Treatments	0.07	0.14	0.07	0.14	0.07	0.14	0.14	0.14

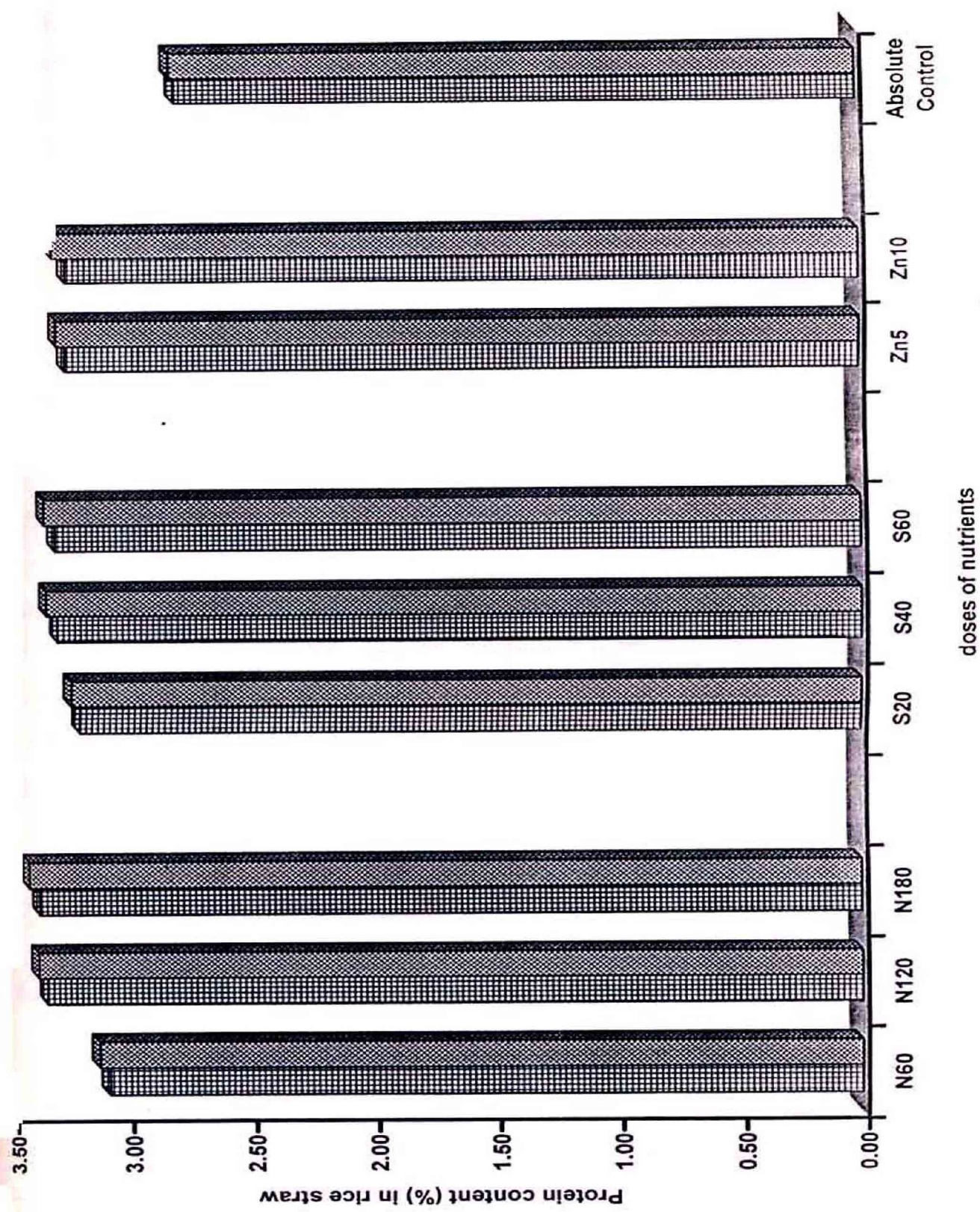


Fig 4.26: Effect of N, S & Zn on Protein content (%) in rice straw

different doses of sulphur increased crude protein production significantly upto 40 kg S ha⁻¹ and thereafter it increased non-significantly whereas zinc dressings increased crude protein production upto 5 kg Zn ha⁻¹ application. The crude protein production increased non-significantly beyond 5 kg Znha⁻¹ during both the years.

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were found to be non-significant on crude protein production by rice grain whereas maximum crude protein production was obtained at N₃S₃Zn₂ level during both the years of investigation.

4.4.2.2 By Rice Straw

The data presented in Table 4.61 (Fig 4.28) clearly visualized that application of nitrogen significantly increased crude protein production by rice straw upto 120 kg N ha⁻¹ and thereafter it increased non-significantly. However, minimum crude protein production was recorded at absolute control during both the years. Similarly, application of sulphur significantly increased crude protein production upto 40 kg S ha⁻¹ and thereafter it increased non-significantly. The zinc dressings increased crude protein production significantly upto 5 kg Zn ha⁻¹ and thereafter it increased non-significantly during both the years.

However, interaction effects of N x S, S x Zn, N x Zn and N x S x Zn were noticed to be non-significant on crude protein production by straw of rice during both the years of study.

4.4.3. Effect of N, S & Zn on Amylose content (%) of Rice

The data in respect of amylose content have been presented in Table 4.62 (Fig 4.29) during both the years. The data obviously revealed that application of 60 kg N ha⁻¹ increased significantly amylose content of rice and thereafter gradual decrease was noted upto 180 kg N ha⁻¹ and this decrease was noted significant after 120 kg N ha⁻¹ application. The data recorded at 60 kg and 120 kg N ha⁻¹ were at par during both the years, however, maximum amylose content was noted at 60 kg N ha⁻¹ application and minimum at 180 kg Nha⁻¹. The data recorded with sulphur show that the application of 40 kg S ha⁻¹ significantly

Table 4.60: Effect of N, S and Zn on crude protein production (Kg ha^{-1}) by rice grain.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	366.53	410.96	414.40	397.29	380.34	422.59	428.35	410.42
	Zn ₂	375.74	420.34	421.34	405.80	391.73	433.45	434.82	420.00
Mean		371.13	415.65	417.87	401.55	386.03	428.01	431.58	415.21
N ₂	Zn ₁	489.47	530.87	535.52	518.62	505.16	546.41	551.19	534.25
	Zn ₂	500.13	540.75	550.97	530.61	517.61	559.03	560.19	545.61
Mean		494.80	535.81	543.24	524.61	511.38	552.72	555.68	539.93
N ₃	Zn ₁	519.18	554.56	558.08	543.94	535.45	570.09	572.92	559.48
	Zn ₂	529.55	565.24	565.88	553.55	549.66	581.55	582.46	571.22
Mean		524.36	559.90	561.98	548.74	542.55	575.82	577.69	565.35
Mean of the means		463.43	503.78	507.69	491.63	479.99	518.85	521.65	506.83
Absolute Control					156.30				162.62

	SE (diff.)	CD (5%)	SE (diff.)	CD (5%)
N	15.76	31.96	14.78	29.97
S	15.76	31.96	14.78	29.97
Zn	12.42	25.22	12.06	24.45
N x S	27.11	N.S.	25.60	N.S.
S x Zn	22.04	N.S.	20.90	N.S.
N x Zn	22.04	N.S.	20.90	N.S.
N x S x Zn	38.26	N.S.	36.19	N.S.
Absolute Control/Treatments	27.72	56.28	26.30	53.33

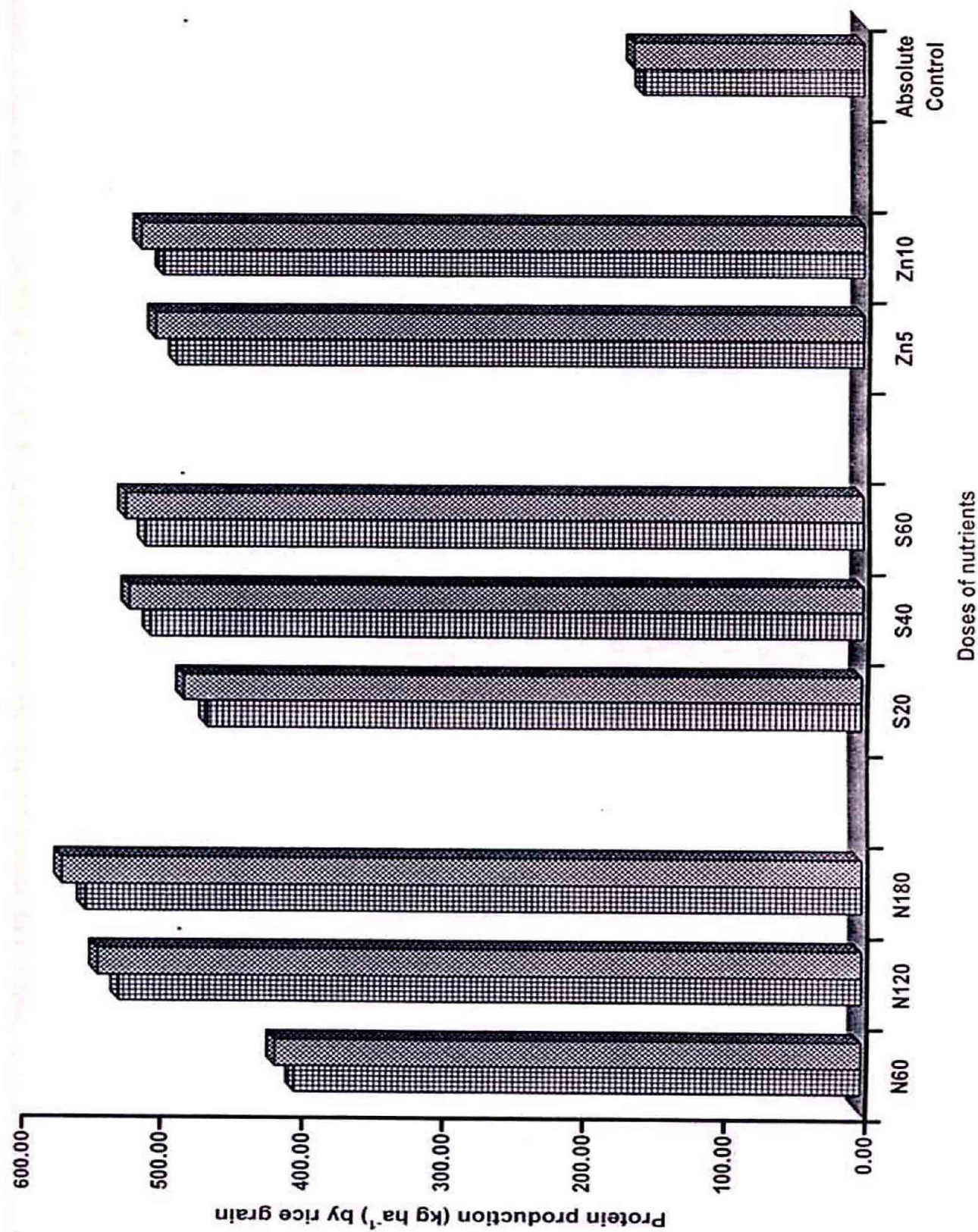


Fig 4.27: Effect of N, S & Zn on Protein production (kg ha⁻¹) by rice grain

Table 4.61: Effect of N, S & Zn on crude protein production (Kg/ha⁻¹) by straw of rice.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	183.36	205.84	209.02	199.40	190.26	213.08	216.18	206.50
	Zn ₂	189.27	211.22	214.28	204.92	196.24	218.45	221.49	212.06
Mean		186.31	208.53	211.65	202.16	193.25	215.76	218.83	209.28
N ₂	Zn ₁	253.72	276.31	279.25	269.76	261.42	285.02	288.04	278.16
	Zn ₂	260.42	283.11	285.95	276.49	268.18	291.04	293.85	284.35
Mean		257.07	279.71	282.60	273.12	264.80	288.03	290.94	281.25
N ₃	Zn ₁	273.04	291.86	294.28	286.39	280.96	300.00	302.39	294.45
	Zn ₂	279.79	297.70	298.99	292.16	287.80	306.74	308.08	300.87
Mean		276.41	294.78	296.63	289.27	284.38	303.37	305.23	297.66
Mean of the means		239.93	261.10	263.62	254.85	247.47	269.05	271.67	262.73
Absolute Control					74.81				79.77

N	SE (diff.)	7.85	CD (5%)	15.95	SE (diff.)	8.05	CD (5%)	16.34
S		7.85		15.95		8.05		16.34
Zn		6.25		12.71		6.48		14.96
N x S		13.53		N.S.		13.87		N.S.
S x Zn		10.99		N.S.		11.39		N.S.
N x Zn		10.99		N.S.		11.39		N.S.
N x S x Zn		19.17		N.S.		19.75		N.S.
Absolute		13.87		28.40		14.09		32.63

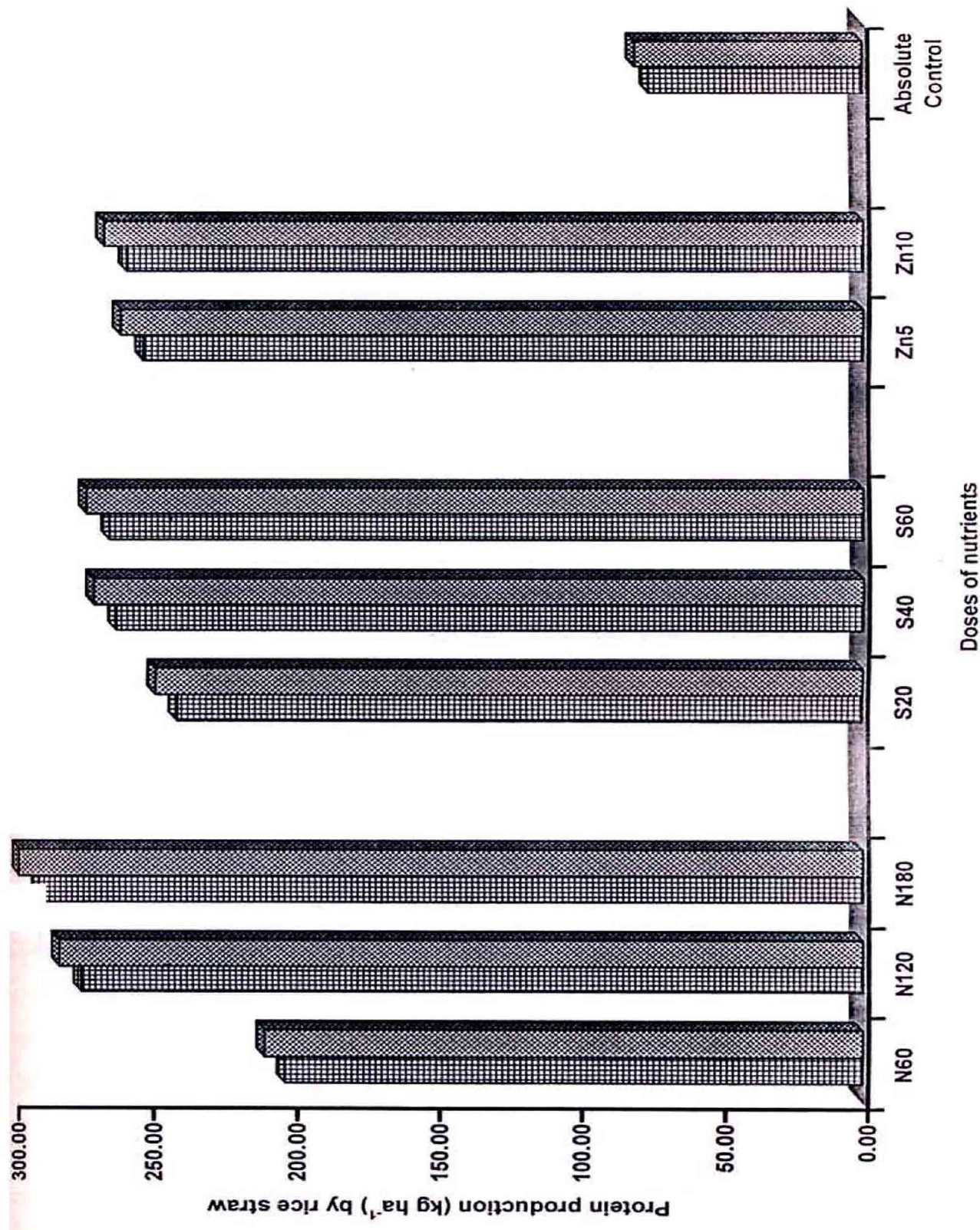


Fig 4.28: Effect of N, S & Zn on Protein production (kg ha⁻¹) by rice straw

increased amylose content of rice over 20 kg S ha⁻¹ application. No further increment was noted after 40 kg S ha⁻¹ application and the data recorded at 40 kg S and 60 kg S ha⁻¹ application were at par during both the years of study. Application of Zn significantly increased amylose content upto 5 kg Zn ha⁻¹ and thereafter increase was noted to be non-significant.

Effects of interactions of N x S, S x Zn, N x Zn and N x S x Zn were noted to be non-significant, however, interactions have decreasing trend on amylose content of rice and maximum values were noted with N₁S₃Zn₂ and minimum with N₃S₁Zn₁ during both the years of experimentation.

4.4.4. Effect of N, S & Zn on Starch content (%) of Rice

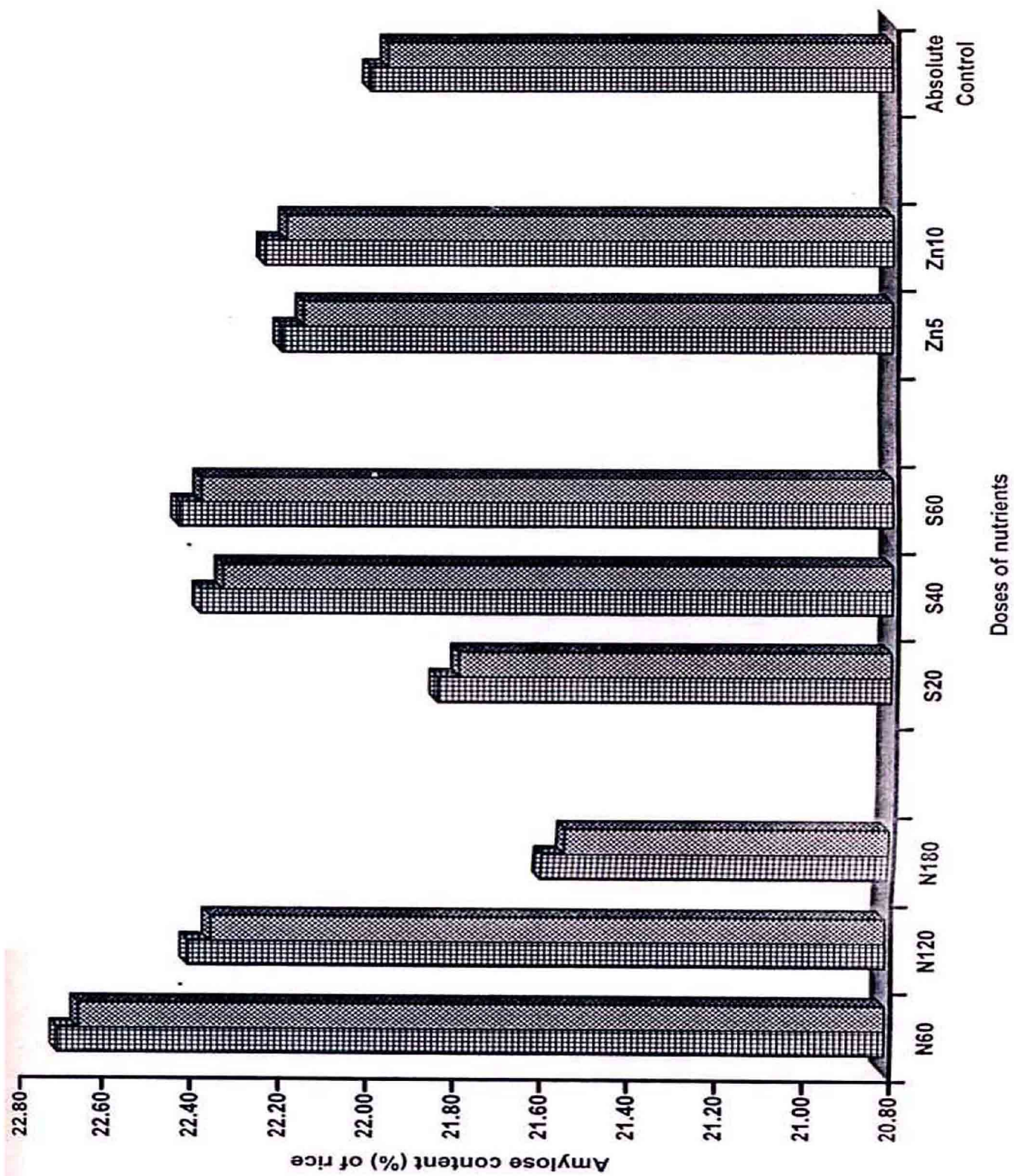
The data on starch content have been presented in Table 4.63 (Fig 4.30) during both the years. The data revealed that application of 60 kg N ha⁻¹ increased starch content significantly and thereafter graded doses of nitrogen decreased starch content of rice during both the years. This decrease was noted non-significant upto 120 kg N ha⁻¹ and thereafter it decreased significantly during both the years. However, minimum starch content was noted at 180 kg N ha⁻¹ application during both the years. Data recorded at 60 kg N and 120 kg N ha⁻¹ application were at par during both the years. Data recorded during both the years were at par in respect of starch content. Application of sulphur increased starch content significantly upto 40 kg S ha⁻¹ application over 20 kg S ha⁻¹ application and thereafter it increased non-significantly during both the years. Similarly, application of graded doses of Zn increased starch content of rice significantly upto 5 kg Zn ha⁻¹ and thereafter increase was noted to be non-significant during both the years of study.

Effects of interactions of N x S, S x Zn, N x Zn and N x S x Zn have been recorded to be non significant, however, interactions have decreasing trend on starch content and maximum values were noted at N₁S₃Zn₂ level and minimum at N₃S₁Zn₁ level during both the years of study.

Table 4.62: Effect of N, S & Zn on amylose content (%) of rice.

Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	22.29	22.83	22.88	22.67	22.24	22.78	22.83	22.62
	Zn ₂	22.33	22.87	22.92	22.71	22.28	22.82	22.87	22.66
Mean		22.31	22.85	22.90	22.69	22.26	22.80	22.85	22.64
N ₂	Zn ₁	21.99	22.53	22.58	22.37	21.94	22.48	22.53	22.32
	Zn ₂	22.03	22.57	22.62	22.41	22.98	22.52	22.57	22.36
Mean		22.01	22.55	22.60	22.39	21.96	22.50	22.55	22.34
N ₃	Zn ₁	21.19	21.73	21.78	21.57	21.14	21.68	21.73	21.52
	Zn ₂	21.23	21.77	21.82	21.61	21.18	21.72	21.77	21.56
Mean		21.21	21.75	21.30	21.59	21.16	21.70	21.75	21.54
Mean of the means		21.84	22.38	22.43	22.22	21.79	22.33	22.38	22.17
Absolute Control					22.00				21.96

N	SE (diff.)	0.17	CD (5%)	0.34	SE (diff.)	0.18	CD (5%)	0.36
S	0.17	0.34	0.18	0.36				
Zn	0.14	0.28	0.14	0.28				
N x S	0.29	N.S.	0.31	N.S.				N.S.
S x Zn	0.24	N.S.	0.25	N.S.				N.S.
N x Zn	0.24	N.S.	0.25	N.S.				N.S.
N x S x Zn	0.41	N.S.	0.44	N.S.				N.S.
Absolute	0.30	0.60	0.32	0.64				
Control/Treatments								



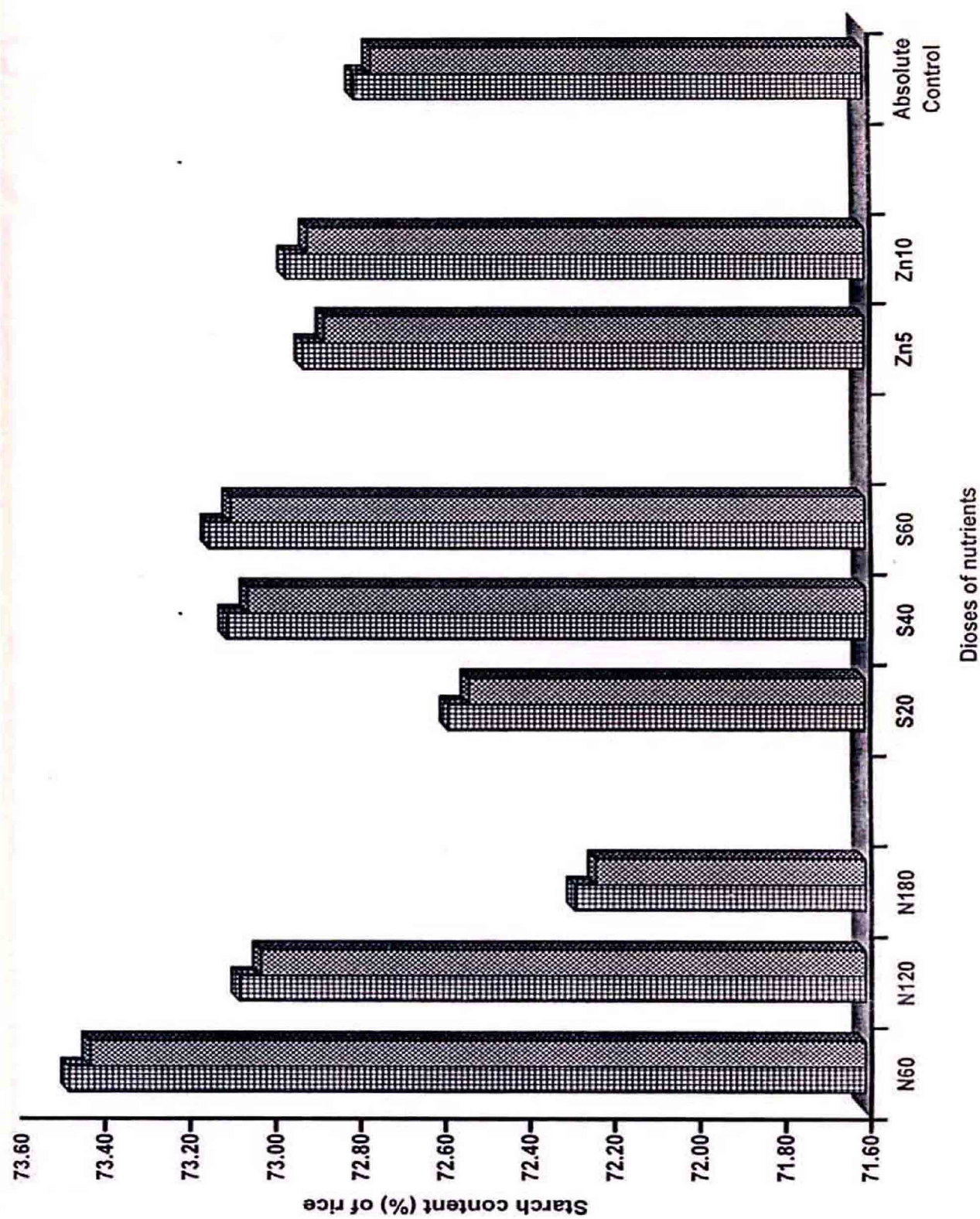
■ 2003 ▨ 2004

Fig 4.29: Effect of N, S & Zn on amylose content (%) of rice

Table 4.63: Effect of N, S & Zn on starch content (%) of rice.

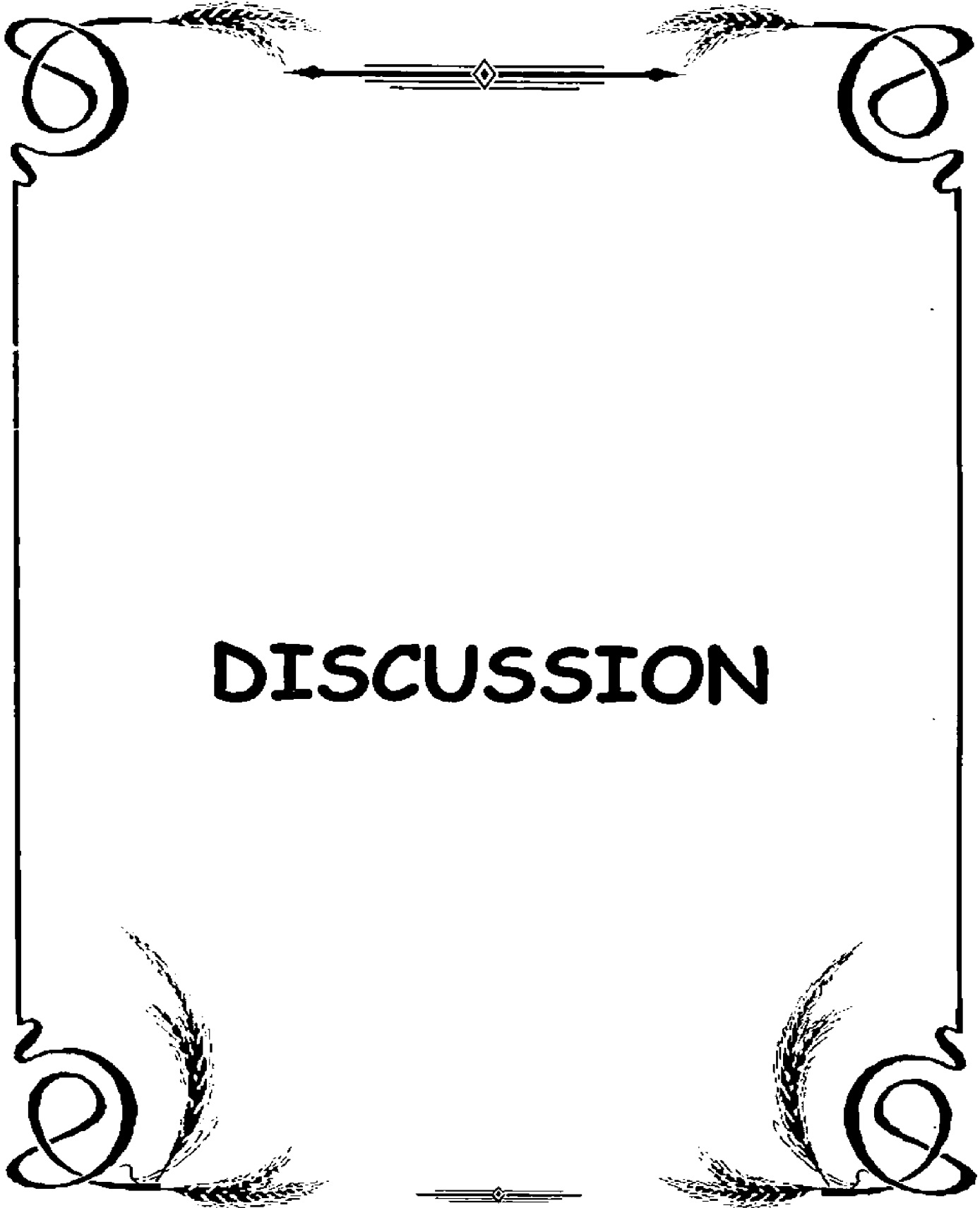
Treatments		2003			Mean	2004			Mean
		S ₁	S ₂	S ₃		S ₁	S ₂	S ₃	
N ₁	Zn ₁	73.09	73.61	73.66	73.45	73.04	73.56	73.61	73.40
	Zn ₂	73.13	73.65	73.70	73.49	73.08	73.60	73.65	73.44
Mean		73.11	73.63	73.68	73.47	73.06	73.58	73.63	73.42
N ₂	Zn ₁	72.69	73.21	73.26	73.05	72.64	73.16	73.21	73.00
	Zn ₂	72.73	73.25	73.30	73.09	72.68	73.20	73.25	73.04
Mean		72.71	73.23	73.28	73.07	72.66	73.18	73.23	73.02
N ₃	Zn ₁	71.90	72.42	72.45	72.26	71.85	72.37	72.40	72.21
	Zn ₂	71.94	72.46	72.49	72.30	71.89	72.41	72.44	72.25
Mean		71.92	72.44	72.47	72.28	71.87	72.39	72.42	72.23
Mean of the means		72.58	73.10	73.14	72.94	72.53	73.05	73.09	72.89
Absolute Control					72.80				72.76

N	SE (diff.)	0.21	CD (5%)	0.42	SE (diff.)	0.20	CD (5%)	0.40
S		0.21		0.42		0.20		0.40
Zn		0.17		0.34		0.16		0.32
N x S		0.36		N.S.		0.34		N.S.
S x Zn		0.29		N.S.		0.28		N.S.
N x Zn		0.29		N.S.		0.28		N.S.
N x S x Zn		0.51		N.S.		0.49		N.S.
Absolute		0.37		0.74		0.35		0.70
Control/Treatments								



■ 2003 ■ 2004

Fig 4.30: Effect of N, S & Zn on starch content (%) of rice



DISCUSSION

Field experiments were conducted in two consecutive *kharif* seasons of 2003 and 2004 to assess the effect of graded doses of nitrogen, sulphur and zinc on growth, yield attributing characters, yield, nutrient content at different stages of crop growth, uptake of nutrients and quality parameters of rice.

Growth and development of the plants are influenced by their genetic structure and constitution though environmental factors and cultural activities are equally important. The above factors play an important role in carrying out the vital processes of the plants which ultimately determine an effective crop production. Thus, the yield can be enhanced and quality can be improved by exploiting a particular genotype of high potential with suitable agronomic manipulation. Some broad generalized conceptions prevail that yield of rice is the function of various intricate factors directly or indirectly related with each other and that increase in yield from efficient management and careful handling of these factors.

Growth characters at various growth stages and yield and yield attributing characters of rice were recorded during both the years of experimentation. Soil samples before experimentation were collected and chemically analysed for available N, P, K, S and Zn following standard procedures. Collected plant samples during the course of experimentations at different stages of crop growth were chemically analysed for N, P, K, S and Zn and their uptakes were also computed for separately during each year. Nitrogen was determined in grains and straw and protein content was calculated. The results thus obtained during both the years are discussed in brief in this chapter with the help of accessible affirmation so as to obtain sound clarifications of the objectives for which the present investigation was planned.

5.1 EFFECT OF LEVELS OF NITROGEN, SULPHUR AND ZINC ON GROWTH, YIELD ATTRIBUTES AND YIELD OF RICE

5.1.1 Growth

It is obvious from the results presented in preceding chapter that the higher rates of nitrogen application enhanced the values of all the growth characters, viz., plant height, number of tillers hill⁻¹, no. of green leaves hill⁻¹ and biomass accumulation (g hill⁻¹) of rice over its lower rate at 30th and 60th day of transplanting during both the years. All the levels of nitrogen, sulphur and zinc in comparison to absolute control significantly increased the values of all the growth characters at both (30th and 60th day of transplanting) the stages of crop growth of rice crop. Much pronounced influence of nitrogen at higher dose was observed on above growth characters as compared to sulphur and zinc, though the maximum values were associated with the highest doses of N, S and Zn. Nitrogen application significantly increased all the growth characters upto 180 kg N ha⁻¹. The increase in values of aforesaid characters of rice due to application of nitrogen may be due to its favourable effect on meristematic activities of plant cells leading to better plant growth and also its favourable effect on photosynthesis process leading to efficient conversion of solar energy into chemical energy because of nitrogen being an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis. Nitrogen is also beneficial for profuse shoot development which is responsible for utilization of mineral nutrients favourable for vigorous vegetative growth of the plants. Maske et al (1997) have reported that application of N @ 120 Kg ha⁻¹ increased significantly the plant height, leaf area hill⁻¹, number of functional leaves hill⁻¹, number of shoots hill⁻¹ and dry matter hill⁻¹ during crop growth period of rice. Similar findings were also reported by Chandra (1992), Murali and Reddy (1995), Chopra *et al.* (1998), Stalin *et al.* (1999), Kano *et al.* (2000), Liu *et al.* (2002), Gadade *et al.* (2004), Rautaray (2004), Verma *et al.* (2004), Singh and Sharma (2005), and Singh *et al.* (2005).

The plant height, number of tillers hill⁻¹, number of green leaves hill⁻¹ and biomass accumulation (g hill⁻¹) of rice crop (Tables 4.10 to 4.17) increased

linearly and significantly with the application of sulphur up to 40Kg ha⁻¹ at both the stages of crop growth during both the years. This may be attributed to its role in development of tissues, xylem and collenchyma fibres. Sulphur also plays a vital role in chlorophyll biosynthesis, which in turn, enhances growth of the plants (Sinha *et al.*, 1995). These result are further supported by the finding of Russel and Chapman (1988), Mukhi and Shukla (1991), Mandal and Haider (1998), Patra *et al.* (1998), Ram *et al.* (1999), Singh & Singh (2002), Chandel *et al.* (2003) and Sriramchandrashekharan *et al.* (2004) in which they reported that the increasing levels of sulphur in rice significantly improved leaf area index, dry matter production, tiller number, harvest index and yield of all plant parts.

The growth attributing characters of rice increased significantly with the application of zinc. Unlike nitrogen and sulphur, higher increase was noted at 5 Kg Zn ha⁻¹ and above this level, the growth did not increase significantly at both the stages of crop growth during both the years. It may be due to the effect of zinc on regulating auxin concentration of plant and its participation in plant metabolism as an activator of several enzymes. Carbonic anhydrase (CA) is the first discovered Zn-containing enzyme which catalyses the hydration of CO₂ in photosynthesis and influences the growth. Similar results have also been reported by Panda and Nayak (1974), Babiker (1986), Zhang *et al.* (1992), Li *et al.* (1992), Panda and Sahu (1999), Kulandaivel *et al.* (2004), Singh and Singh (2004) and Tripathi and Tripathi (2004).

Likewise, nitrogen and sulphur alone, their interactions did not significantly increase growth characters at 30th and 60th day of transplanting (DOT) during both the years of experimentation. However, maximum growth was observed at N₃S₃ level which might be due to synergistic effect of N on S but this was not significantly higher from lower doses of sulphur. These results are further supported by Singh and Singh (2002). The interactive effects of SxZn, NxZn and NxSxZn also did not show significant effect on growth attributes though these had increasing trend at both the stages of crop growth during both the years. Maximum increase was recorded at N₃S₃Zn₂ level. These results are corroborated with the findings of Mandal and Haider (1998), Stalin *et al.* (1999) and Shanmugam and Veeraputhran (2000).

5.1.2 Yield Attributes (Maturity Characteristics)

The data on various yields attributes i.e. plant height at maturity (cm.), number of productive tillers m^{-2} , number of panicles $hill^{-1}$, total number of spikelets $hill^{-1}$, number of filled grains $panicle^{-1}$, panicle weight (g) and test-weight of grains were influenced significantly with the application of different doses of N, S and Zn during both the years. All the yield attributes increases significantly up to 120 kg of N application during both the years of study. Effect of nitrogen on various yield attributes was maximum at 180 kg N ha^{-1} except test weight of grains which decreased at 180 kg ha^{-1} of N application. All these characters were *at par* with its lower level i.e. N_2 level. However, total no. of spikelets and weight of panicle increased significantly upto N_3 level during both the years. The higher values of all the attributes as influenced by nitrogen application might be due to more favourable effect of nitrogen as compared to other mineral nutrients (Tables 4.18 to 4.24 and Fig 4.1). The results obtained in present investigation are in agreement with the findings of Balasubramanian and Palaniappan (1991), Awan *et al.* (2000), Bhowmick and Nayak (2000), Chopra and Chopra (2000), Mendhe *et al.* (2002), Maiti *et al.* (2003), Ram *et al.* (2004), Singh *et al.* (2004), Arivazhagan and Ravichandran (2005), Naik and Paryani (2005) and Singh *et al.* (2005). Similarly, sulphur application also improved yield attributing characters of rice significantly (Table 4.18 to 4.24). The highest enhancement was noted at 40 kg S ha^{-1} application. This could be due to low inherent available sulphur status of the soil of experimental field (Table 3.2). The sulphur deficient rice plants are associated with low levels of sugars which resulted in poor photosynthetic activity. Thus, sulphur addition to an optimum dose of 40 Kg Sha^{-1} might have fulfilled the requirement for proper photosynthetic activity and also may be due to its role in the development of xylem and collenchyma fibres. The results are in conformity with the findings of Randhawa (1973), Alam *et al.* (1985), Raju *et al.* (1994), Hoque and Jahiruddin (1994), Gautam Kumar (1999) and Sriramchandrashekharan *et al.* (2004).

The effect of Zn application on yield attributes was significant upto Zn_1 level and, thereafter, it did not increase significantly upto Zn_2 level at all the stages of crop growth during both the years. This might be due to low native zinc

status of the soils (Table 3.2). The application of zinc is attributed to the increased photosynthetic activity as catalysed by zinc containing enzyme which consequently resulted in higher accumulation of photosynthates in the yield attributing parts of rice. Similar results on yield attributes due to zinc application were also reported by Panda and Nayak (1974), Gill and Singh (1978), Balakrishnan and Natarajaratnam (1986), Channabasavanna and Biradar (2001), Muhammad *et al.* (2002), Kulandaivel *et al.* (2004) and Tripathi and Tripathi (2004).

The interactive effects of N_xS, S_xZn, N_xZn and N_xS_xZn were recorded non-significant on yield attributes of rice. However, yield attributes increased due to combined application of N_xS and N_xZn and maximum yield attributes were recorded at N₃S₃Zn₂ level. This could be due to synergistic effects of N, S and Zn and also due to antagonistic effects of S and Zn at their higher doses. These results are in close conformity with the findings of Tiwari (1989), Takkar *et al.* (1989), Mazid (1993), Shi *et al.* (1996), Gautam Kumar (1999), Shanmugam and Veeraputhran (2000), Subbiah and Kumaraswamy (2000), Duraisami *et al.* (2001), Muhammad *et al.* (2002), Sarfraz *et al.* (2002) and Singh and Singh (2002).

5.1.3. Yield of Grain and Straw (qha⁻¹)

Grain yield of rice significantly increased with increasing levels of nitrogen, sulphur and zinc upto 120 Kg N, 40 Kg S and 5Kg Zn over absolute control during both the years, respectively (Table 4.25 and Fig. 4.2). From the data, it is evident that further increase in nitrogen, sulphur and zinc levels upto 180, 60 and 10 Kg ha⁻¹, respectively had non-significant effect on the grain yield of rice. On an average, the highest grain yield of 58.36 and 59.87 qha⁻¹ recorded at 120 Kg Nha⁻¹ were calculated 180.03 and 177.94 percent higher than the lowest grain yield of 20.84 and 21.54 qha⁻¹ obtained at no nitrogen application during 2003 and 2004, respectively. Similarly, sulphur application at 40 Kg Sha⁻¹ obtained grain yield of 56.51 and 57.90 qha⁻¹ were calculated 171.16 and 168.80 percent higher than recorded at no sulphur application(absolute control) during both the years, respectively. Likewise, the grain yield of 55.23 and 56.56 qha⁻¹ recorded at 5Kg Zn ha⁻¹ level computed to the tune of 165.01 and 162.58

percent higher than the lowest yield recorded at no zinc in 1st and 2nd years, respectively.

Similarly, straw yield was also influenced by the addition of nitrogen, sulphur and zinc significantly upto 120 Kg N, 40 Kg S and 5 Kg Zn ha⁻¹ (Table 4.26). It was observed that application of different doses of nitrogen enhanced straw yield of rice (Fig 4.3) quadratically and significantly upto 120 kg N ha⁻¹, and thereafter it was recorded to be non-significant during both the years. The significant effect of nitrogen application on grain and straw yield of rice might be due to adequate nitrogen supply for shoot development and increased photosynthetic efficiency of the leaf leading to higher accumulation of biomass and its translocation to grains portion. The initial advantage of nitrogen application led to higher and efficient growth development and also proportionate utilization of other mineral elements required by the plants. The overall increase in mean grain and straw yields at 120 kg N ha⁻¹ might be attributed to simultaneous increase in growth characters like plant height, number of tillers, green leaves and biomass accumulation and yield attributing characters like number of productive tillers m⁻², number of panicles hill⁻¹, total number of spikelets hill⁻¹ and number of filled grains panicle⁻¹ which might have contributed substantially to increased grain and straw yields. The results of investigation are parallel to the findings of Singh *et al.* (1979), Knade and Kabra (1986), Antil *et al.* (1989), Amarsingham (1990), Raju *et al.* (1990), Song (1990), Balasubramanian and Palaniappan (1991), Choudhary and Bhuiyan (1991), Balasubramanian *et al.* (1993), Mazid (1993), Singh and Om (1993), Mondal *et al.* (1994), Medhi *et al.* (1996), Muthukrishnan *et al.* (1996), Tiwana and Narang (1997), Singh and Shree Devi (1997), Singh *et al.* (1998 a), Marr *et al.* (1999), Pandey *et al.* (1999), Panda *et al.* (1999), Gangaiah and Prasad (1999), Hemalatha *et al.* (2000), Ikramullah and Kumar (2001), Subbiah *et al.* (2001), Sudha and Chandini (2002), Dongarwar *et al.* (2003), Maiti *et al.* (2003), Parwar *et al.* (2003), Singh *et al.* (2004) and Naik and Paryani (2005).

Similarly, straw yield was also influenced by the addition of sulphur upto the level of 40 Kg S ha⁻¹. Significant responses to sulphur application might be due to low content of available sulphur (Pasricha *et al.*, 1977). The overall

increase in mean grain and straw yield at 40Kg S ha⁻¹ might be attributed to simultaneous increase in growth and yield attributing characters viz., plant height, number of tillers hill⁻¹, total number of spikelets hill⁻¹, number of filled grains panicle⁻¹ and weight of panicle which might have contributed to increased grain and straw yields. The results are in conformity with the findings of Acharya (1973), Das and Dutta (1973), Dargan *et al.* (1976), Tiwari *et al.* (1983 b), Islam *et al.* (1987), Ahmed *et al.* (1988), Tiwari (1989), Tripathi and Sharma (1994), Thakur *et al.* (1996), Sahu and Nanda (1997), Gupta *et al.* (1998), Patra *et al.* (1998), Sarkunan *et al.* (1998), Sakal *et al.* (1999), Ram *et al.* (1999), Subbaiah *et al.* (2001 b) and Tiwari *et al.* (2003) who reported increase in yield of rice crop due to sulphur application.

Application of Zn also affected straw yield significantly upto 5KgZnha⁻¹ and thereafter, the increase was noted to be non-significant during both the years of study. The overall increase in mean grain and straw yields at 5 Kg Zn ha⁻¹ might be attributed to simultaneous increase in growth and yield attributing characters because of significant role of zinc in photosynthetic activity as well as in protein synthesis which increased yield attributing characters. Similar results have also been reported by Dargan *et al.* (1976), Agarwala *et al.* (1980), Nagarajan and Manickam (1986), Vyas *et al.* (1990), Anandswaroop (1991), Indulkar and Malewar (1991), Sahay *et al.* (1992), Rashid and Fox (1992), Das *et al.* (1994), Singh and Sharma (1994), Tomar *et al.* (1994), Chen and Fan (1997), Alam *et al.* (1998), Mian *et al.* (2001), Kumar *et al.* (2002) and Jadhav *et al.* (2003b).

The grain and straw yield of rice also increased by combined application of N, S and Zn i.e. NxS, SxZn, NxZn and NxSxZn interactions but these interactions could not touch the level of significance. NxS interaction affected grain and straw yields favourably and highest grain and straw yields were recorded by this combination at N₃S₃ level during both the years. However, maximum grain and straw yield was recorded with the combination of highest doses of N, S and Zn i.e. at N₃S₃Zn₂ level during both the years of experimentation. These results are corroborated with the findings of Randhawa (1973), Balakrishnan and Natarjaratnam (1986), Ahmed *et al.* (1988), Sahay *et al.* (1992), Singh and Sharma (1994), Tomar *et al.* (1994), Chen and Fan (1997), Alam *et al.* (1998), Mian *et al.* (2001), Kumar *et al.* (2002) and Jadhav *et al.* (2003b).

al. (1992), Raju *et al.* (1994), Akhtar *et al.* (1994), Nandram (1996), Khandra and Dixit (1996), Channal and Kandaswamy (1997), Hasan (1998), Tripathi *et al.* (1999), Gautam Kumar (1999), Shanmugam and Veeraputhran (2000), Bhowmick and Nayak (2000), Subbiah and Kumaraswamy (2000), Jadhav *et al.* (2003b), Mythili *et al.* (2003) and Hegde and Sudhakarbabu (2004) in which they reported that the combined application of nitrogen and sulphur and nitrogen with zinc increased grain and straw yield upto 180 Kg N, 60 Kg S and 10 Kg Zn ha⁻¹ due to increase in growth and yield attributing characters of rice.

5.2. EFFECT OF LEVELS OF N, S & Zn ON CONTENT AND UPTAKE OF NUTRIENTS

5.2.1. EFFECT OF NITROGEN, SULPHUR AND ZINC ON CONTENT OF NUTRIENTS

5.2.1.1. Nitrogen

The contents of nitrogen in plant increased significantly with unit increase in levels of nitrogen, sulphur and zinc at all the stages of crop growth (30th and 60th day of transplanting and at harvest i.e. in grain and straw) over absolute control during both the years (Table 4.27 to 4.30 and Fig 4.4 & 4.5). It might be attributed to the favourable effect of nitrogen on its absorption and translocation by plants. Application of nitrogen significantly increased N content upto 180 Kg N ha⁻¹ at both the growth stages (30th and 60th day of transplanting) of crop due to more requirement of nitrogen at an early stage for vigorous growth and increased photosynthetic activity. The content of N in grain increased significantly upto 120kg N ha⁻¹ and thereafter it did not increase significantly. The similar trend was noticed in case of straw also. The increasing trend of N content due to application of nitrogen is also supported by Singh *et al.* (1979), Shukla and Sharma (1986), Alam and Azmi (1989), Bhardwaj and Omanwar (1994), Matiwade and Sheelavantar (1995), Laza *et al.* (1996), Medhi *et al.* (1996), Fu *et al.* (1999), Marr *et al.* (1999), Stalin *et al.* (1999), Raghavaiah *et al.* (2000), Swamy and Mandal (2003) and Vijaybaskar *et al.* (2004).

The contents of nitrogen in plants at different stages of crop growth increased significantly with increase in sulphur and zinc upto 40kg S and 5kg Zn ha⁻¹ levels, respectively over absolute control during both the years. It might be attributed to synergistic effects of sulphur and zinc on the absorption of nitrogen. It was further observed that N content was found to increase upto 60 Kg S and 10 Kg Zn ha⁻¹ with an unit increase in levels of both the nutrients at different stages of crop growth during both the years. However, the N contents at different stages of crop growth including grain and straw at 40 and 60 Kg S and 5 and 10 Kg Zn ha⁻¹ levels were statistically non-significant. There was a decrease in N content with the advancement in age of the crop in all the stages of crop growth, except grain where it was increased (Joseph and Prasad, 1992). Effect of sulphur on nitrogen content of rice crop is also supported by Wallihan and Sharpless (1974), Martel and Zizka (1977), Mazid (1993), Sakal *et al.* (1999), Nad *et al.* (2001) and Sarfraz *et al.* (2002). Effect of Zn on N content of rice is also reported by Singh and Prasad (1978), Dev and Shukla (1980), Sahu *et al.* (1996), Shanmugam and Veeraputhran (2001) and Kumar *et al.* (2002).

The effects of interactions of NxS, SxZn, NxZn and NxSxZn have increasing trend on N content but it did not reach the level of significance and maximum content was noted at N₃S₃Zn₂ level during both the years. Similar works have also been reported by Wallihan and Sharpless (1974), Ismundaji (1975), Moss *et al.* (1981), Shukla and Sharma (1986), Gupta *et al.* (1993), Malarvizhi *et al.* (1993), Mazid (1993), Manchanda *et al.* (1993), Dixit and Patro (1994), Marr *et al.* (1999), Nad *et al.* (2001), Shanmugam and Veeraputhran (2001), and Sarfraz *et al.* (2002).

5.2.1.2. Phosphorus

Phosphorus concentration at different stages of crop growth i.e. 30th and 60th day of transplanting and at harvest of the crop (grain and straw) enhanced significantly with increasing levels of nitrogen, sulphur and zinc over absolute control (Table 4.31 to 4.34 and Fig 4.6 & 4.7). The phosphorus concentration increased significantly at all the stages of crop growth with the application of nitrogen upto 120 Kg N ha⁻¹ and, thereafter, the increase was non-significant during both the years. It might be due to the effect of N on the availability of

phosphorus and its regulation on phosphorus uptake due to more development of roots and shoots of plant. Similar results are also reported by Alam and Azmi (1989), Bhardwaj and Omanwar (1994), Medhi *et al.* (1996), Raghavaiah *et al.* (2000), Tripathi and Tiwari (2002), and Maiti *et al.* (2003).

The phosphorus concentration increased significantly at all the stages of crop growth upto the levels of 40 Kg S and 5 Kg Zn ha⁻¹ and, thereafter, there was a non-significant decrease at 60 Kg S and significant decrease at 10 Kg Zn ha⁻¹ noted during both the years. Thus, phosphorus shows synergistic behaviour with sulphur and zinc at their lower levels but at higher levels of sulphur (60 Kg S ha⁻¹) and zinc (10 Kg Zn ha⁻¹), phosphorus had an antagonistic effect with sulphur and zinc. The beneficial effect of sulphur on phosphorus concentration is also supported by Ivanic (1977), Sinha *et al.* (1995), Singh *et al.* (1997), Sakal *et al.* (1999), Sen *et al.* (2002) and Islam *et al.* (2006). The application of zinc also increased P concentration at its low levels but at high doses of Zn application P content decreased. This is in agreement with the findings of Hofuer and Kovanci (1973), Singh (1976), Singh and Prasad (1978), Mali and Shaikh (1993), Tomar *et al.* (1994), Singh *et al.* (1999) and Kumar *et al.* (2002).

Effects of interactions of NxS, NxZn and NxSxZn have increasing and SxZn has decreasing trend on P content at different stages of rice crop but did not reached to the level of significance. Similar results are also reported by the findings of Shukla and Sharma (1986), Mali and Shaikh (1993), Bhardwaj and Omanwar (1994), Singh *et al.* (1999), Shanmugam and Veeraputhran (2001) and Islam *et al.* (2006).

5.2.1.3. Potassium

The data presented in Table 4.35 to 4.38 and Fig 4.8 & 4.9 reveal that the addition of Nitrogen, Sulphur and Zinc with their increasing levels increased significantly the potassium content in rice plant at different stages of crop growth. It was also visualized from the data that nitrogen, sulphur and zinc had synergistic effect on the absorption of potassium resulting in significant increase in potassium contents with increasing levels of N, S and Zn being highest at 180 Kg N, 60 Kg S and 10 Kg Zn ha⁻¹ during both the years. However, potassium

contents at 180 and 120 Kg N ha⁻¹, 60 and 40 Kg S ha⁻¹ and 5 and 10 Kg Zn ha⁻¹ were statistically *at par* at different stages of crop growth during 1st and 2nd years, respectively. It is also apparent from the data that potassium, unlike P, does not accumulate in the grain. The potassium content of grain was lower as compared to straw of rice. It might be due to the fact that smaller amounts of K than that of N and P move from the vegetative parts to the developing panicle and spikelets. This could be because of low mobility of potassium from vegetative parts to grains portion. About 23 to 25 percent of the potassium was translocated from the vegetative parts to the developing grain. The positive effects of nitrogen, sulphur and zinc addition on K content have also been reported by Ismundaji (1975), Shukla and Sharma (1986), Malarvizhi *et al.* (1993), Medhi *et al.* (1996), Bhandari *et al.* (1996), Sakal *et al.* (1999), Singh *et al.* (1999), Kumar *et al.* (2002) and Vijaybaskar *et al.* (2004).

The combined application of nitrogen, sulphur and zinc also affected K content in grain and straw of rice but could not touch the level of significance. Similar findings are also reported by Sakal *et al.* (1999), Sarfraz *et al.* (2002) and Kumar *et al.* (2002).

5.2.1.4. Sulphur

Sulphur content at different stages of crop growth increased significantly with increasing levels of sulphur upto 40 Kg S ha⁻¹, thereafter it increased non-significantly upto 60 Kg S ha⁻¹ over absolute control during both the years (Table 4.39 to 4.42 and Fig 4.10 & 4.11). Nitrogen and zinc application also increased the sulphur content significantly upto 120 Kg N and 5 Kg Zn ha⁻¹ during both the years. At 180 Kg N ha⁻¹ sulphur content increased non-significantly and at 10 Kg Zn ha⁻¹ application S content decreased significantly at all the stages of crop growth during both the years. It is attributed to antagonistic effect of Zn on sulphur concentration. An expected increase in sulphur concentration with increase in nitrogen and sulphur level is not questionable because addition of increasing levels of nitrogen and sulphur increased its availability to crop. Similar findings have also been recorded by Wallihan and Sharpless (1974), Ismundaji (1975), Pillai and Singh (1975), Moss *et al.* (1981), Tiwari *et al.* (1983 a,b), Alam *et al.* (1985), Mazid (1993), Malarvizhi *et al.* (1993),

Ganeshmurthy *et al.* (1995), Marr *et al.* (1999), Singh *et al.* (1999), Chandel *et al.* (2003).

Interactions effect of NxS has synergistic and NxZn, SxZn and NxSxZn have antagonistic effect on S content at different stages of crop growth period of rice during both the years. The results are in conformity with the findings of Wallihan and Sharpless (1974), Ismundaji (1975), Martel and Zizka (1977), Shukla and Prasad (1979), Moss *et al.* (1981), Kochar *et al.* (1990), Mazid (1993), Singh *et al.* (1997), Singh (2000), Nad *et al.* (2001) and Islam *et al.* (2006).

5.2.1.5. Zinc

The concentration of zinc in rice shoot at different stages of crop growth including grain and straw was significantly increased by nitrogen, sulphur and zinc application upto 120 KgN, 40 KgS and 10KgZn ha⁻¹ application respectively during both the years (Table 4.43 to 4.46 and Fig 4.12 & 4.13). At highest level of S application (60kg Sha⁻¹) Zn content decreased significantly during both the years. It is due to antagonism between S and Zn at their higher levels of application. Higher concentration of zinc in plant at different stages due to nitrogen and sulphur application may be ascribed to increased solubility of zinc in soil as a result of lowering of soil pH. Results of present investigation are corroborated with the findings of Shukla and Prasad (1979), Singh and Karrwasra (1987), Chakraborty and Mandal (1993) and Tiwana and Narang (1997).

It is visualized from the data that application of Zn significantly increased zinc content upto 10 Kg Zn ha⁻¹ at different stages of crop growth including grain and straw during both the years. The maximum content was recorded at 10 Kg Zn ha⁻¹ application. Similar findings have also been reported by Hofuer and Kovanci (1973), Pathak *et al.* (1975), Singh (1976), Singh *et al.* (1983), Gukova *et al.* (1985), Sharma *et al.* (1986), Singh and Abrol (1987), Singh and Sakal (1987), Biswapati *et al.* (1988), Tomar *et al.* (1994), Kumar and Singh (1997), Patnaik and Raj (1999), Kamal *et al.* (1999), Prasad *et al.* (2000), Kumar *et al.* (2002), Muhammed *et al.* (2002) and Khan *et al.* (2004).

Effects of interactions of NxS, SxZn, NxZn and NxSxZn have been recorded to be non-significant on zinc concentration at different stages of crop growth including grain and straw of rice during both the years. Similar results were also reported by Dev and Shukla (1980), Singh *et al.* (1989), Kochar *et al.* (1990), Mali and Shaikh (1993), Sinha *et al.* (1995), Singh *et al.* (1997), Singh *et al.* (1999) and Marr *et al.* (1999).

From the data on contents of N, P, K, S and Zn (Table 4.27 to 4.46), it is quite apparent that absorption of these nutrient was recorded comparatively higher at an early stage of crop growth, which declined with advancing age of the crop. This might be due to higher availability of these nutrients in the soil at an early stage due to addition of nitrogen, sulphur and zinc in available forms at the time of transplanting which resulted in their higher availability. The decline in concentration of these nutrients with advancing age might be due to dilution of nutrient elements in increased biomass production. It is also evident from the data that the grains accumulated more contents of N, P, S, and Zn showing their high mobility whereas straw had more potassium indicating low mobility. This shows the translocation of N, P, S and Zn from vegetative organs to grains at the time of maturity. The higher concentration of potassium in straw might be due to the fact that potassium plays an important role in photosynthesis, which takes place in the vegetative parts of the plant, and thus, plant vegetative parts accumulate higher amount of potassium.

5.2.2. EFFECT OF NITROGEN, SULPHUR AND ZINC ON UPTAKE OF NUTRIENTS

5.2.2.1. Nitrogen

The uptake of nitrogen in grain and straw of rice increased significantly with increasing N levels over absolute control (Table 4.47 and 4.48 and Fig 4.14 & 4.15). It might be attributed to increased N content in grain and straw with concomitant increase in yield of grain and straw upto 120 Kg N ha⁻¹ application during both the years. The results are in conformity with the findings of Singh *et al.* (1979), Sudhakar *et al.* (1986), Baijigitov and Moiseeva (1987), Amarsingham (1990), Monapara *et al.* (1993), Matiwade and Sheelavantar

(1995), Singh *et al.* (1995), Laza *et al.* (1996), Medhi *et al.* (1996), Singh *et al.* (1998a), Stalin *et al.* (1999), Suresh *et al.* (1999), Jaiswal and Singh (2001), Swamy and Mandal (2003) and Singh *et al.* (2004), and Mhaskar and Thorat (2005).

N uptake by grain and straw also increased significantly with the application of increased levels of sulphur and zinc over absolute control. This increase was upto the levels of 40 Kg S and 5 Kg Zn ha⁻¹ and thereafter it increased non-significantly upto 60 Kg S and 10 Kg Zn ha⁻¹. The N uptake by grain and straw with 40 Kg S and 5 Kg Zn ha⁻¹ commensurated with grain and straw yields and N content (Table 4.24 and 4.25, 4.29 and 4.30). Pasricha *et al.* (1977), Singh and Prasad (1978), Dev and Shukla (1980), Sedberry *et al.* (1988), Khanda and Dixit (1996), Sakal *et al.* (1999), Wani and Refique (2000), Shanmugam and Veeraputhran (2001), Sudha and Chandini (2002) also observed increase in N uptake with application of S & Zn to rice crop. Nitrogen uptake also increased by combined application of N, S and Zn but it did not reach the level of significance which is in conformity with the observations of several workers [Ahmed *et al.* (1988), Mazid (1993), Gupta *et al.* (1993), Dixit and Patro (1994), Kamal *et al.* (1999), Singh and Singh (2002), Sarfraz *et al.* (2002), and Jadhav *et al.* (2003)].

5.2.2.2. Phosphorus

Nitrogen has synergistic effect on phosphorus content and also plays an important role in phosphorus availability to plant roots. Because nitrogen application significantly enhanced phosphorus content and grain yield upto 120 Kg N ha⁻¹ then its uptake also increased upto 120 Kg N ha⁻¹ in both grain and straw of rice (Table No. 4.49 and 4.50 and Fig 4.16 & 4.17). Similar results have been reported by Narang *et al.* (1980), Tripathi and Upadhyay (1988), Balasubramaniyan *et al.* (1991), Balasubramanian *et al.* (1993), Murali and Reddy (1995), Singh *et al.* (1995), Panda *et al.* (1999), Tripathi and Tiwari (2002), Sitaramayya *et al.* (2002), Sudha and Chandini (2002), Maiti *et al.* (2003), Parihar (2004) and Mhaskar and Thorat (2005).

However, in accordance with concentration of phosphorus, its uptake increased with increasing levels of sulphur and zinc upto 40 Kg S and 5 Kg Zn ha⁻¹ which seems to be associated with increased sulphur and zinc availability from applied sulphur and zinc with a concomitant increase in crop yield. The increase in phosphorus content on sulphur application may occur because sulphur and phosphorus both are related in a number of metabolic phenomena in plant such as protein synthesis and oil biosynthesis. Thus, with increasing sulphur concentration in plants, phosphorus requirements would also be increased simultaneously. The second reason may be due to better root development of the crop, which increased the concentration of phosphorus per unit dry matter produced (Acharya and Subbiah, 1971). Thus, sulphur and zinc application at moderate levels (40 Kg S and 5 Kg Zn ha⁻¹) appeared to have induced better root development and showed beneficial effect in phosphorus uptake (Singh et al. 1997). Similar results are also reported by the findings of Singh and Prasad (1978), Malarvizhi *et al.* (1993), Dixit and Patro (1994), Sinha *et al.* (1995), Sakal *et al.* (1999), Wani and Refique (2000), Sarfraz (2002). However, the uptake of phosphorus decreased at 60 Kg S and 10 Kg Zn ha⁻¹ which might be due to depressive effect of sulphur and zinc at their higher levels of application (Singh and Karrwasra, 1987, Tiwari, 1989, and Dixit and Patro, 1994).

However, combined application of NxS, SxZn, NxZn and NxSxZn have been noted to be non-significant on uptake of P. This is in conformity with the findings of Dixit and Patro (1994), Kamal *et al.* (1999), Jadhav *et al.* (2003) and Islam *et al.* (2006).

5.2.2.3. Potassium

The data presented in Table 4.51 and 4.52 and Fig 4.18 & 4.19 reveal that addition of nitrogen, sulphur and zinc with their increasing levels increased significantly the potassium uptake in grain and straw of rice during both the years. It is visualized from the data that nitrogen, sulphur and zinc had synergistic effect on the absorption of potassium significantly upto 120 Kg N, 40 Kg S and 5 Kg Zn ha⁻¹ during both the years. However, the potassium uptake in both grain and straw at 180 Kg N, 60 Kg S and 10 Kg Zn ha⁻¹ levels were

statistically at par with their lower levels during both the years. It is also apparent from table 4.51 that potassium, unlike P does not accumulate in the grain. It might be due to the fact that smaller amounts of K than that of P and N move from the vegetative parts to the developing spikelets. About 23 to 25% of the potassium was translocated from the vegetative parts to the developing grain. This could be due to the fact that the mobility of potassium was less from vegetative to grains portion. Potassium was apparently translocated from all parts of the plants except the stalks, wherein potassium increased during grain maturation. Consequently, there was more and more accumulation of K in straw than grain. The positive effect of N, S and Zn addition on potassium uptake have also been reported by Singh and Prasad (1978), Baijigitov and Moiseeva (1987), Tandon and Sekhon (1988), Tripathi and Upadhyay (1988), Narang *et al.* (1990), Balasubramaniyan *et al.* (1991), Monapara *et al.* (1993), Chakraborty and Mandal (1993), Balasubramanian *et al.* (1993), Murali and Reddy (1995), Singh *et al.* (1995), Panda *et al.* (1999), Sakal *et al.* (1999), Wani and Refique (2000), Kumar *et al.* (2002), Maiti *et al.* (2003), Mhaskar and Thorat (2005) and Arivazhagan and Ravichandran (2005).

Interactions effect of N x S, S x Zn, N x Zn and N x S x Zn were synergistically related but did not have significant effect on potassium uptake during both the years. The results are in conformity with the findings of Dixit and Patro (1994), Kamal *et al.* (1999), Sakal *et al.* (1999), Sarfraz *et al.* (2002) and Jadhav *et al.* (2003).

5.2.2.4 Sulphur

The sulphur uptake by grain and straw (Table 4.53 and 4.54 and Fig 4.20 & 4.21) increased significantly with increasing levels of nitrogen, sulphur and zinc upto 120 Kg N, 40 Kg S, and 5 Kg Zn ha⁻¹ in both grain and straw of rice and thereafter the increase was noticed to be non-significant during both the years . It seemed to be associated with increased sulphur availability from applied N, S and Zn with a concomitant increase in crop yield. Nitrogen, sulphur and zinc application to a moderate level (120 Kg N, 40 Kg S and 5 Kg Zn ha⁻¹) appeared to have induced better root development and showed beneficial effect on S uptake (Sinha *et al.*, 1995 and Singh *et al.* 1997). S uptake by nitrogen and sulphur application increased significantly which stood supported by the

findings of Pasricha *et al.* (1977), Ahmed *et al.* (1988), Mazid (1993), Marr *et al.* (1999), Sakal *et al.* (1999), Poongothai *et al.* (1999), Wani and Refique (2000), Sudha and Chandini (2002), Sarfraz *et al.* (2002) and Sen *et al.* (2002).

Application of zinc significantly increased S uptake upto 5 Kg Zn ha⁻¹ and thereafter it decreased non-significantly upto 10 Kg Zn ha⁻¹ showing an antagonistic relationship between S and Zn at their higher levels of application. These results are also corroborated with the findings of Mukhi and Shukla (1991) and Singh *et al.* (1997). However, interactions of N, S and Zn did not affect significantly the S uptake both grain and straw during both the years. These results are also corroborated with the findings of Shukla and Prasad (1979), Singh and Karrwasra (1987), Ahmed *et al.* (1988), Kochar *et al.* (1990), Singh *et al.* (1997), Kamal *et al.* (1999), Singh (2000), Singh and Singh (2002), Sudha and Chandini (2002) and Islam *et al.* (2006).

5.2.2.5 Zinc

It is visualized from the data given in tables 4.55 and 4.56 (Fig 4.22 & 4.23) that graded doses of N Application increased zinc uptake significantly. Zinc concentration and uptake significantly increased upto 120 Kg N ha⁻¹ in grain and straw of rice showing synergistic effect of nitrogen to zinc because grain and straw yield increased significantly upto 120 Kg N ha⁻¹, due to increased availability of zinc in soil. Nitrogen application increased zinc uptake in grain and straw of rice is also supported by Chakarborty and Mandal (1993), Tiwana and Narang (1997), Marr *et al.* (1999) and Duhan and Singh (2002).

The uptake of zinc increased significantly with the application of S and Zn upto 40 Kg S and 10 Kg Zn ha⁻¹ but beyond 40 Kg S ha⁻¹ application Zn uptake decreased to a non-significant level due to antagonistic effect of S with Zn at their higher levels. It seems to be associated with increased availability from applied S and Zn with concomitant increase in crop yield. Sulphur and zinc application appeared to have induced better root development and showed beneficial effect on Zn uptake. Results of present investigation are corroborated with the findings of Sharma *et al.* (1986), Singh *et al.* (1989), Kochar *et al.* (1990), Mukhi and Shukla (1991), Sahay *et al.* (1992), Singh and Kumar (1993),

Singh *et al.* (1994), Singh and Sharma (1994), Sinha *et al.* (1995), Nandram (1996), Channal and Kandaswamy (1997), Trivedi *et al.* (1998), Jadhav *et al.* (2003), Patil and Meisheri (2003) and Tripathi and Tripathi (2004).

Interaction effects of N x S, S x Zn, N x Zn and N x S x Zn have been found to be non-significant on Zn uptake, however, they have increasing trend due to synergistic effects of N x Zn, N x S and N x S x Zn and antagonism between S and zinc at their higher levels. These results are also supported by the findings of Singh and Karrwasra (1987), Gupta *et al.* (1993), Dixit and Patro (1994), Khanda and Dixit (1996), Singh *et al.* (1997) and Shanmugam and Veeraputhran (2001).

5.3 OPTIMUM REQUIREMENT OF NITROGEN, SULPHUR AND ZINC FOR MAXIMUM GRAIN YIELD

It is evident from the response curves (Fig 4.24) that grain yield of rice behaved curvilinearly with increasing doses of N, S and Zn during both the years and decreased at 180 kg N, 60 kg S and 10 kg Zn ha⁻¹ levels in comparison to 120 kg N, 40 kg S and 5 kg Zn ha⁻¹, respectively. This clearly indicates that optimum requirement of nitrogen, sulphur and zinc for maximum economic grain yield exists between 120 and 180 kg N, 40 and 60 kg S and 5 and 10 kg Zn ha⁻¹ levels. From response curves (Fig 4.24) and response equations (Table 4.57), it was computed that maximum economic grain yield of 62.61, 61.48 and 60.66 q ha⁻¹ at 156 kg N, 43.69 kg S and 7.24 kg Zn ha⁻¹ could be obtained, respectively. In support of results obtained in present investigation, several workers have also noticed decline in yield of rice crop after certain levels of nitrogen (Singh *et al.*, 1979; Knade and Kabra, 1986; Panda *et al.*, 1999; Bhowmick and Nayak, 2000; Duraisami *et al.*, 2001). Sitaramayya *et al.*, 2002; Parvar *et al.*, 2003; Raghuwanshi *et al.*, 2003 and Singh *et al.*, 2004 also reported similar response equations for N in rice.

Likewise, Singh *et al.* (1979) in field experiment found that application of N up to 200kg ha⁻¹ increased plant height, number of productive tillers, length of panicle, fertile grains and grains weight per panicle which ultimately enhanced the grain and straw yields but the increase beyond 160kg N ha⁻¹ was rather

negligible. The results further confirmed that the use of nitrogen progressively enhanced the uptake of nutrients as reported by earlier workers (Sharma and Singh, 1971). Response function fitted to grain yield and found to be quadratic and on this basis they worked out optimum economic level of nitrogen to be 186 kg ha⁻¹. Singh *et al.* (1998 b) also reported same results.

This is clearly indicated that optimum requirement of sulphur and zinc for maximum economic grain yield exists between 40 and 60 kg S ha⁻¹ and 5 and 10 kg Zn ha⁻¹ levels. In support of results obtained in present investigation, several workers have also noticed decline in yields of several crops after certain levels of sulphur (Ram and Dwivedi, 1992; Tiwari, 1989 and Gupta *et al.*, 1998). Sakal *et al.*, 1999 also reported similar response equations for S in rice.

Likewise, Singh *et al.* (1983) reported that application of zinc up to 5 kg ha⁻¹ increased significantly the grain and straw yield of maize, where as at 10 kg Zn ha⁻¹ level, the yields tended to decrease. Sahay *et al.* (1992) reported that the yield response to 25 kg ha⁻¹ zinc sulphate in paddy was from 1.093 to 1.111tha⁻¹ and in wheat from 0.585 to 0.835 tha⁻¹. Kochar *et al.* (1990) also recorded similar decreasing trend in rice yield at 10 ppm Zn application. The results of present investigation are also in close conformity with the findings of Rashid and Fox (1992), Singh and Kumar (1993) and Tiwari and Dwivedi (1993).

5.4 EFFECT OF N, S AND Zn ON QUALITY PARAMETERS

5.4.1 & 2 PROTEIN CONTENT AND PROTEIN PRODUCTION BY GRAIN AND STAW

The data presented in Tables 4.58 to 4.61 (Fig 4.25, 4.26, 4.27 & 4.28) clearly reveal that N, S and Zn application enhanced significantly the protein content during both the years. Nitrogen is a constituent element of proteins, and nitrogen and sulphur have synergistic relationship (Shukla, 1992 and Ram and Dwivedi, 1992).

Nitrogen is an essential constituent of protein and takes part in the protein synthesis. The protein content in rice grain (Table 4.58) is the resultant of multiplication of nitrogen content (%) in grain with a common factor of 5.95 and

in straw of rice multiplication of 6.25 with nitrogen content of straw (Table 4.59). Protein content in grain and straw increased significantly with the increasing levels of N up to 120 kg N ha⁻¹ but highest protein content was noted at 180 kg N ha⁻¹ application during both the years. Protein production is the multiplication of grain and straw yield with the protein content (%) in grain and straw of rice, respectively, during both the years. The increase in the content of nitrogen in grain and straw also increased protein content in grain and straw and so that protein production significantly up to 120 kg N ha⁻¹ during both the years of study. Similar results have also been reported by the findings of Sabhamuni (1990), Zhou *et al.* (1992), Deka and Borah (1993), Kumar *et al.* (1996), Patel *et al.* (1997), Khanna *et al.* (2002), Singh and Singh (2002), Tripathi and Tiwari (2002), Premi and Kalia (2003), Jin Jun *et al.* (2004), Panda and Srivastava (2004); Shen Ming Xing *et al.* (2004), Leesawatwong *et al.* (2005) and Liu *et al.* (2005).

Sulphur is an essential constituent of S-containing amino acids i.e. methionine, cystine and cysteine helps in the formation of proteins. Under intensive cropping and concentrated fertilization some sulphur deficiency occurs. It usually added to the soil in the form of elemental sulphur or gypsum. Root growth is inhibited by S-deficiency (Stewart and Porter, 1969). Sulphur taken up by plant cells must be reduced because in the major S-containing organic molecules, S is present in a reduced form (SH). These organic compounds include methionine, cystine and cysteine as well as the proteins. The SH (Sulphydryl) group from cystine can be transferred to homoserine forming homocysteine. Ultimately converted to methionine by a CH₃ group transfer (Lehninger, 1975). Cystine is synthesized by two molecules of cysteine with the elimination of 2H. Singh and Singh (1970), Baba (1971), Verma *et al.* (1973), Das *et al.* (1975), Pasricha and Randhawa (1975), Aulakh *et al.* (1976), Suzuki (1977), Kushwaha and Srivastava (1978), Saroha and Singh (1979), Kamat *et al.* (1981), Sagare and Bhalkar (1986), Srinivasan and Natarajaratnam (1986), Saraf (1988), Tiwari (1989), Ram and Dwivedi (1992), Malarvizhi *et al.* (1993), Srikrishna (1995), Tripathi *et al.* (1997 b), Mishra (1999), Sakal *et al.* (1999), Wani *et al.* (2000) and Chandel *et al.* (2003) reported an increase in protein content due to sulphur application in different food crops.

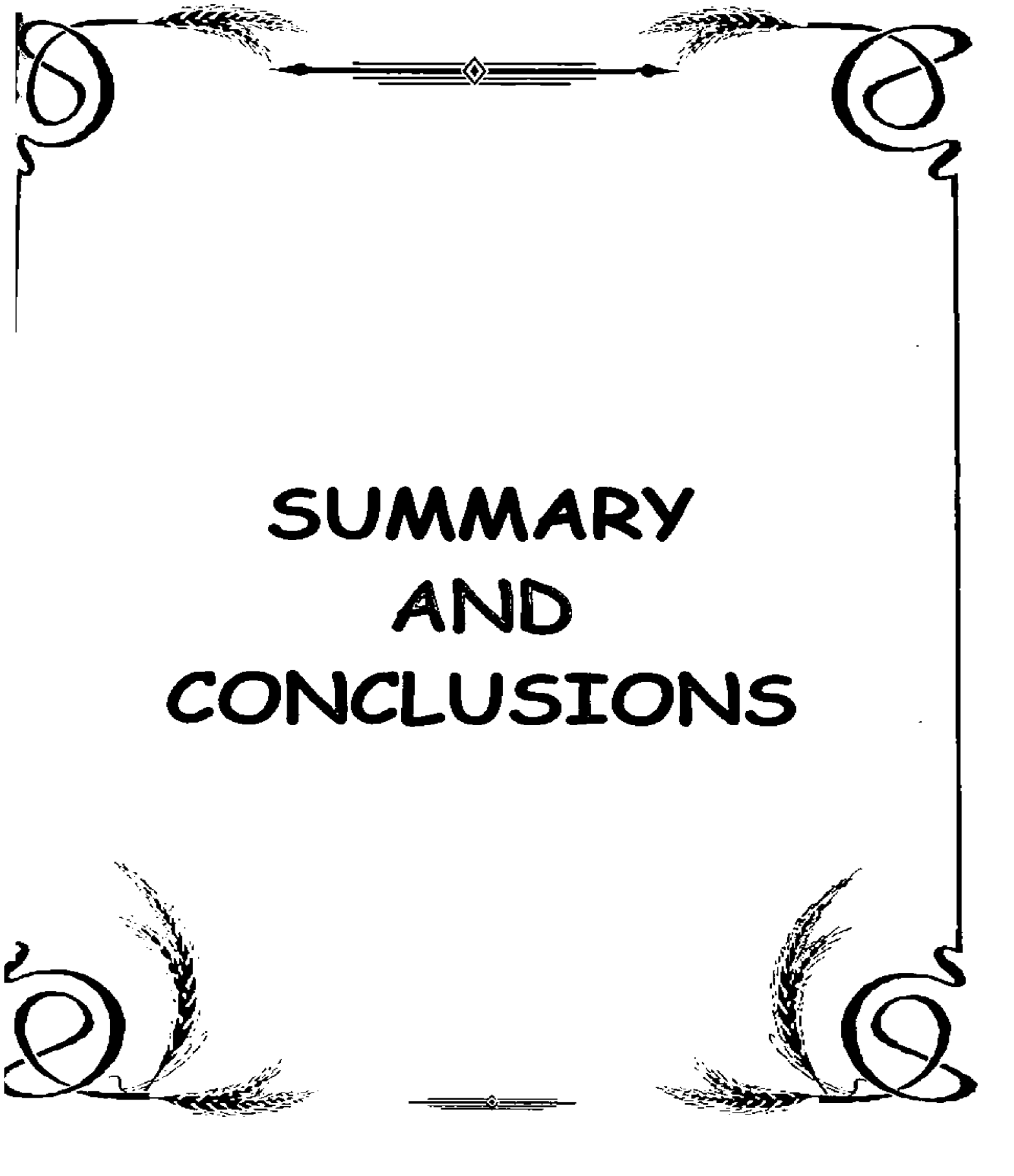
The increase in protein content due to zinc addition might be attributed to its role in enzyme like carbonic anhydrase and glutamic dehydrogenase activities (Nicholas and Goodman, 1958) which is manifested in an increase in protein biosynthesis. Zinc is closely involved in the N-metabolism of the plants. Zinc deficiency causes a sharp decrease in the levels of RNA and the ribosome content of cells. This reduction in RNA synthesis leads to an inhibition of protein formation while glucose, NPN and DNA are relatively increased (Prince, 1962). Results of present investigation are corroborated with the findings of Youssef and Abdel Rahman (1976), Orabi and Adbel-Aziz (1982), Ram and Murphy (1983), Krishnaveni (1983), Srinivasan and Natarajaratnam (1986), Keshwa and Jat (1992), Sahoo and Das (1992), Srikrishna (1995), Shi *et al.* (1996), Chen and Fan (1997), Tripathi *et al.* (1997 b), Fecencko and Lozek (1998), Panda and Sahu (1999), Tripathi and Tripathi (2004) and Khan *et al.* (2004).

5.4.3&4. AMYLOSE & STARCH CONTENT

Amylose is one of two components of starch. Starch is composed of amylose and amylopectin, then increase in the content of amylose and amylopectin gradually increase starch content. Application of nitrogen decreased significantly the amylose and starch content after 120 Kg N ha⁻¹ (Fig 4.29&4.30) during both the years. Increase in the level of nitrogen gradually decreased the quality of rice because manufactured starch converted into some other components such as protein (Awasthi *et al.* 1989). Same type of results are also reported by the findings of Gomez *et al.* (1979), Wakamatsu (1991). Higher levels of nitrogen (0 to 90 Kg N ha⁻¹) increased the amylose content of the long slender varieties by 3.0 – 9.0 percent (Rao *et al.* 1993). Grain yield and content of carbohydrates and protein were highest with N + K₂SO₄ + MO (Trivedi and Verma, 1996). Patel *et al.* (1997) reported that quality and yield were increased significantly at applications of 80 Kg N ha⁻¹ as compared with rates of 40 Kg N ha⁻¹. These results are also supported by the findings of Hemalatha *et al.* (1999), Subbiah and Kumaraswamy (2000), Maeda *et al.* (2002), Amjid *et al.* (2003), Jadhav *et al.* (2003a) and Panda and Srivastava (2004).

Data on amylose and starch content is presented in Tables 4.62 and 4.63, respectively during both the years. It is apparent from these Tables that starch and amylose content increased significantly with the increase in the levels of sulphur and zinc. Sulphur plays a vital role in various metabolic activities and chlorophyll synthesis (Zaidi and Singh, 1997). Due to application of sulphur amylose and starch content increased to a significant level. These results are corroborated with the findings of IRRI (1971), Saroha and Singh (1979), Shukla (1992) and Mishra (1999).

Zinc application increased significantly the starch content. According to Jung *et al.* (1975) zinc has a possible role in plant metabolism and is involved in starch synthesis. It was found that the starch content, the activity of the enzyme starch synthetase and number of starch grains were all more depressed in zinc deficient beans. Orabi and Abdel Aziz (1982) have reported an increase in starch content due to zinc application in maize, Yousseff and Abdel Rehman (1976) also reported the beneficial effect of zinc on starch content of wheat. Krishnaveni (1983) reported that zinc application increased the starch content of maize. Zaidi and Singh (1997) also showed the importance of Zn in starch synthesis.



SUMMARY AND CONCLUSIONS

India is facing problems of food shortage, population explosion, environmental pollution and shortage of power simultaneously. The growth rate of food production is not keeping pace with increasing population and thus the quality of life has deteriorated to such an extent that there is partial starvation or malnutrition in several parts of the world. Not only this, situation may worsen in the years to come. India's food problem could not be solved on a permanent basis without a major production advance on a sustained basis which accounts for the large area and thus it plays an important role in the agricultural economy of the country. Rice is an important food grain crop which plays a dominant role in agricultural production of the country. India has achieved spectacular increase in rice yield in comparison to other cereals and it has found a prominent place even in traditionally wheat growing states of U.P., Punjab, Rajasthan, Haryana and M.P.

Introduction of high yielding varieties of rice, use of chemical fertilizers, improved agronomic practices and plant protection measures have opened a new vistas in the country. Optimum doses for nitrogen, phosphorus and potassium were recommended as 120 kg N, 60 kg P_2O_5 and 60 kg K_2O for rice crop. However, it has commonly been observed that the normal growth of the crop could not be obtained due to liberal application of nutrients in rice for a long period. This has been attributed to nutrient imbalances caused by soil fertility depletion through intensive cropping on the same land. Continuous cropping has created secondary and micronutrient imbalances mainly of sulphur, Zn, Fe, Mn and Cu. Among these, sulphur and zinc deficiency is more conspicuous in cereal based cropping system because same crops or varieties are grown continuously which remove large quantities of sulphur and zinc from the same horizons of soil ecosystem.

In view of the above facts, the present investigation entitled, "**Studies on nitrogen, sulphur and zinc nutrition in rice**" was planned and conducted at Fertilizer Research Station, Uttari Pura, C.S. Azad University of Agriculture and

Technology, Kanpur during *kharif* seasons of 2003 and 2004 to gather the information on :

- (i) the effect of nitrogen, sulphur and zinc on yield and yield attributing characteristics of rice,
- (ii) effect of nitrogen, sulphur and zinc on nutrient concentration and their uptake/ removal by rice,
- (iii) effect of nitrogen, sulphur and zinc on the quality characteristics of rice, and
- (iv) optimum requirement of nitrogen, sulphur and zinc for maximum yield.

The treatments consisted of three levels of each of nitrogen and sulphur and two levels of zinc, viz., 60, 120 and 180 kg N ha⁻¹; 20, 40 and 60 kg S ha⁻¹ and 5 and 10 kg Zn ha⁻¹, respectively. There were 18 treatment combinations with one absolute control. These treatments were replicated thrice. The rice var. Vijeta was undertaken in the study. The experiment was laid out in a factorial Randomized Block Design. In both the years, the experiment was conducted on different fields to avoid the residual effects. The initial fertility status of the experimental site is given in the Materials and Methods.

The observations on growth characters were recorded as plant height, number of tillers hill⁻¹, biomass accumulation (g) hill⁻¹ and number of green leaves hill⁻¹ during both the years. At harvest, grain and straw yields were recorded separately plot wise for both the years. Among the yield attributing characteristics height of plants at maturity, number of productive tillers m⁻², number of panicles hill⁻¹, total number of spikelets hill⁻¹, number of filled grains panicle⁻¹, panicle weight and test weight (1000-grains) of grains were noted. Nutrient content and uptake of major nutrients such as nitrogen, phosphorus and potassium and one secondary nutrient sulphur were estimated chemically. Micronutrient (zinc) content and uptake by rice was also computed for. Grain and straw samples were also drawn out and analysed for their crude protein, amylose and starch contents.

The results, thus, obtained have been summarized here as under:

6.1 Effect of N, S & Zn on growth, yield and yield attributing characters of rice

6.1.1 Growth characteristics

All the growth characters i.e. height of plants, number of tillers hill⁻¹, number of green leaves hill⁻¹ and biomass accumulation g hill⁻¹ increased significantly with increasing levels of nitrogen, sulphur and zinc up to 180 kg N, 40 kg S and 5 kg Zn ha⁻¹ during both the years at 30th and 60th day of transplanting. Maximum values of all the growth characters of plants were noted at highest levels of nitrogen (180 kg N ha⁻¹), sulphur (60 kg S ha⁻¹) and zinc (10 kg Zn ha⁻¹) and minimum at absolute control during both the years. Interactions of N x S, S x Zn, N x Zn and N x S x Zn also influenced all the growth characters of plants and maximum values were noted at N₃S₃, S₃Zn₂, N₃Zn₂ and N₃S₃Zn₂ level but they did not reach to the level of significance during both the years of investigation.

6.1.2 Yield attributing characteristics

The height of plants at maturity, number of productive tillers m⁻², number of panicles hill⁻¹ and number of filled grains panicle⁻¹ increased significantly with increasing levels of N, S and Zn up to N₁₂₀, S₄₀ and Zn₅ being maximum at their highest levels i.e., at N₁₈₀, S₆₀ and Zn₁₀ and minimum at absolute control during both the years of study. Interactions of these nutrients also increased above yield attributing characteristics of rice being maximum at N₁₈₀S₆₀, S₆₀Zn₁₀, N₁₈₀Zn₁₀ and N₁₈₀S₆₀Zn₁₀ but did not touch the level of significance during both the years.

The weight of panicle and total number of spikelets hill⁻¹ increased with increasing levels of nitrogen, sulphur and zinc significantly up to N₁₈₀, S₄₀ and Zn₅ being maximum at N₁₈₀, S₆₀ and Zn₁₀ level and minimum at absolute control during both the years. Interactions of these nutrients have increasing trend but did not increase significantly being maximum at N₁₈₀S₆₀, S₆₀Zn₁₀, N₁₈₀Zn₁₀ and N₁₈₀S₆₀Zn₁₀ during both the years of investigation.

Test weight of grains (1000-grain weight) increased significantly with increasing levels of nitrogen, sulphur and zinc upto N₁₂₀, S₄₀ and Zn₅ being

maximum at N_{120} , S_{40} and Zn_{10} level and minimum at absolute control during both the years. Interactions were found as non-significant.

6.1.3 Grain and straw yield

The rice crop responded significantly to nitrogen, sulphur and zinc application and accordingly grain and straw yields increased with increasing levels of these nutrient elements upto 120 kg N, 40 kg S and 5 kg Zn ha^{-1} and thereafter there was a non-significant increase in grain and straw yields to a considerable extent. The maximum grain yields of 58.36 and 59.87 q ha^{-1} were recorded at 120 kg N ha^{-1} level which accounted for 180.03 and 177.92 per cent increase over absolute control in 2003 and 2004, respectively. Similarly the highest straw yields were recorded at 120 kg N ha^{-1} which accounted for 195.70 and 192.34 per cent higher over absolute control during 1st and 2nd year, respectively.

Application of 40 kg S ha^{-1} resulted in substantial increase in grain and straw yields during both the years. The magnitudes of responses of grain were 171.16 and 168.80 per cent and of straw 185.23 and 182.27 per cent over absolute control during 2003 and 2004, respectively at 40 kg S ha^{-1} application.

Application of 5 kg Zn ha^{-1} also resulted in substantial increase in grain and straw yields during both the years. The maximum grain yields of 55.23 and 56.56 q ha^{-1} were recorded at 5 kg Zn ha^{-1} level which accounted for 165.01 and 162.58 per cent increase over absolute control in 2003 and 2004, respectively. Similarly, the highest straw yields were recorded at 5 kg Zn ha^{-1} which accounted for 178.64 and 175.89 per cent higher over absolute control during 1st and 2nd year, respectively. Thus, it is inferred that magnitude of response of rice to nitrogen application was much higher as compared to sulphur and zinc additions. It is also extracted out that maximum yield of rice grain and straw can be obtained by the application of 120 kg N, 40 kg S and 5 kg Zn ha^{-1} . Interactions did not influence grain and straw yields significantly. However, maximum grain and straw yields were recorded at $N_{180}S_{60}Zn_{10}$ level during both the years.

2 Effect of N, S and Zn on content and uptake of nutrients

The contents of different elements viz., N, P, K, S and Zn in present investigation were increased significantly by N, S and Zn application in plants at different stages of crop growth i.e. 30th and 60th day of transplanting and harvest (grain and straw) stages during both the years.

The concentration of nitrogen at 30th and 60th day of transplanting increased significantly with increasing levels of N, S and Zn upto N₁₈₀, S₄₀ and Zn₅ level and in grain and straw of rice it increased significantly upto N₁₂₀, S₄₀ and Zn₅ and hereafter it increased non-significantly being maximum at N₁₈₀, S₆₀ and Zn₁₀ and minimum at absolute control during both the years. Interactions of these nutrients did not influence N contents significantly but they have increasing trend being maximum at N₁₈₀S₆₀, S₆₀Zn₁₀, N₁₈₀Zn₁₀ and N₁₈₀S₆₀Zn₁₀ during both the years of study.

Phosphorus content also increased with the application of different doses of nitrogen, sulphur and zinc significantly upto N₁₂₀, S₄₀ and Zn₅ and thereafter it decreased non-significantly at S₆₀ and significantly at Zn₁₀ level being maximum at N₁₈₀, S₄₀ and Zn₅ and minimum at absolute control during both the years. Interactions did not influence significantly the P content being maximum at N₁₈₀S₄₀Zn₅ level at all the stages of crop growth including grain and straw of rice during both the years.

K content increased with increasing doses of nitrogen, sulphur and zinc significantly up to N₁₂₀, S₄₀ and Zn₅ and thereafter it increased non-significantly being maximum at N₁₈₀, S₆₀ and Zn₁₀ and minimum at absolute control during both the years. Interactions of these nutrients have increasing trend on K content but did not touch the level of significance being maximum at N₁₈₀S₆₀, S₆₀Zn₁₀, N₁₈₀Zn₁₀ and N₁₈₀S₆₀Zn₁₀ at all the stages of crop growth during both the years.

Application of graded doses of nitrogen, sulphur and zinc significantly increased S content upto N₁₂₀, S₄₀ and Zn₅ and thereafter it increased non-significantly but 10 kg Zn ha⁻¹ application decreased the S content significantly due

antagonistic effect being maximum at N_{180} , S_{60} and Zn_5 level and minimum at absolute control during both the years. Interactions of these nutrients did not influence significantly the S content being maximum at $N_{180}S_{60}$, $S_{60}Zn_5$, $N_{180}Zn_5$ and $N_{180}S_{60}Zn_5$ level at all the stages of crop growth including grain and straw of rice during both the years.

Application of different doses of nitrogen, sulphur and zinc also enhanced Zn content at all the stages of crop growth i.e. 30th and 60th DOT and at harvest of crop (grain and straw) significantly upto N_{120} , S_{40} and Zn_{10} levels and thereafter non-significant increase was noted at N_{180} and significant decrease at S_{60} during both the years. Maximum Zn contents were recorded at N_{180} , S_{40} and Zn_{10} due to the application of different doses of N, S and Zn and minimum at absolute control at all the stages of crop growth during both the years. Interactions were recorded to be non-significant at all the stages of crop growth being maximum at $N_{180}S_{40}$, $S_{40}Zn_{10}$, $N_{180}Zn_{10}$ and $N_{180}S_{40}Zn_{10}$ during both the years of study.

Likewise, the contents of N, P, K, S and Zn their uptake also increased significantly in grain and straw by the application of graded doses of N, S and Zn during both the years. On an average, the uptake of N and K by grain and straw significantly increased upto 120 kg N, 40 kg S and 5 kg Zn ha⁻¹ application and thereafter there was a non-significant increase at highest levels of N, S and Zn being maximum at 180 kg N, 60 kg S and 10 kg Zn ha⁻¹ and minimum at absolute control during both the years. Interactions of these nutrients also increased N and K uptake but they did not touch the level of significance being maximum at $N_{180}S_{60}$, $S_{60}Zn_{10}$, $N_{180}Zn_{10}$ and $N_{180}S_{60}Zn_{10}$ levels during both the years. Phosphorus uptake in grain and straw increased significantly up to 120 kg N, 40 kg S and 5 kg Zn ha⁻¹ and thereafter it increased non-significantly up to highest dose of N and decreased non-significantly up to highest doses of S and Zn being maximum at 180 kg N, 40 kg S and 5 kg Zn ha⁻¹ and lowest at absolute control during both the years. Interactions of these nutrients did not influence significantly the P uptake and maximum values were noted at $N_{180}S_{40}$, $S_{40}Zn_5$, $N_{180}Zn_5$ and $N_{180}S_{40}Zn_5$ levels during both the years.

S uptake in grain and straw also increased due to increasing doses of N, S and Zn significantly up to 120 kg N, 40 kg S and 5 kg Zn ha⁻¹ and thereafter it increased non-significantly at highest doses of N and S and decreased non-significantly at highest dose of Zn being maximum at 180 kg N, 60 kg S and 5 kg Zn ha⁻¹ application and minimum at absolute control during both the years. Interactions of these nutrients did not influence significantly the S uptake but maximum values were noted at N₁₈₀S₆₀, S₆₀Zn₅, N₁₈₀Zn₅ and N₁₈₀S₆₀Zn₅ levels during both the years.

Similarly, Zn uptake increased significantly with increasing doses of N, S and Zn up to 120 kg N, 40 kg S and 5 kg Zn ha⁻¹ and thereafter, increases non-significantly up to highest doses of N and Zn and decreased non-significantly at highest dose of S in both grain and straw being maximum at N₁₈₀, S₄₀ and Zn₁₀ and lowest at absolute control during both the years. Interactions of these nutrients did not significantly increase Zn uptake in both grain and straw but maximum values were noted at N₁₈₀S₄₀, S₄₀Zn₁₀, N₁₈₀Zn₁₀, N₁₈₀S₄₀Zn₁₀ levels during both the years.

6.3 Optimum requirement of nitrogen, sulphur and zinc for maximum grain yield

The optimum requirement of nitrogen, sulphur and zinc for maximum economic grain yield of 62.61 q, 61.48 q and 60.66 q ha⁻¹ was computed as 156 kg, 43.69 kg and 7.24 kg ha⁻¹, respectively.

6.4 Effect of nitrogen, sulphur and zinc on quality characteristics of rice

6.4.1 Protein

The application of nitrogen, sulphur and zinc with varying levels influenced significantly crude protein content in rice grain and straw during both the years. The protein, on an average, increased with increasing levels of nitrogen from 8.42 to 9.04 and 8.48 to 9.10 per cent being highest at 180 kg N ha⁻¹ and lowest at

absolute control in 2003 and 2004, respectively in grain of rice. Similar trend was also noticed in case of straw during both the years. In case of S and Zn, protein content increased with increasing doses of S and Zn significantly up to 40 kg S and 5 kg Zn ha⁻¹ and thereafter it increased non-significantly being maximum at 60 kg S and 10 kg Zn ha⁻¹ in both grain and straw during both the years. Crude protein production was also recorded highest at highest doses of N, S and Zn application in both grain and straw during both the years. However, combined application of N, S and Zn did not increase significantly the crude protein content and production by grain and straw being maximum at N₁₈₀S₆₀, S₆₀Zn₁₀, N₁₈₀Zn₁₀ and N₁₈₀S₆₀Zn₁₀ during both the years.

5.4.2.& 3 Amylose and starch:

Amylose is the main component of starch and starch is composed of amylose and amylopectin. The amylose and starch contents were significantly influenced by nitrogen, sulphur and zinc applications. Amylose and starch contents decreased significantly at highest dose of nitrogen being maximum at 60 kg N ha⁻¹ and minimum at 180 kg N ha⁻¹ during both the years. Sulphur and zinc dressings significantly increased amylose and starch contents up to 40 kg S and 5 kg Zn ha⁻¹ and thereafter these did not increase significantly being maximum at 60 kg S and 10 kg Zn ha⁻¹ during both the years. Interaction effects were recorded non-significant during both the years of experimentation with respect to amylose and starch contents.

Conclusion

On the basis of aforementioned summary, it is hereby concluded that:

1. Rice (*Oryza sativa* L.) responded favourably and significantly to the application of nitrogen, sulphur and zinc up to their certain levels. Growth characteristics viz., plant height, number of tillers hill⁻¹, number of green leaves hill⁻¹ and biomass accumulation g hill⁻¹ at 30th and 60th day of transplanting increased significantly with increasing application of nitrogen, sulphur and zinc up to 180 kg N, 40 kg S and 5 kg Zn ha⁻¹.

2. Yield attributing characteristics viz., plant height at maturity, number of productive tillers m^{-2} , number of panicles $hill^{-1}$, number of filled grains $panicle^{-1}$ and test weight of grains were enhanced positively and significantly with the application of nitrogen, sulphur and zinc up to 120 kg N, 40 kg S and 5 kg Zn ha^{-1} application. However, as an exception, total number of spikelets $hill^{-1}$ and weight of panicle (g) increased significantly up to 40kgS, 5kgZn and 180 kg ha^{-1} of N application.
3. Grain and straw yield increased significantly with the application of nitrogen, sulphur and zinc up to 120 kg N, 40 kg S and 5 kg Zn ha^{-1} , but the maximum grain yield could be achieved with the application of optimal dose of 156 kg N, 43.69 kg S and 7.24 kg Zn ha^{-1} . Therefore, farmers may be suggested to apply optimum dose of nitrogen, sulphur and zinc for maximum economic return from rice crop.
4. The contents of P, K and S at 30th and 60th day of transplanting and the contents of N, P, K and S at harvest stage (i.e. grain and straw) increased significantly up to 120 kg N, 40 kg S and 5 kg Zn ha^{-1} application while N content at 30th and 60th day of transplanting increased up to the level of 180 kg N ha^{-1} . Only content of Zn at different stages of crop growth i.e. at 30th and 60th day of transplanting and harvest both in grain and straw increased significantly up to 10 kg Zn ha^{-1} , 120 kg N ha^{-1} and 40 kg S ha^{-1} application. Uptake of these nutrients was also affected favourably and increased significantly up to 120 kg N, 40 kg S and 5 kg Zn ha^{-1} , application.
5. The quality parameters of the produce viz., protein, starch and amylose contents were influenced significantly with the application of nitrogen, sulphur and zinc. Protein content was increased significantly with nitrogen, sulphur and zinc application upto 120 kg N, 40 kg S and 5 kg Zn ha^{-1} , respectively. Contents of amylose and starch also increased significantly with the application of sulphur and zinc while addition of nitrogen depressed amylose and starch contents beyond 120 kg N ha^{-1} . These results allow me to infer that

application of sulphur and zinc while addition of nitrogen depressed amylose and starch contents beyond 120 kg N ha⁻¹. These results allow me to infer that application of N, S and Zn besides augmenting the crop yields, also improves the quality of rice grain.

Therefore, on the basis of present investigation, it is hereby inferred that application of nitrogen, sulphur and zinc @ 156 kg, 43.7 kg and 7.2 kg ha⁻¹, respectively can very safely be recommended as optimum dose to obtain maximum grain yield with improved quality parameters of rice cultivar-Vijeta under North Indian conditions.

ABSTRACT

A field experiment was carried out to study the effect of nitrogen, sulphur and zinc nutrients on yield and mineral nutrition of rice in two consecutive **Kharif** seasons of 2003 and 2004 at Fertilizer Research Station, Uttar Pura, C S Azad University of Agriculture and Technology, Kanpur. The treatments consisted of three levels of each of nitrogen (60, 120 and 180 Kg N ha⁻¹) and sulphur (20, 40 and 60 Kg S ha⁻¹) and two levels of zinc (5 and 10 Kg ha⁻¹) with one absolute control, respectively. These treatments were replicated thrice with test crop rice (CV Vijeta). The experiment was laid out in a factorial Randomized Block Design. During both the years, the experiment was conducted on different sites to avoid residual effects.

Rice crop (*Oryza sativa* L.) responded favorably and significantly to the application of N, S and Zn up to their certain levels. Though on an average, maximum grain and straw yields were produced with the application of 120 kg N, 40 Kg S, and 5 Kg Zn ha⁻¹ but the optimal grain yield could be achieved with the application of 156 Kg N, 43.7 Kg S and 7.2 Kg Zn ha⁻¹. Therefore, farmers may be advised to apply optimum levels of nitrogen, sulphur and zinc for maximum return from the rice crop. Growth characters viz., plant height, number of tillers hill⁻¹, number of green leaves hill⁻¹ and biomass accumulation (g hill⁻¹) at 30th and 60th day of transplanting were influenced positively and significantly with the application of N, S and Zn and found maximum at 180 Kg N, 40 Kg S and 5 kg Zn ha⁻¹ levels. Yield attributing characteristics viz., plant height, number of productive tillers m⁻², number of panicles hill⁻¹, total no. of spikelets hill⁻¹, no. of field grains panicle⁻¹, panicle weight (g) and test weight of grains (1000—grains weight) were influenced

significantly and positively with the application of nitrogen, sulphur and zinc and were noticed maximum at 120 Kg N, 40 Kg S and 5 Kg Zn ha⁻¹ levels. However, interactions effect were found to be non significant.

The contents of N, P, K, S and Zn at different stages of crop growth and their uptake in grain and straw increased significantly up to 120 Kg N, 40 Kg S and 5 kg Zn ha⁻¹ while contents of nitrogen at 30th and 60th day of transplanting (DOT) and content of zinc at all the stages of crop growth increased significantly up to 180 Kg N and 10 Kg Zn ha⁻¹, respectively during both the years. However, interaction effects were non-significant. The quality parameters of rice viz., protein, amylose and starch contents of rice grain increased significantly by the application of nitrogen, sulphur and zinc. Protein content in rice grain and straw increased significantly upto 120 Kg N, 40 Kg S and 5 Kg Zn ha⁻¹ during both the years. Amylose and starch contents increased significantly up to 40 Kg S and 5 Kg Zn ha⁻¹ but application of nitrogen beyond 120 Kg ha⁻¹ decreased both amylose and starch contents significantly. However, interaction effects were noted as non - significant. These results allow me to infer that application of N, S and Zn on rice crop, besides augmenting the crop yield, improves the quality of rice grain.

On the basis of aforementioned findings, it is here by inferred that the application of N, S and zinc to rice crop, besides augmenting the crop yield, improves the quality of the produce and soil health as well.

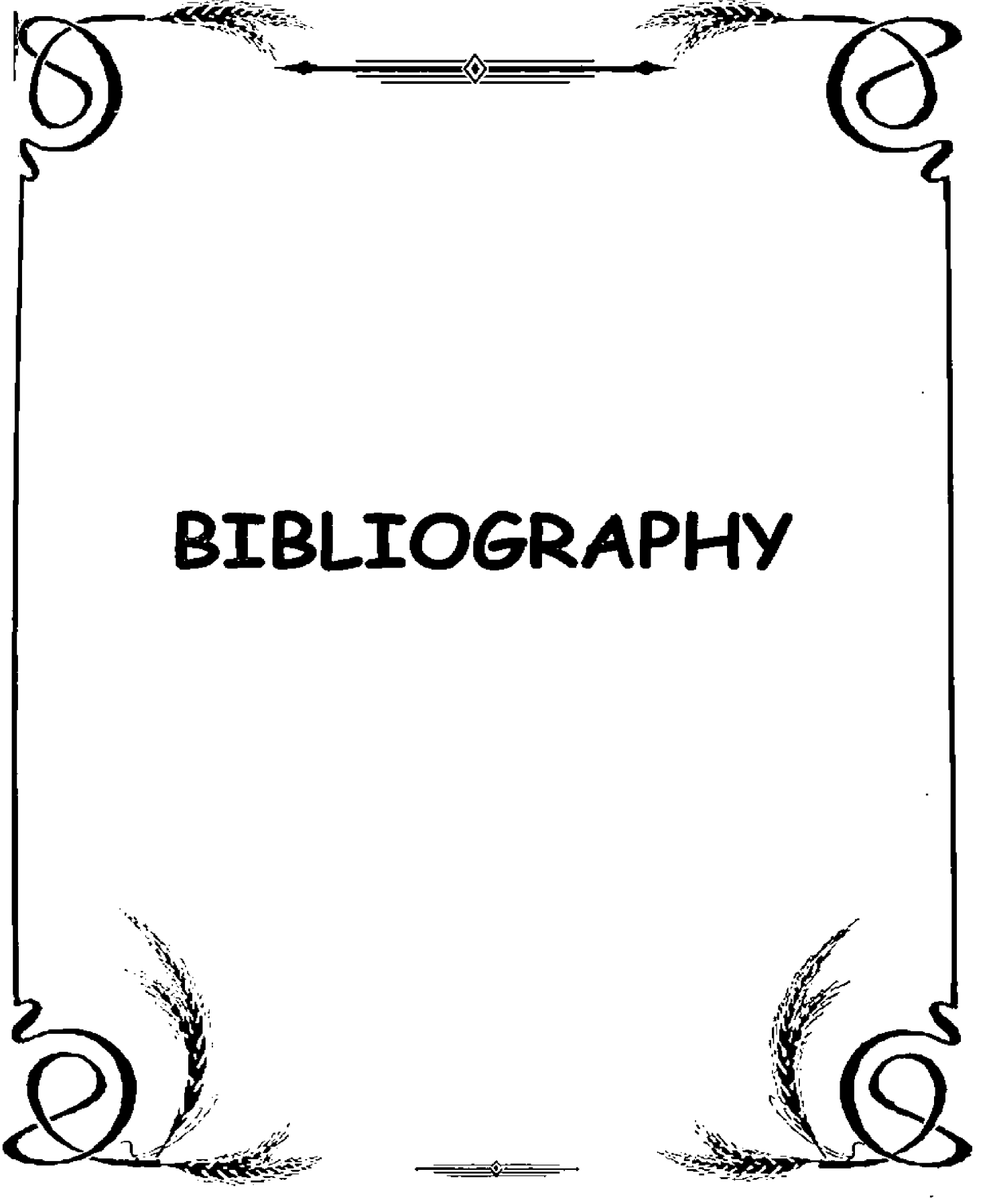
सारांश

नत्रजन, गन्धक तथा जस्ता पोषकों के प्रभाव का धान की उपज एवं खनिज पोषण पर आधारित अध्ययन करने के लिए एक प्रक्षेत्र परीक्षण उर्वरक अनुसंधान केन्द्र, उत्तरी पुरा, च० शे० आ० कृषि एवं प्रौद्योगिक विश्वविद्यालय, कानपुर में वर्ष 2003 तथा 2004 के खरीफ मौसम में किया गया था । जिसमें नत्रजन, गन्धक तथा जस्ता के विभिन्न उपचार संबंधो एवं उनके विभिन्न मात्रात्मक स्तरों (नत्रजन 60, 120 तथा 180 किग्रा० हे०, गन्धक 20, 40 तथा 60 किग्रा० प्रति हे० और जस्ता 5 तथा 10 किग्रा० प्रति हे०) के प्रभावों को फैक्टोरियल यादृच्छिकीकृत खण्ड अभिकल्पना के अन्तर्गत परिणामों की गणना का विवेचन एक सम्पूर्ण नियन्त्रित उपचार सहित किया गया । प्रक्षेत्र परीक्षण के परिणामों को संक्षेप में निम्न रूप से व्यक्त किया जा सकता है। धान (प्रजाति-विजेता) पर नत्रजन, गन्धक तथा जस्ते का प्रभाव एक निश्चित प्रयोग की मात्रा स्तर तक ही पाया गया, मात्रा बढ़ाने पर प्रभाव ऋणात्मक पाया गया अथवा प्रभावी रूप से नहीं बढ़ा । 120 किग्रा० नत्रजन, 40 किग्रा० गन्धक तथा 5 किग्रा० जस्ता के उपचार सम्बन्ध का प्रभाव धान की अधिकतम दाना तथा पुआल की उपज प्राप्त करने के लिए उपयुक्त पाया गया । लेकिन अधिकतम उपज प्राप्त करने के लिए 156 किग्रा० नत्रजन, 43.7 किग्रा० गन्धक तथा 7.2 किग्रा० प्रति हे० जस्ता का प्रयोग प्रक्षेत्र परीक्षण के परिणाम द्वारा सुनिश्चित किया गया । वृद्धि लक्षणों जैसे प्रति पौधा कल्लों की संख्या, पौधे की ऊँचाई, प्रति पौधा हरी पत्तियों की संख्या तथा शुष्क पदार्थ संचयन पर नत्रजन, गंधक तथा जस्ता का प्रभाव सकारात्मक रूप से बढ़ता हुआ पाया गया । यह प्रभाव 180 किग्रा० नत्रजन, 40 किग्रा० गंधक तथा 5 किग्रा० जस्ता प्रति हे० के सम्बन्ध उपचार स्तर तक सार्थक रूप से बढ़ता हुआ पाया गया ।

अतः कृषकों के दिशानिर्देश के लिये नत्रजन, गन्धक तथा जस्ता का वह स्तर जो उपज तथा उपज से सम्बन्धित लक्षणों को प्रभावित करता है जैसे पौधे की ऊँचाई, प्रति पौधा कल्लों की संख्या, प्रति वर्ग मी० में उत्पादक कल्लों की संख्या,

प्रति पौधा बालियों की संख्या, प्रति पौधा कुल दानों की संख्या, प्रति बाली भरे हुए (स्वस्थ) दानों की संख्या, बाली का वजन (ग्रा०) तथा दानों का परीक्षण भार आदि एवं अधिकतम प्रतिफल भी प्रदान करता हो, ऐसा स्तर 120 किग्रा० नत्रजन, 40 किग्रा० गंधक तथा 5 किग्रा० जस्ता प्रति हे० के सम्बन्ध उपचार स्तर पर पाया गया । नत्रजन, फॉस्फोरस, पोटेशियम , गंधक तथा जस्ता के धान द्वारा अवशोषण तथा पौधों में सान्द्रण का स्तर विभिन्न वृद्धि अवस्थाओं पर मापा गया जो कि 120 किग्रा० नत्रजन, 40 किग्रा० गंधक तथा 5 किग्रा० जस्ता प्रति हे० के उपचार स्तर तक सार्थक रूप से बढ़ा पाया गया जबकि नत्रजन की सान्द्रता पौधों में रोपने के 30वें तथा 60वें दिन पर सार्थक रूप से 180 किग्रा० नत्रजन के प्रयोग स्तर तक बढ़ा हुआ पाया गया । केवल जस्ता का सान्द्रण फसल वृद्धि की प्रत्येक अवस्था (दानों तथा भूसा में भी) पर सार्थक रूप से 10 किग्रा० जस्ता के प्रयोग स्तर तक बढ़ा हुआ पाया गया । ये प्रभाव दोनों वर्षों के परीक्षण परिणामों में समान रूप से पाये गये । गुणवत्ता प्रांचलो में प्रोटीन की मात्रा धान के दानों तथा भूसा में 120 किग्रा० नत्रजन, 40 किग्रा० गंधक तथा 5 किग्रा० जस्ता प्रति हे० के सम्बन्ध उपचार स्तर तक सार्थक रूप से बढ़ती हुई पायी गयी । चावल के दानों में एमाइलोज तथा स्टार्च की प्रतिशत मात्रा (सान्द्रण) पर गंधक तथा जस्ता का प्रभाव धनात्मक जबकि नत्रजन का प्रभाव ऋणात्मक पाया गया । एमाइलोज तथा स्टार्च का सान्द्रण 40 किग्रा० गंधक तथा 5 किग्रा० जस्ता पर सार्थक रूप से बढ़ा, जबकि 120 किग्रा० नत्रजन के बाद सार्थक रूप से घटता हुआ पाया गया ।

इन परीक्षण परिणामों से यह निष्कर्षित किया जाता है कि नत्रजन, गंधक तथा जस्ता का धान की फसल में प्रयोग से उपज में वृद्धि के साथ उसके उत्पाद की गुणवत्ता तथा मृदा स्वास्थ्य में भी सुधार आता है ।



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