SULPHUR-ZINC INTERACTION IN INTEGRATED NUTRIENT SUPPLY SYSTEM OF WETLAND RICE (*Oryza sativa* L.)

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DECLARATION

I hereby declare that this thesis entitled **"Sulphur-Zinc Interaction in Integrated Nutrient Supply System of wetland rice (*Oryza sativa* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Sulphur-Zinc Interaction in Integrated Nutrient Supply System of wetland rice (*Oryza sativa* L.)"** is a record of research work done independently by Mr. Vipin, K.S. (2004-11-38) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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EXTERNAL EXAMINER

DEDICATED TO MY FAMILY
AND FRIENDS

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LIST OF ABBREVIATIONS

%	-	Per cent
@	-	At the rate of
^0C	-	Degree celsius
ANOVA	-	Analysis of variance
BCR	-	Benefit cost ratio
cm	-	Centimetre
cm^2	-	Square centimetre
DAT	-	Days after transplanting
DMP	-	Dry matter production
et al.	-	And others
Fig.	-	Figure
FYM	-	Farmyard manure
g	-	Gram
ha	-	Hectare
K	-	Potassium
K_2O	-	Potash
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
LAI	-	Leaf area index
m	-	Metre
mg	-	Milligram
mg g^{-1}	-	Milligram per gram
g ha^{-1}	-	Gram per hectare
min.	-	Minute
ml	-	Millilitre
mm	-	Millimetre
MOP	-	Muriate of potash
N	-	Nitrogen
P	-	Phosphorus
P_2O_5	-	Phosphate
POP	-	Package of Practices Recommendations
q ha^{-1}	-	Quintal per hectare
RH	-	Relative humidity
Rs	-	Rupees
S	-	Sulphur
t	-	Tonnes
t ha^{-1}	-	Tonnes per hectare
Zn	-	Zinc
$ZnSO_4$	-	Zinc Sulphate

INTRODUCTION

1. INTRODUCTION

Ensuring food security is becoming as important as never before for the ever-increasing population of our country. For meeting the production goals we have to increase production of rice and wheat, both of which continues to dominate as a result of their better productivity compared to other food grains. Rice contributes approximately 45 percent of total production and continues to hold key to sustain food sufficiency in our country. In Kerala rice is grown in an area of 2.87 lakh ha with an annual production of 5.70 lakh tonnes (Farm guide, 2006).

It is a well known fact that the yield levels of rice in different parts of our country is much lower than that of potential yield levels that can be achieved. The average productivity of rice crops in India is 2 t ha^{-1} whereas yield potential of most of the varieties is around 5 to 6 t ha^{-1}. The situation is not different in Kerala also, which has an average rice productivity of around 1.99 t ha^{-1}(Farm guide, 2006). This yield gap is widening day by day alarmingly. Here the most practicable solution to these problem is to narrow down this gap by increasing the productivity particularly in states like Kerala, where more area cannot be brought under rice cultivation due to population pressure on land.

One of the main components of crop management that can effectively improve or make a difference is the adequate or balanced crop nutrition with all the nutrients. Over the years, farmers resorted to apply only three major nutrients viz. N, P and K or fertilizers constituting mixture of these nutrients that completely discarded the much-needed attention for secondary and micronutrients. This situation coupled with scarce use of organic manures, high intensive cropping with high yielding varieties had led to depletion of soil resource of secondary and micronutrients, which gradually resulted in decreased yield.

Among the secondary nutrients, sulphur is being widely recognized as fourth major nutrient along with nitrogen, phosphorus and potassium. Rice absorbs sulphur in amounts equal to phosphorus and is required for synthesis of aminoacids, metabolites, volatile compounds etc. It is also a component of enzymes involved in photosynthesis for chlorophyll formation. Deficiency of this element will seriously alter the growth and development of rice plant, which in turn will result in reduction of yield. Intensive rice cultivation with non-sulphur containing fertilizers like urea and mussorie phosphate aggravates the problem of S deficiency.

In Kerala, several workers reported occurrence of sulphur deficiency in soil. Tandon (1991) reported that sulphur deficiency found in all districts of Kerala, which ranged from 20 per cent in Thiruvananthapuram to 55 per cent in Palghat. Analysis of soil samples as part of the project titled "Sulphur in Balanced Fertilization" launched by the Fertilizer Association of India (FAI) in collaboration with the The Sulphur Institute (TSI), Washington and International Fertilizer Association (IFA), Paris showed that 49 per cent of soil samples of India were deficient in sulphur and with respect to Kerala, almost all the samples were found either deficient or potentially deficient in available sulphur. In most of these areas the important causes which can be related to sulphur deficiency are 1) Intensive cultivation with high yielding varieties 2) Lack of organic matter addition 3) High use of sulphur free high analysis fertilizers like urea, diammonium phosphate and complex fertilizers. 4) Less crop residue recycling and 5) Declining reserves of soil sulphur due to higher sulphur removal compared to addition through fertilizers.

Similarly importance of micronutrients in increasing crop yields has now gained prominence than ever before as reports of their deficiencies are coming in increasingly especially in rice. Among micronutrients, zinc deficiency has emerged as the most important one in India.

Zinc is involved in auxin metabolism, promotion of synthesis of cytochrome, stability of cytoplasmic ribosomes and root cell membrane, synthesis of proteins and IAA, carbohydrate metabolism and also an enzyme component in photosynthesis. Zinc containing enzyme (alcohol dehydrogenase) plays an important role in anaerobic root respiration in rice and the processes is impaired under zinc deficiency. Though zinc is needed only in small quantities, inadequate or its lack of supply reduces crop yield markedly despite NPK application in required quantities and severe deficiency of zinc leads to a condition known as "Khaira disease" of paddy.

Large number of long-term experiments in manuring and fertilization has depicted depletion of available micronutrients status of Indian rice soils particularly zinc. The reasons for zinc deficiency are 1) Lesser application of organic manures 2) Intensive cropping with high yielding varieties which resulted in removal of large quantities of zinc from available fractions in soil over the years 3) Use of high analysis fertilizers free of micronutrients 4) High use of phosphatic fertilizers resulting in phosphorus induced zinc deficiency 5) Use of poor quality irrigation water without drainage.

With the adoption of intensive farming, farmers shifted from use of organic to inorganic high analysis fertilizers alone. Continous use of chemical fertilizers without any organic sources leads to gradual decline of organic matter content and native nitrogen status of soil and availability of micronutrients, which results in lower rice production. The conjoint use of organic manures with chemical fertilizers is important as this not only sustains higher level of productivity but also improves soil health and hence the nutrient use efficiency. Under integrated application, nutrients added are utilized more effectively, which contribute more to the overall growth and development of plant expressing in yield. Both sulphur and zinc are known to have a positive effect on rice plant under integrated nutrient supply system.

Keeping the above facts under consideration an experiment was carried out to study the response of sulphur and zinc under integrated nutrient supply system of wetland rice with the following objectives:

(1) To study the individual response of sulphur and zinc and their interaction effect under integrated nutrition in wetland rice ecosystem of humid tropics.

(2) To workout the economics of cultivation.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Yield potential of crops like rice has to be harnessed through better management of agricultural production system, an important factor being proper nutrient management or balanced fertilization. One of the reasons for non-improvement of yield of crops in recent years is the over-emphasis given only to primary nutrients without giving required attention to secondary and micronutrients. Years of high intensive cultivation with high yielding varieties together with scarce use of organic manures and over use of high analysis fertilizers free of secondary and micronutrients has led to depletion of these nutrients in soil resulting in development of deficiency symptoms and decreased yield. Among these, sulphur and zinc are reported to be widely deficient in Indian soils.

Moreover, the excessive use of chemical fertilizers and pesticides are causing environmental hazards. It is, therefore, necessary to develop a sustainable production system with maximum productivity and minimum environmental pollution. In this context, integrated approach should be given more emphasis involving use of organics like FYM and chemical fertilizers comprising secondary and micronutrients.

So the present study was undertaken to study the response of both sulphur and zinc under integrated use of nitrogen nutrition in wetland rice. Here, a brief review on response of rice to sulphur, zinc and integrated nitrogen nutrition are given.

2.1 Effect of sulphur on rice

2.1.1 Effect on growth characters

Karim and Khan (1958) observed increase in height and LAI of rice plants with sulphur applications up to 28 kg ha^{-1}. Howard and Ensminger (1962) reported reduction in height of rice under S deficiency. In rice variety Jyothi, application of 10 kg S ha^{-1} increased the plant height (Muraleedharan and Jose, 1993). Nair (1995) observed progressive and significant increase in height of rice variety Jyothi upto 30 kg S ha^{-1} in Kerala. Sudha (1999) also reported an increase in height of rice plant due to S application up to 25 kg ha^{-1}. Application of S @ 15 kg ha-1 significantly increased plant height at harvest stage of rice (Mini, 2005).

According to Suzuki (1978) deficiency of sulphur reduces the number of tillers in rice. Blair *et al.* (1978) also observed decrease in tiller number of rice under conditions of S deficiency. Blair *et al.* (1979) found that tiller number of rice at active tillering, maximum tillering and maturity stages significantly and progressively increased up to 80 kg S ha^{-1}. Ahmed *et al.* (1988) observed significant increase in tiller production of rice upto 30 kg S ha^{-1}. Muraleedharan and Jose (1993) reported significantly higher tiller number in rice with level of 10 kg S ha^{-1}. Nair (1995) observed significant increase in tiller number at maturity in rice with the application of 30 kg S ha^{-1}. Sudha (1999) reported an increase in number of tiller m^{-2} of rice plant due to S application upto 25 kg ha^{-1}. Application of 40 kg S ha^{-1} resulted in significantly higher tiller number in rice (Chandel *et al.*, 2003). Application of S @ 15 kg ha^{-1} increased number of tillers $hill^{-1}$ in rice (Mini, 2005).

George (1989) observed a significant increase in LAI of rice with sulphur application upto 30 kg S ha^{-1}. Nair (1995) could observe progressive and significant increase in LAI of rice upto 30 kg S ha^{-1}. Sudha (1999) observed significant influence on LAI at 60 DAT and at harvest due to sulphur application in rice. Leaf Area Index of rice increased with sulphur application upto 40 kg S ha^{-1} (Chandel *et al.*, 2003). Mini (2005) also reported increase in LAI with S application in rice.

Blair *et al.* (1979) found an increase in dry matter production at active tillering, maximum tillering and maturity stages in rice with S application. Gupta and Otoole (1986) also observed higher dry matter production of rice with application of sulphur. George (1989) observed higher dry matter production with sulphur application in rice cv. Jaya. Mondal *et al.* (1994) observed improvement in DMP of rice when sulphur-containing fertilizers were used over non-sulphur containing ones. Significantly higher dry matter production of rice with higher S levels upto 30 kg ha^{-1} was reported by Nair (1995). Sulphur application had significant influence on DMP at all the growth stages of rice (Sudha, 1999). Chandel *et al.* (2003) reported significant improvement in DMP of rice with increasing levels of S upto 45 kg S ha^{-1}. Application of S @ 15 kg ha^{-1} increased the DMP at 30 DAS and at harvest in rice (Mini, 2005).

Reduction in chlorophyll content of rice was observed under conditions of S deficiency (Nanawati *et al.*, 1973). Suzuki (1978) found that deficiency of sulphur in rice makes it chlorotic at tillering. Sudha (1999) reported an increase in chlorophyll content of rice at all growth stages with levels of S upto 12.5 kg S ha^{-1} and significant influence on chlorophyll content was noticed towards the later growth stage of 60 DAT. According to Mini (2005) sulphur application had significant influence on chlorophyll content of rice.

2.1.2 Effect on yield attributes

Blair *et al.* (1979) reported progressive and significant increase in number of panicles plant^{-1} when sulphur application was increased to 80 kg ha^{-1} in rice. Ismunadji *et al.* (1987) observed progressive increase in panicle number, percentage of filled grains panicle^{-1} and thousand grain weight in rice upto 20 kg S ha^{-1}. An increase in the number of panicle, number of ears panicle^{-1} and grain yield of rice cv. IR-50 were obtained by the application of 100 kg ammonium sulphate per hectare (Momuat *et al.*, 1985). Hossain *et al.* (1987) reported higher number of grains panicle^{-1} for rice with S application. Ahmed *et al.* (1989) reported an increased filled grain number panicle^{-1} and percentage of filled grains in rice with sulphur application. George (1989) found that S application could increase panicle number, number of grains panicle^{-1}, panicle length, thousand grain weight of rice with S application.

Muraleedharan and Jose (1993) reported that rice variety Jyothi gave higher grain number panicle^{-1} and thousand grain weight with S @ 10 kg ha^{-1}, compared to control. Sulphur application significantly influenced the yield attributes of rice irrespective of source and dose (Chowdhury and Majumdar, 1994). (Mondal *et al.*, 1994) observed improvement in filled grains panicle^{-1} and thousand-grain weight of rice when S bearing fertilizers was used over non-S bearing ones. Nair (1995) opined that number of productive tillers m^{-2}, number of grains panicle^{-1} and weight of panicle of rice were increased significantly due to sulphur application.

Sudha (1999) reported an increase in the number of productive tillers, number of grains panicle^{-1} and thousand-grain weight of rice with S application upto 25 kg ha^{-1}. Mini (2005) found out that S application @ 15 kg ha^{-1} had a significant influence on thousand grain weight and increased the panicle length, panicle weight, number of filled grains panicle^{-1} in rice.

2.1.3 Effect on Grain and straw yield

2.1.3.1 Grain yield

Several workers reported increase in rice yield with sulphur application (Nambiar, 1985; Alam *et al.*, 1985; Hossain *et al.*, 1987; Ramanathan and Saravanan, 1987; Mamaril *et al.*, 1991; Clarson and Ramaswamy, 1992; Chowdhury and Majumdar, 1994). According to

Hoque and Jahiruddin (1994), BR-3 rice responded significantly to the fertilization with 20 kg ha^{-1} in a continuous rice cropping system. Yield of rice was improved when crop was fertilized with S bearing fertilizers (75 per cent of the recommended dose of N and P through SSP) over non-S bearing ones (Mondal *et al.*, 1994). In a field experiment during the kharif season of 1991 at Maruteri, AP, Raju *et al.* (1994) observed that rice cv. Chaitanya could produce 28.8 and 26.4 per cent increase in grain yields with the application of 25 and 50 kg sulphur ha^{-1} respectively compared with no sulphur. Zia *et al.* (1995) reported that ammonium sulphate produced better grain yields in rice over urea application. Application of 30 kg S ha^{-1} increased grain yield of medium duration rice cv. Jyothi (Nair, 1995). Similar results were obtained by Sahu *et al.* (1996).

In black soil of Orissa, Sahu and Nanda (1997) reported that grain yield of rice increased upto 5.06 t ha^{-1} with S application of 40 kg ha^{-1}. Field trials conducted in the states of Andhra Pradesh, Gujarat, Delhi, Punjab, Rajasthan, Orissa, Tamil Nadu, West Bengal and Uttar Pradesh revealed that S application increased paddy yields under normal conditions by 17 percentage (Malik, 1997; Ram *et al.*, 1997). At RARS, Jammu, experiments on rice with S application at 10, 20, 30 and 40 kg ha^{-1} resulted in increased yield of rice by 14.2, 24.2, 25.6 and 20.1 per cent respectively over control (Gupta *et al.*, 1998). In an experiment on rice-wheat cropping system, Sakal *et al.* (1999) identified 40 kg S ha^{-1} as the optimum level of sulphur for rice. Sakal *et al.* (2001) reported that direct effect of sulphur produced maximum grain yield response in rice to the tune of 14.3 q ha^{-1} at 45 kg S ha^{-1} dose.

. Basavaraj and Math (2003) reported that average grain yield of rice was 2791 kg ha^{-1} without S application and it increased to 3291, 3546 and 3546 kg ha^{-1} at 15, 30 and 45 kg S ha^{-1} respectively. The increase in yield was 18, 27 and 28 per cent over control. Average increase in grain yields of rice recorded at 15, 30 and 45 kg S ha^{-1} were 98, 153 and 179 kg ha^{-1} respectively (Biswas, 2003). In alluvial and red soils of West Bengal, maximum grain and straw yield of 5027 and 4874 kg ha^{-1} respectively were obtained when S was applied @ 45 kg ha^{-1} in rice (Biswas and Rajendra Rai, 2003).

In field experiments on alluvial coastal soils of orissa, Mahapatra *et al.* (2003) found that application of sulphur significantly increased rice yield at different levels of 15, 30 and 45 kg ha^{-1} resulting in average increased response of 643, 867 and 1257 kg ha^{-1} respectively. Misra *et al.* (2003) reported that grain yield of rice, increased upto 30 kg S ha^{-1} and highest per cent response of 8.9 per cent to S application was observed at 30 kg ha^{-1}. Maximum grain yield of 4290 kg ha^{-1} was obtained at 30 kg S ha^{-1} in rice *i.e.* an increase in yield of 802.5 kg ha^{-1} over control (Sen *et al.*, 2003). John *et al.* (2005) observed significant yield increase of 448 kg ha^{-1} due to S application @ 15 kg ha^{-1} over control in rice.

Sheela (2005) reported that the three levels of S (15, 30 and 45 kg S ha^{-1}) tried were on par and superior to control in increasing grain yields of rice. Onfarm experiment conducted on sulphur deficient soil under rice-wheat cropping system indicated that grain yield of rice increased substantially with 30 to 40 kg S ha^{-1} application (Singh *et al.*, 2005).

2.1.3.2 Straw yield

Biddappa and Sarkunan (1980) observed that straw yield of rice were highest at 60 kg S ha^{-1}. Increase in straw yield with S application was reported by several workers (Vijayachandran, 1987; Hossain *et al.*, 1987; Malarvizhi *et al.*, 1990; Chowdhury and Majumdar, 1994). Application of 30 kg S ha^{-1} increased straw yield of medium duration rice cv. Jyothi (Nair, 1995). Sakal *et al.* (1999) reported increase in straw yield with application of 40 kg S ha^{-1}.

Basavaraj and Math (2003) obtained increase in straw yields of 13, 27 and 23 per cent at 15, 30 and 45 kg S ha^{-1} respectively over control in rice. Mahapatra *et al.* (2003) reported that straw yield of rice increased progressively with increasing levels of S and difference was significant at 30 and 45 kg S ha^{-1}. Misra *et al.* (2003) reported that straw yield of rice, increased upto 30 S kg ha^{-1} but significant only upto 15 kg S ha^{-1}. Maximum straw yield of 5817.5 kg ha^{-1} was recorded with sulphur application at 45 kg S ha^{-1} in rice (Sen *et al.*, 2003). Sheela (2005) reported significant increase in straw yield of rice at all levels of S applied (15, 30 and 45 kg ha^{-1}) over control.

2.1.4 Uptake of nutrients and nutrient status of soil

Addition of sulphur containing fertilizers resulted in higher uptake of N, P, K and S in rice (Mondal, 1994). Mondal and Mondal (1996) found out sulphur uptake was highest when 100 per cent of recommended dose of fertilizers was applied through S-containing fertilizers. Sulphur uptake increased when rice was fertilized with ammonium sulphate compared to urea (Zia *et al.*, 1995). Nair (1995) reported that with increase in sulphur levels, there was increase in uptake of N, K and S in rice. Sakal *et al.* (1999) found that increasing levels of sulphur progressively increased the N, P and S uptake by rice crop.

Sudha (1999) observed increase in uptake of N, P, K and S by rice and available sulphur content of soil upto the level of 25 kg S ha^{-1}. Basavaraj and Math (2003) found that uptake of S in rice increased with increase in the level of sulphur. Biswas (2003) recorded S uptake by rice, which were 6.1, 6.9, 8.3 and 9.6 kg ha^{-1} at 0, 15, 30 and 45 kg ha^{-1} respectively. Application of levels of S upto 25 kg S ha^{-1} resulted in increased uptake of S by rice (Chandel *et al.*, 2003). John *et al.* (2005) reported that significant increase of S uptake in rice was noticed over no application and the highest crop uptake was noticed at 45 S kg ha^{-1}.

Mini (2005) found out that S application had a significant influence on N. P. K and S uptake by rice and available N, P, K and S content of soil, which was more in those plots where S was applied. Jena *et al.* (2006) reported increased uptake of N, K and S by rice with increasing sulphur levels.

2.2 Effect of zinc on rice

Anilakumar *et al.* (1992) reported that availability of Zn and Cu in the soil decreased continuously with period of submergence and crop growth. When soils are submerged the concentration of most nutrient elements in the soils increases, but the availability of zinc to plant decreases. (Singh *et al.*, 1999)

2.2.1 Effect on growth characters

Prasad and Umar (1993) recorded higher tiller number, DMP and LAI in rice with $ZnSO_4$ application. Highest plant height and tillers hill^{-1} was recorded at 15 kg Zn ha^{-1} through $ZnSO_4$ (Chaphale, 1999). Growth attributes of rice, viz. number of tillers, DMP, and LAI increased due to application of $ZnSO_4$ (Kulandaivel *et al.*, 2004). Plant height was significantly increased by the application of $ZnSO_4$ upto 30 kg ha^{-1} (Ghatak *et al.*, 2005).

2.2.2 Effect on yield attributes

According to Mariam and Koshy (1977) zinc application increased the number of grains panicle^{-1} in rice. Prasad and Umar (1993) reported higher panicles m^{-2}, grains panicle^{-1}, and weight of panicle of rice with $ZnSO_4$ application. Application of zinc increased fertile spikelets panicle^{-1}, which was directly reflected in yield of rice. (Binod Kumar and Singh, 1996). Application $ZnSO_4$ significantly increased effective tillers hill^{-1}and number of grains panicle^{-1} of rice (Kumar *et al.*, 1999).

Channabasavanna *et al.* (2001) reported significant influences of $ZnSO_4$ on yield attributes like panicles hill^{-1} and seeds panicle^{-1} in rice. Bhat *et al.* (2002) recorded maximum panicle number and panicle weight with application of $ZnSO_4$ with recommended fertilizer dose in rice. The yield parameters increased significantly by the application of Zn (Khan *et al.*, 2003). Yield attributes of hybrid rice such as panicles m^{-2}, grains $panicle^{-1}$, and weight of panicle were perceptibly improved by the use of various levels of $ZnSO_4$ (Kulandaivel *et al.*, 2004). Zinc fertilization in rice significantly increased effective tillers, panicle length and grains $panicle^{-1}$ with highest values recorded at 30 kg $ZnSO_4$ ha^{-1} (Ghatak *et al.*, 2005). Naik and Das (2006) observed that different yield attributes like per cent of filled grains, number of panicles m^{-2} and thousand seed weight of rice were significantly increased by application of zinc.

2.2.3 Effect on yield

Samai *et al.* (1976) reported that $ZnSO_4$ at all levels increased grain yield of rice over control. Bhuiya *et al.* (1981) observed considerable yield increase in rice cv. IR-8 due to Zn application to soil. Similar results were obtained by Jahiruddin *et al.* (1981). Application of Zn significantly increased grain and straw yield of rice (Altaf Hossain *et al.*, 1987). Uddin *et al.* (1981) found better yield of rice with application of 20 kg $ZnSO_4$ ha^{-1} compared with dose achieved under dipping roots of seedlings in 1 % ZnO suspension.

Das (1986) observed the best rice response in the range of 20-25 kg $ZnSO_4$ ha^{-1}. Saborit *et al.* (1988) observed higher grain yields of rice with application of $ZnSO_4$ than without Zn. Salam and Subramanian (1988) reported that application of Zn gave yields of 3.69, 3.53 and 4.81 t ha^{-1} in South West monsoon, North East monsoon and Summer season respectively compared with 3.21, 3.12 and 4.21 t ha^{-1} respectively without Zn in rice.

In the transplanted rice field, highest yield (5254 kg ha^{-1}) was obtained in the treatment where 0.5 % $ZnSO_4$ was sprayed at 3 weeks after transplanting, which was at par with that of two sprayings and soil application of 25 kg $ZnSO_4$ ha^{-1} but all these treatments were significantly found to be superior to the control and soil application of 12.5 kg $ZnSO_4$ ha^{-1} (Binod Kumar and Singh, 1996). Khanda and Dixit (1996) reported that application of zinc significantly increased grain and straw yields of rice over no zinc application. He also reported that both the sources and method of application of Zn significantly influenced the yield and among the sources, $ZnSO_4$ increased the grain yield by 2.5 % and straw yield by 4.2% over Zn-EDTA, probably due to optimal supply of Zn from $ZnSO_4$.

In rice-wheat cropping system Kunde and Puste (1997) observed favourable influence of $ZnSO_4$ on grain yield of rice. Successive increase in Zn levels upto 11.2 kg ha^{-1} significantly increased the grain and straw yields of rice (Trivedi *et al.*, 1998). Highest yield of both grain and straw of rice were obtained from combined application of Zn @ 15 kg ha^{-1} through $ZnSO_4$ with NPK dose, which are 48.80 % and 56.44% respectively over control (Chaphale, 1999). The grain and straw yield of rice increased significantly with the application of zinc sulphate as compared to control (Kumar *et al.*, 1999).

Under transplanted condition, significant increase in grain, straw and pooled yields of rice were observed upto 30 kg $ZnSO_4$ ha^{-1} and recorded highest harvest index of 43% (Rao and Shukla, 1999). In deep black soils, response of rice to the applied $ZnSO_4$ was upto 11.8% at 25 kg ha^{-1} over the control (Channabasavanna *et al.*, 2001). Mani *et al.* (2001) reported that 25 kg $ZnSO_4$ ha^{-1} as Zn-pressmud excelled all other treatments by registering 46.1% yield increase in rice over control and 26.9% increase over $ZnSO_4$ without organic enrichment.

Yield advantage obtained by applying $ZnSO_4$ with recommended fertilizer dose was 22.7 per cent over recommended fertilizer dose alone and 12 per cent over recommended fertilizer dose + 10 t FYM ha^{-1} in rice (Bhat *et al.*, 2002). Application of 25 kg $ZnSO_4$ ha^{-1} significantly increased paddy yield over NPK alone (Patil and Meisheri, 2003). In hybrid rice-wheat cropping system, best treatmental effect of higher grain yield (62 q ha^{-1}) and straw yield of rice was recorded with application of 30 kg $ZnSO_4$ ha^{-1} (Kulandaivel *et al.*, 2004). Maximum grain and straw yields of rice were obtained by application of 30 kg $ZnSO_4$ ha^{-1} which increased grain yield by 20.1 per cent and straw yield by 19.7 per cent over control (Ghatak *et al.*, 2005). Naik and Das (2006) observed significant increase in grain yield of rice with application of zinc.

2.2.4 Effect on economics

Highest additional returns were obtained under treatment of 100:50:50 NPK and 15 kg Zn ha^{-1} through $ZnSO_4$ in rice (Chaphale, 1999). Profitable responses through zinc application on kharif rice were reported by Mehla (1999). All the Zn treatments showed higher net returns and benefit: cost ratio than the control (Mani *et al.*, 2001). Maximum net return was obtained with application of 30 kg $ZnSO_4$ ha^{-1} in rice. (Ghatak *et al.*, 2005).

2.2.5 Effect on nutrient uptake and soil nutrient status

Kasana and Chaudhury (1983) reported increased Zn uptake by rice due to Zn application. Ahmed *et al.* (1990) reported that complexed and residual Zn contributed more to Zn uptake by rice. Khanda and Dixit (1996) reported increased uptake of N with application of zinc during all growth stages of rice. On an average, the total Zn uptake in rice increased with successive rise in Zn level up to 11.2 kg ha^{-1} (Trivedi *et al.*, 1998). Modak and Chavan (1999) observed an increase in uptake of N, P, K and Zn by grain and straw of rice due to application of Zn with NPK. Under transplanted condition of rice significant increase in total nutrient uptake was observed upto 30 kg $ZnSO_4$ ha^{-1} (Rao and Shukla, 1999). Patil and Meisheri (2003) observed increase in Zn uptake by grain, straw and Zn content in soil when Zn was applied in rice.

Application of different levels of $ZnSO_4$ to hybrid rice had significant influence on Zn uptake and Zn content of soil (Kulandaivel *et al.*, 2004). Arvind Verma *et al.* (2005) found out that FYM alone or in combination with chemical fertilizers significantly increased the Zn content over 100% NPK. Response of rice to zinc application occurred since 1997 when DTPA extractable Zn declined to 1.48 kg ha^{-1} from the initial level of 1.99 kg ha^{-1} (Yaduvanshi and Swarup, 2005). Application of 30 kg $ZnSO_4$ ha^{-1} recorded highest uptake of Zn, N and K by rice (Ghatak *et al.*, 2005). The zinc content of grain and straw of rice were significantly higher in zinc treated plot over control (Naik and Das, 2006).

2.3 Effect of combined application of S and Zn on rice

Hoque and Khan (1981) observed increase in the grain yield of rice was highest for the combined application of $ZnSO_4$ and gypsum followed by that of ZnO and gypsum. Islam *et al.* (1985) reported complementary effect of S and Zn on each other. Altaf Hossain *et al.* (1987) reported that gypsum along with either ZnO or $ZnSO_4$ gave the maximum tillers $hill^{-1}$, maximum spikelets $panicle^{-1}$ and grains $panicle^{-1}$ under moist and submerged conditions in rice. He also reported that Zn and S alone or in combination with Zn significantly increased grain and straw yield of rice and under submerged conditions, gypsum would be applied along with either $ZnSO_4$ or ZnO to ensure higher yield.

Ramanathan and Saravanan (1987) found out that Ammonium sulphate - $ZnSO_4$ combination recorded higher grain yield in rice than other treatments. In a continuous rice cropping pattern, Hoque and Jahiruddin (1994) observed that maximum grain yield of 5243 kg ha^{-1} (77 % increase over control) was recorded due to S (20 kg ha^{-1}) + Zn (10 kg ha^{-1}) treatment particularly when they are applied on all the crops.

Arvind Verma *et al.* (2005) found out that application of S alone or in combination with Zn significantly increased the available S content and application of Zn alone or in combination with S along with 100% NPK significantly increased the Zn content of the soil over rest of the treatments.

2.4 Effect of S under integrated condition

Mondal *et al.* (1994) observed that DMP, yield components like filled grains panicle^{-1}, thousand grain weight and yield of rice improved when the rice crop was fertilized with N, P (75% of the recommended dose of N, P through SSP) K along with FYM @ 10 t ha^{-1}. Sudha (1999) reported that integration of higher NPK rates along with FYM and S level of 25 kg ha^{-1} registered higher growth and yield attributes, grain yield and N and K uptake in rice. It was also observed a significant influence on S uptake with combination of 10 t ha^{-1} of FYM along with higher NPK rates and integration of 10 t ha^{-1} of FYM along with the highest sulphur level of 25 kg ha^{-1} registered higher sulphur status of soil.

Chettri and Mondal (2005) reported that application of 100 per cent of recommended dose of NPK through S containing fertilizers (ammonium sulphate, diammonium phosphate and MOP) along with FYM improved the grain yield of both rainy season and winter season rice and uptake of nutrients.

2.5 Effect of Zn under integrated condition

Devarajan and Krishnasamy (1996) found out that chelation of Zn with manures enhanced the yield of rice. Khanda and Dixit (1996) reported that combined application of N and Zn increased the grain yield of rice by 7.2% and straw yield by 12.9% over sole N. This also increased the nutrient uptake by 13.9% over sole N. Zinc sulphate at 20 kg ha^{-1} incubated or blended with either with pressmud or FYM was at par with zinc sulphate at 40 kg ha^{-1} alone in respect of grain and straw yields of rice and N and Zn contents and their uptake by the crop and also maintained almost equal amounts of available Zn in soil (Kumar *et al.*, 1999).

Application of Zn at 5 ppm with NPK and FYM significantly increased the grain yield, straw yield and uptake of Zn in rice over recommended dose of NPK alone (Modak and Chavan, 1999). Channabasavanna *et al.* (2001) found out that application of FYM with 25 kg ZnSO4 ha^{-1} significantly increased grain yield of rice by 15.4 per cent over control and no increase to 50 kg $ZnSO_4$ ha^{-1}. Mani *et al.* (2001) reported that 25 kg $ZnSO_4$ ha^{-1} as Zn-pressmud registered 26.9% yield increase over $ZnSO_4$ without organic enrichment.

Patil and Meisheri (2003) reported significantly higher yield and uptake of Zn by straw, grain and increase in Zn content of soil where 25 kg $ZnSO_4$ ha^{-1} was applied in combination with 10 t ha^{-1} of FYM in rice. Arvind Verma *et al.* (2005) found out that FYM alone or in combination with chemical fertilizers significantly increased the Zn content over 100% NPK.

2.6 Effect of combined application of S and Zn under integrated condition

Application of N fertilizers in combination with gypsum or $ZnSO_4$ or S registered higher grain production than the N fertilizers alone and the percentage increase by the addition of gypsum, $ZnSO_4$ and S were 14.1, 17.2 and 24.8% respectively indicating the beneficial response for combined application of N with Zn and S (Ramanathan and Saravanan, 1987).

In a field experiment conducted on S and Zn deficient soil of Tamil Nadu to study the effect of green manure and inorganic S and Zn fertilizer combinations in the yield of short duration rice cultivar, ADT 36, Mythili *et al.* (2003) observed that NPK (100:50:50 N: P_2O5: K_2O kg ha^{-1}), Zn as $ZnSO_4$ (5 kg Zn ha^{-1}) and S as gypsum (50 kg S ha^{-1}) coupled with green manure (*Sesbania aculeata* @ 10 t ha^{-1}) produced the highest grain (5627 kg ha^{-1}) and straw yields (5723 kg ha^{-1}).

2.7 Effect of organic form of N on rice

2.7.1 Effect on growth characters

Subbiah *et al.* (1983) reported increase in DMP of rice variety 'Rasi' due to incorporation of organic residues @ 10 t ha^{-1}. Incorporation of organic manures increased the dry matter production of rice (Krishnamoorthy *et al.*, 1994). Sharma (1994) opined that FYM application increased plant height, tillers, and dry matter in rice than without it.

Babu (1996) obtained significant increase in the plant height, tiller production, LAI of rice variety Pavizham with FYM addition @ 10 t ha^{-1}. Sudha (1999) observed reduction in chaff percentage, increase in tiller counts and chlorophyll content of rice with higher levels of FYM addition (10 t ha^{-1}). Application of FYM significantly increased tiller number of rice (Satyanarayana *et al.*, 2002). Highest LAI DMP was obtained in FYM treated plots and it was significantly different from other treatments (Tamal and Sinha, 2006)

2.7.2 Effect on yield attributes

Reduction in chaff percentage in rice due to organic matter addition was reported by Prakash *et al.* (1990). Farmyard manure addition increased number of panicles m^{-2} and grain yields of rice (Zia *et al.*, 1992). Sharma and Sharma (1994) reported that incorporation of FYM in rice could increase the number of panicles m^{-2}, grain number $panicle^{-1}$ in rice. In rice-wheat cropping system, Rathore *et al.* (1995) observed significantly higher grain number $panicle^{-1}$, panicle number m^{-2}; thousand grain weight with FYM applied plots over control.

In rice-rice cropping system, Deepa (1998) found that number of panicles and thousand grain weight of rice variety Kanchana was better in plots which received organic manure, when compared to treatments which received 100 per cent recommended NPK through chemical fertilizers. Singh *et al.*, (1998) observed an increase in grain number panicle^{-1}, thousand grain weight and grain yield with addition @ 7.5 t ha^{-1} in rice. Sudha (1999) observed increase in panicle number and grain number panicle^{-1} of rice with higher levels of FYM addition (10 t ha $^{-1}$). The panicle length of rice was significantly influenced due to green manuring (Dwivedi and Thakur, 2000).

While studying integrated use of organic manures and inorganic nitrogen fertilizers for the cultivation of lowland rice in vertisol, Pandey *et al.* (2001) found out the significant influence of organic manures on panicle weight of rice. Application of FYM significantly increased filled grains panicle^{-1} and thousand grain weight of rice (Satyanarayana *et al.*, 2002). Dutta and Bandyopadhyaya (2003) reported that yield components of rice were significantly higher in FYM treated plots as compared to the unfertilized control. Under rice-rice cropping system, higher number of panicle bearing tillers, straight ear heads and thousand grain weight were observed more in organic manure applied plots as compared to inorganic fertilized plots (Satheesh and Balasubramanian, 2003).

2.7.3 Effect on yield

Field experiments with rice-wheat rotation were conducted during five consecutive years on a coarse-textured low organic matter soil showed that by amending the soil with 12 t FYM ha^{-1}, the yield of wetland rice in the absence of fertilizers was increased by 32 per cent (Maskina *et al*, 1988). In a rice-wheat cropping system on a humid hilly soil of India application of organic manures resulted in higher grain yields in rice (Rai *et al.*, 1990). Brar and Dhillon (1994) observed that grain yield of rice reached upto 6.7 t ha^{-1} using 40 t ha^{-1} of FYM as against 4.1 t ha^{-1} in control plot. Sharma (1994) observed 26 per cent increase in yield of rice with the application of 10 t ha^{-1} of FYM.

Sharma and Sharma (1994) reported that incorporation of FYM in rice could increase the grain yield in rice. In rice-wheat cropping system, Rathore *et al.* (1995) observed significantly higher grain yields with FYM applied plots over control. Babu (1996) obtained significant increase in the straw yield of rice variety Pavizham with FYM addition @ 10 t ha^{-1}. In rice-rice cropping system, Deepa (1998) found that straw yield of rice variety Kanchana was better in plots which received organic manure, when compared to treatments which received 100 per cent recommended NPK through chemical fertilizers. Singh *et al.* (1998) observed an increase in grain yields with FYM addition @ 7.5 t ha^{-1} in rice. Sudha (1999) observed increase grain yield of rice with higher levels of FYM addition (10 t ha^{-1}).

Application of farmyard manure at 10 t ha^{-1} increased grain yield of rice by 25% compared to no farmyard manure control. Application of FYM significantly increased straw yield of rice (Satyanarayana *et al.*, 2002). Dutta and Bandyopadhyaya (2003) reported that yield of rice was significantly high in FYM treated plots as compared to the unfertilized control. The grain yield of rice increased significantly with the application of organic manures over the recommended NPK (through chemical fertilizer) during two years (1996 and 1997) of experimentation (Satheesh and Balasubramanian, 2003). Significantly higher grain and straw yield was obtained in FYM treated plots. (Tamal and Sinha, 2006)

2.7.4 Effect on nutrient uptake and nutrient status of soil

Verma and Dixit (1989) found out that incorporation of FYM increased the NPK uptake both with and without addition of N fertilizers in paddy. Improvement in available P status of soil due to incorporation of FYM was reported by Dhargawe *et al.* (1991). Sharma and Mittra (1991) opined that FYM could increase NPK uptake in rice. Sharma and Sharma (1994) reported that incorporation of FYM in rice could increase the soil organic carbon and available N, P and K contents in rice. Sudha

(1999) observed that organic manure addition at all levels could maintain the available N, P, K and S status of soil well above the original status before the experiment. It was also observed that an increase in uptake of N, P and K occurred with higher levels of FYM addition (10 t ha^{-1}). Dutta and Bandyopadhyaya (2003) observed increased uptake of nutrients (N, P and K) when FYM was applied to the rice compared to control. Application of FYM considerably increased organic carbon and available nutrients (N, P and K) after harvest of rice (Dutta and Bandyopadhyaya, 2003).

Total nutrient uptake by rice crop differed significantly due to organic manure applied treatments which exhibited 22.7% and 21.5% higher total P and K respectively in both the seasons of study (rabi and kharif) when compared to chemical nitrogen fertilizer applied treatments (Satheesh and Balasubramanian, 2003).

2.8 Effect of substitution of inorganic nitrogen by organic form on rice

2.8.1 Effect on growth characters

Dubey and Verma (1999) found out an improvement in growth characters of rice with conjunctive fertilizer N and organic sources. Sindhu (2002) reported that use of vermicompost for substituting 50 per cent N and recorded an appreciable increase in plant height and DMP of rice. Application of 50 per cent of recommended dose through green manure and 50 per cent of N through urea to rice resulted in improvement in plant height in rice (Bhoite, 2005).

Vasantharao *et al.* (2004) observed that growth characters like plant height, tiller number, leaf area index and dry matter production increased in those treatments which received combination of 50 % N each through fertilizer and different organic sources like green leaf manure, poultry manure, FYM and neem cake.

2.8.2 Effect on yield attributes

Yield attributes such as panicles m^{-2}, total number of grains panicle¯1, number of filled grains $panicle^{-1}$ and thousand grain weight were improved by application of 50 % N each through fertilizer and different organic sources like green leaf manure, poultry manure, farmyard manure and neem cake (Vasantharao *et al.*, 2004). Application of 50 per cent of recommended dose through green manure and 50 per cent of N through urea to rice resulted in improvement in panicles m^{-1} row length, grains $panicle^{-1}$ and thousand grain weight (Bhoite, 2005).

2.8.3 Effect on yield

In a cropping sequence integrated use of 12 t ha^{-1} of FYM and 80 kg ha^{-1} of inorganic nitrogen gave higher yield in rice comparable as that with 120 kg of inorganic nitrogen ha^{-1} (Meelu, 1981; Meelu *et al.*, 1981). Application of 120 kg N ha^{-1} alone increased the yield by 3.9 t ha^{-1}, and was comparable to rice yield obtained with 80 kg N and 12 t FYM ha^{-1}, which indicated that 12 t FYM ha^{-1} could be substituted for 40 kg N as inorganic fertilizer in rice (Meelu and Gill, 1982). In rice-rice cropping system, Kulkarni *et al.* (1983) reported that application of 12 t ha^{-1} of FYM along with 90 kg N ha^{-1} gave comparable yields in rice as that of 120 kg N alone.

Kaushik *et al.*, (1984) showed the possibility of saving N and P by applying FYM to the rice crop in rice-wheat crop sequence. Comparable yields to that of NPK @ 120:60:40 kg ha^{-1} was obtained with application of lower rates of NPK and FYM (Kavimandan *et al.*, 1987). Khan *et al.* (1988) observed comparable yield in rice through the application of 30 kg N ha^{-1} in the form of FYM at puddling and 30 kg N ha^{-1} as urea to that of 60 kg N ha^{-1} as urea. Singh and Verma (1990) obtained significant improvement in grain and straw yields of rice through application of FYM as the same level of inorganic fertilizers than without FYM.

At Maruteri (A.P) and CSRC, Karamana under rice-rice cropping system, it was found that 50 per cent N substitution through FYM in kharif followed by application of 100 per cent NPK in rabi produced significantly higher grain yield than applying 100 per cent chemical fertilizer during both seasons (PDCSR, 1992). Half to one third dose of chemical nitrogen could be substituted by organic N without any yield loss (Malik and Jaiswal, 1993). Mathew *et al.* (1993) showed that when FYM was regularly applied in all seasons @ 5 t ha^{-1}, saving of fertilizers from a recommended fertilizer dose of 70:35:35 kg NPK ha^{-1} could be achieved to the extent of 1/3 dose of N and K_2 O and 2/3dose of P_20_5. Increase in yield of rice through substitution of 25 per cent of inorganic nitrogen by FYM was reported by Singh *et al.* (1996). In a study on integrated nutrient management in a rice-rice cropping system, Deepa (1998) obtained higher straw yield with integration of nutrients, which supplied 50 per cent of the recommended N through FYM and the rest through chemical fertilizers for rice variety Kanchana.

All organic sources including FYM can be used to substitute 25 to 50 per cent nitrogen needs of rice crop with significant yield advantage in some cases (Hegde, 1998). Through integrated nutrient management in rice-rice system, saving of 25 per cent of applied nitrogen and reduction of 50 per cent in application of inorganic nitrogen can be achieved (Thakur *et al.*, 1999). Integration application of one third or one quarter of N as vermicompost and the rest as NPK led to improvement in grain yield of rice compared to inorganic N alone (Rani and Srivastava, 1997). Dubey and Verma (1999) obtained the highest increase in yield in rice by the combined use of 50 per cent NPK and 50 per cent organic manures. Grain yield and straw yield was highest when different types of organic amendments were applied in combination with nitrogen fertilizer in 50:50 ratio in comparison to the treatment where nitrogen was applied as urea alone (Salik and Samjoy, 1999).

Sindhu (2002) reported that use of vermicompost for substituting 50 per cent N and recorded an appreciable increase straw yield of rice. In rice-maize sequence, results indicated that there is possibility of saving of N fertilizer to the extend of 50 per cent by using rice straw or FYM without reduction in grain yield (Mallikarjuna *et al.*, 2004). Parihar (2004) opined that grain yields with 80 kg N ha^{-1} (50 per cent through green manure and 50 per cent through urea) were comparable to 80 kg N ha^{-1} (50 per cent through FYM and 50 per cent through urea), but both were significantly higher than 80 kg N ha^{-1} through urea. Application of 50 per cent of recommended dose through green manure and 50 per cent of N through urea to rice resulted in significant increase of N uptake (Bhoite, 2005)

2.8.4 Effect on economics

Verma (1990) reported that there is possibility of saving inorganic fertilizers to the extent of 50 per cent through incorporation of FYM in rice. Sindhu (2002) reported that use of FYM for substituting 50 per cent N resulted in higher net returns and BCR. Application of 50 per cent of RD through green manure and 50 per cent of N through urea to rice resulted in resulted in higher net returns and BC ratio (Bhoite, 2005). Maximum rice yield was recorded when 25 per cent of N was substituted by green leaf manure (Yadav *et al.*, 2005).

2.8.5 Effect on nutrient uptake and nutrient status of soil

In a study on INM in a rice-rice cropping system Deepa (1998) obtained higher K uptake and higher status of available NPK of soil at harvest with integration of nutrients, which supplied 50 per cent of the recommended N through FYM and the rest through chemical fertilizers for rice variety Kanchana. Tiwari and Tripathi (1998) suggested that organic manures could be substituted upto 50 per cent of nutrients along with improvement of physico - chemical properties in paddy soils without hindering the production of succeeding crop. Study conducted on changes in soil fertility under rice (*Oryza sativa* L.)- lentil (*Lens culinaris)* cropping system showed that substituting 50 per cent of the recommended N through various sources like FYM and green manure did not show any significant variation in total uptake of N, P and K by rice and a slight increase in the available N status of soil as compared to N solely applied through prilled urea (Singh *et al.*, 2001).

Substitution of organic sources to a tune of 25 per cent of the recommended dose recorded the highest P uptake and available K status of soil (Sujathamma *et al.*, 2001). They also observed highest total N content in the soil with 50 per cent N through vermicompost and 50 per cent N as fertilizer. The combination of 25% N substituted by dhanicha as green manure and 75% of the recommended dose of N (60 kg ha^{-1}) enhanced crop productivity of the system, including an improvement of everlasting physico-chemical properties of the soil as a whole (Puste *et al.*, 2001). Sindhu (2002) reported that use of vermicompost for substituting 50 per cent N and recorded an appreciable increase in N and P uptake, available K status of soil.

Better supply and uptake of applied N through substitution of 50% of N fertilizer with organic manures (Mallikarjuna *et al.*, 2004). Parihar (2004) opined that total NPK uptake with 80 kg N ha^{-1} (50 per cent through green manure and 50 per cent through urea) were comparable to 80 kg N ha^{-1} (50 per cent through FYM and 50 per cent through urea), but both were significantly higher than 80 kg N ha^{-1} through urea. Maximum rice NPK uptake was recorded when 25 per cent of N was substituted by green leaf manure (Yadav *et al.*, 2005).

2.9 Effect of combined use of organic and inorganic form of nitrogen on rice

2.9.1 Effect on growth characters

In an experiment conducted on Integrated Nutrient Management at

RARS, Pattambi, Mathew *et al.* (1994) reported higher plant height and tiller number of rice variety Jyothi with the integration of 10 t ha^{-1} FYM along with chemical fertilizers in comparison to chemical fertilizers alone. In a study at RRS Moncompu, Babu (1996) observed that the integration of FYM @ 10 t ha^{-1} along with chemical fertilizers could increase the plant height, tiller count, LAI, chlorophyll content and DMP of medium duration rice variety Pavizham. DMP was highest with application of 75 kg N ha^{-1} as urea along with 25 kg N as vermicompost compared to urea alone (Jadhav *et al.* 1997).

Sudha (1999) found out that combination of 10 t ha^{-1} of FYM along with the highest NPK dose recorded higher tiller counts, LAI, chlorophyll content, DMP, of rice. Growth characters were improved by integrated use of organic and inorganic fertilizers in rice. (Patra *et al.*, 2000). In fine grain 'Ponni rice'-the treatments having the combination of organics and inorganics fertilization showed significant improvement in growth parameters of rice (Balasubramanniyan, 2004). The inorganic fertilizer application of 60:40:30 kg NPK ha^{-1} supplemented with FYM 5 t ha^{-1} produced highest plant height, LAI, number of tillers $hill^{-1}$ and DMP in scented rice (Santhosh *et al.*, 2004).

2.9.2 Effect on yield attributes

In an experiment conducted on INM at RARS, Pattambi, Mathew *et al.* (1994) reported higher panicle number, filled grains $panicle^{-1}$ and thousand grain weight of rice with 10 t ha^{-1} FYM along with chemical fertilizers in rice variety Jyothi with the integration of 10 t ha^{-1} of FYM along with chemical fertilizers in comparison with chemical fertilizers alone. Mondal *et al.* (1994) observed an increase in panicle number m^{-2}, grain number $panicle^{-1}$ and thousand grain weight in rice with increased NPK rates along with FYM application. Application of 75 percent of the recommended dose of NPK (60:30:30 kg ha^{-1}) in conjunction with 10 t FYM ha^{-1} produced highest and significant number of panicles m^2, grain number panicle^{-1}, filled grains panicle^{-1} and test weight of rice (Paste *et el.*, 1995). Combining 125 per cent NPK with 10 t ha^{-1} FYM gave higher number of panicles m^{-2} and grain number panicle^{-1} in rice (Patra *et al.*, 1998).

Singh *et al.* (1998) observed increase in grain number panicle^{-1} and thousand grain weight of rice with higher NPK rates along with 7.5 t ha^{-1} of FYM. Sudha (1999) found that combination of 10 t ha^{-1} of FYM along with the highest NPK dose recorded higher panicle number m^{-2} and grain number panicle^{-1} of rice. Yield characters were improved by the integrated use of organic and inorganic fertilizers in rice (Patra *et al.*, 2000). Dutta and Bandyopadhyaya (2003) reported that FYM, green leaf manure and blue green algae in combination with inorganic fertilizers improved yield components of rice. In fine grain 'Ponni rice'-the treatments having the combination of organics and inorganics fertilization showed significant improvement in yield parameters of rice. (Balasubramanniyan, 2004). Application of inorganic fertilizer (60:40:30 kg NPK ha^{-1}) along with farmyard manure 5 t ha^{-1} recorded highest effective tillers m^{-2} in scented rice (Santhosh *et al.*, 2004).

2.9.3 Effect on yield

Pandey and Tripathi (1992) observed higher yield in rice with integrated use of inorganic and organic N fertilizer. Combined application of FYM and NPK resulted in a grain yield increase of 7.6 per cent in rice over application of NPK alone (Anilakumar *et al.*, 1993).Jayakrishnakumar et al. (1994) reported that permanent pot experiments on integrated nutrient supply system in rice sequence in different locations revealed that 50 to 25 per cent of fertilizer nitrogen could be substituted by locally available organic sources of N like FYM, glyricidia and paddy straw. In an experiment conducted on Integrated Nutrient Management at RARS, Pattambi, Mathew *et al.* (1994) observed significantly higher grain yields and comparable straw yields of rice with

10 t ha^{-1} FYM along with chemical fertilizers in rice variety Jyothi with the integration of 10 t ha^{-1} FYM along with chemical fertilizers in comparison to chemical fertilizers alone. Integrated use of organic and inorganic fertilizers resulted in maximum yield (Pandey *et al.*, 1995).

Rajamannar *et al.* (1995) concluded that combined application of organic manures with the recommended levels of N increased the grain yields of rice over sole application of organic manures or inorganic nitrogen. Sheeba and Chellamuthu (1996) reported increased grain yields up to 5.6 t ha^{-1} and straw yield upto 7.3 t ha^{-1} with the combined application of organic manures and chemical fertilizers. Higher grain yields of rice were obtained with the combined application of NPK @ 90: 60: 90 kg ha^{-1} along with 10 t FYM ha^{-1} (Roy *et al.*, 1997).

Mondal and Chettri (1998) studied the effect of INM on productivity and fertility building under rice based cropping systems and reported significantly higher grain yield upto 5.3 t ha^{-1}, which combined application of 50 per cent of the recommended nitrogen along with 10 t ha^{-1} FYM than that with inorganics alone. Singh *et al.* (1998) observed higher grain yields with higher NPK rates along with 7.5 t ha^{-1} of FYM. James Martin (1999) reported that combined use of *Azospirillum*, green manure, *Sesbania rostrata* and *Azolla* along with 50 per cent chemical fertilizer resulted in yield comparable to that of application of prilled urea. Saxena *et al.* (1999) reported that NPK @ 100: 80: 60 kg ha^{-1} along with 10 t ha^{-1} FYM produced significantly higher yield of rice.

Sudha (1999) found out that combination of 10 t ha^{-1} of FYM along with the highest NPK dose recorded higher grain yield and straw yield in rice. Singh *et al.* (2000) found out that FYM with recommended dose of NPK gave the highest grain yield (5.16 t ha^{-1}) and application of FYM contributed to yield up to 50 per cent of the recommended NPK. Integrated use of organic and inorganic fertilizers was found significantly better than inorganic fertilizers alone for higher yield in rice (Pandey *et al.*, 2001). Chakraborty *et al.* (2003) reported that combined application of inorganic (urea) and organic (farmyard manure) sources increased the grain yield by 72% over no input (control). Dutta and Bandyopadhyaya (2003) reported improvement in yield of rice due to application of FYM, green leaf manure and blue green algae combination with inorganic fertilizers.

In fine grain 'Ponni rice'-the treatments having the combination of organics and inorganics fertilization showed significant improvement in on grain yield (Balasubramanniyan, 2004). In a field experiment conducted on sandy loam soil (Inceptisols) during kharif season of 2000, Santhosh *et al.* (2004) found out significant increase in grain and straw yield of rice when 5 t ha^{-1} of FYM was applied in combination with inorganic fertilizer dose of 60:40:30 kg NPK ha^{-1}. Integrated use of *Sesbania* along with 180 kg N ha^{-1} gave higher grain yield of 7.1 t ha^{-1} in rice (Patro *et al.*, 2005).

Rowl and Sarawgi (2005) found out that grain yield and straw yield were significantly higher under 100 per cent of recommended dose of N blended with FYM and 100 per cent of recommended dose of nitrogen + 5 t FYM ha^{-1} than inorganic fertilizers alone. Integrated use of organic and inorganic fertilizers led to increased NPK uptake in rice (Khanda *et al.*, 2005). Yaduvanshi and Swarup (2005) reported that farmyard manure, gypsum and pressmud along with NPK fertilizer use significantly enhanced yields over NPK treatment alone. The application of farmyard manure (FYM) along with NPK further increased the total productivity of the rice-wheat-mungbean cropping system compared to NPK after two crop cycles of the system (Sharma and Sharma, 2006).

2.9.4 Effect on nutrient uptake and nutrient status of soil

Enhanced uptake of N, P and K in rice was observed with the integrated application of nutrients (Singhania and Singh, 1991). Sheeba and Chellamuthu (1996) opined that application of FYM conjointly with

100 per cent NPK registered higher N and P uptake in t ha^{-1} and highest total N, P and K contents in soil in rice. According to Mishra and Sharma (1997) integrated application of fertilizers and FYM resulted in appreciable build up of NPK in soil. Beillaki *et al.* (1998) N and P content of soil after experiment was improved when FYM used either alone or in combination with recommended NPK.

Mondal and Chettri (1998) studied the effect of INM on productivity and fertility building under rice based cropping systems and reported significantly higher NPK and sulphur uptake in rice, higher balance of NPK nutrients in soil after the experiment which combined application of 50 per cent of the recommended nitrogen along with 10 t ha^{-1} FYM than that with inorganics alone. Sudha (1999) found that combination of 10 t ha^{-1} of FYM along with the highest NPK dose recorded N, P, K, S uptake and soil content and BC ratio in rice. Sengar *et al.* (2000) reported increased uptake of NPK when FYM used in combination with chemical fertilizers and improved the available N and P content of soil.

Integrated use of organic and inorganic fertilizers was found significantly better than inorganic fertilizers alone for N uptake (Pandey *et al.*, 2001). The NPK fertility of the soil was enhanced and more organic carbon was present following the FYM+N treatment than with NPK fertilizers applied at the currently recommended rate (Roy *et al.*, 2001). In a field experiment conducted on sandy loam soil in West Bengal, Dutta and Bandyopadhyaya (2003) found that FYM, green leaf manure and blue green algae alone or in combination with inorganic fertilizers considerably improved organic carbon and available nutrients (N, P and K) after harvest of rice.

In fine grain 'Ponni rice'-the treatments having the combination of organics and inorganics fertilization showed appreciable influence on grain yield and N uptake and availability (Balasubramanniyan, 2004).

Application of NPK+FYM showed the highest increase in organic C, available N, available P and available K content in soil. Integrated nutrient management is one of the best methods for resilience of soil fertility under rice-wheat cropping system (Sharma and Sharma, 2004). Integrated use of Sesbania along with 180 kg N ha $^{-1}$ improved the total NPK uptake by the rice crop (Patro *et al.*, 2005).

Rowl and Sarawgi (2005) found out that N content and uptake were significantly higher under 100 per cent of recommended dose of N blended with FYM and 100 per cent of recommended dose of nitrogen + 5 t FYM ha^{-1} than inorganic fertilizers alone. Integrated use of organic and inorganic fertilizers led to increased grain yield in rice (Khanda *et al.*, 2005). Application of 100 per cent NPK + FYM @ 15 t ha^{-1} recorded highest organic carbon content (Laxminarayana, 2006).

The application of farmyard manure (FYM) along with NPK further increased the total productivity of the rice-wheat-mungbean cropping system by 0.3-0.6 t ha^{-1}, the organic C by 0.13%, the available N by 10.7 kg ha^{-1}, the available P by 4.7 kg ha^{-1}and the available K by 15 kg ha^{-1}compared to NPK after two crop cycles of the system (Sharma and Sharma, 2006). Ubaid khan *et al.* (2006) reported that use of green manure in combination with urea gave significantly higher yield of rice grain and straw, which is same as those obtained with FYM or wheat straw incorporated in conjunction with urea N at 150 kg ha^{-1}.

From the above review of literature it was evident that integrated nutrient supply significantly exerted an influence on growth and yield of rice. Several workers also emphasized the role of sulphur and zinc in improving the growth and yield of rice and it was found that sulphur and zinc had a definite role under integrated nutrient condition in rice soils. So it is imperative to study the response of sulphur and zinc under integrated nitrogen nutrition in wetland rice.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was undertaken to study the response of sulphur and zinc and their interaction in integrated nutrition in wetland rice ecosystem. The details of materials used and methods adopted are presented in this chapter.

3.1 MATERIALS

3.1.1 Experimental Site

The experiment was conducted at Cropping Systems Research Centre (CSRC), Karamana, Thiruvananthapuram, of the Kerala Agricultural University. It is located at 8.5°N latitude and 76.9°E longitude at an altitude of 29 m above mean sea level.

3.1.2 Soil

The soil of the experimental site is sandy loam with pH 5.3, high in organic carbon, medium in available nitrogen and medium in available phosphorus and potassium content. Soil samples were collected from 30 cm depth and a composite sample was used for the determination of physico-chemical properties. The important physicochemical properties studied are given in Table 3.1.

3.1.3 Climate

The experimental site enjoys a humid tropical climate. The data on various weather parameters during the cropping period are given in the Appendix I and illustrated in Fig.3.1.

3.1.4 Cropping History of the Field

The experimental field had a uniform bulk crop of rice prior to lay out of the experiment.

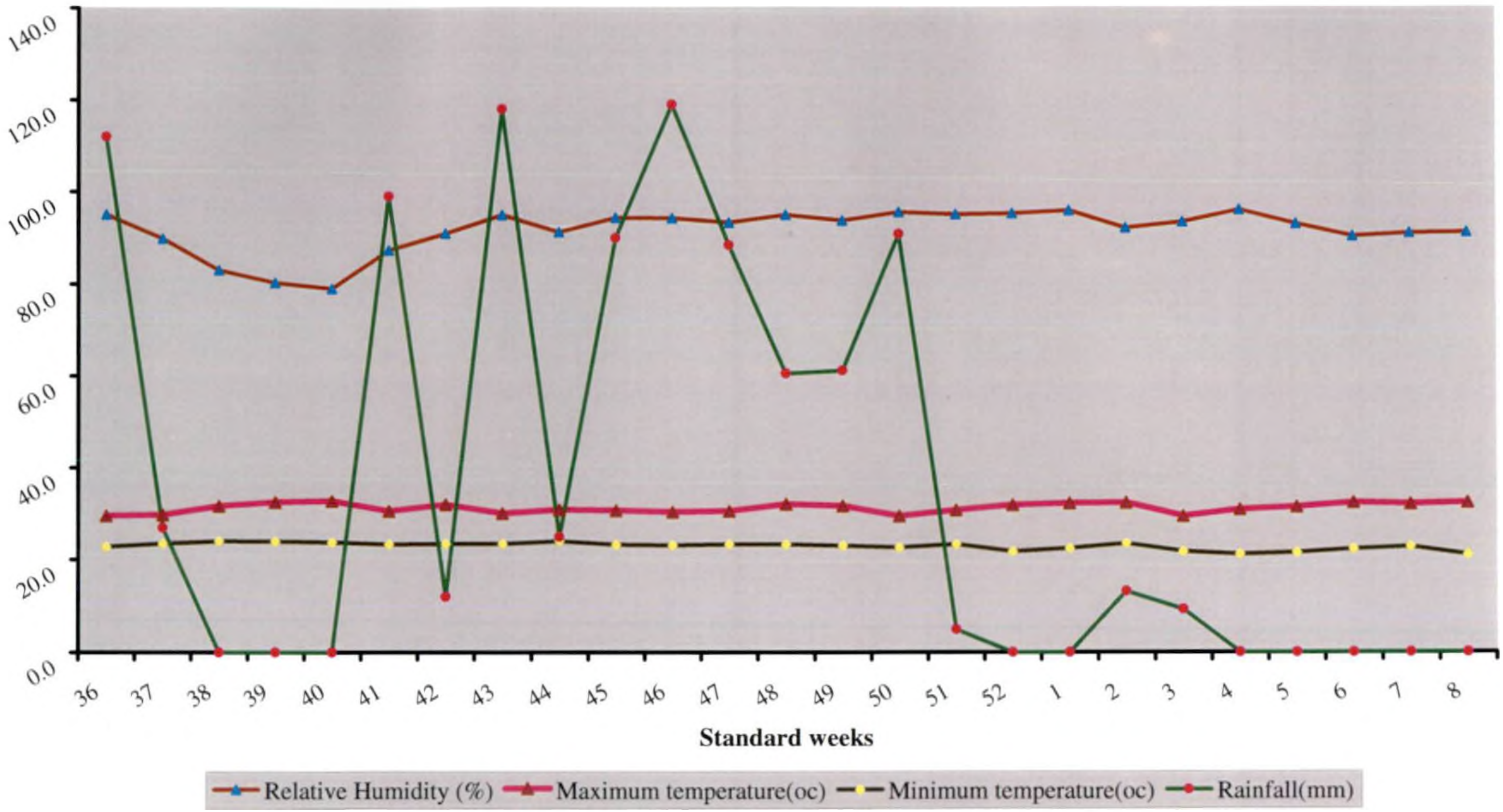

Fig. 1. Weather parameters during the cropping period (September 2005 to February 2006)

3.1.5 Season

The field experiment was conducted during the second crop season of the year 2005. The crop was planted on 31st October 2005 and harvested on 6th February 2006.

Table.3.1.Physico-chemical properties of the experimental site

A. Physical composition

Sl. No.	Parameter	Content (%)	Methods used
1	Sand	70	Bouyoucos Hydrometer method (Bouyoucos, 1962)
2	Silt	7	
3	Clay	21	

B. Chemical composition

Sl. No.	Parameter	Content	Rating	Methods used
1	pH	5.3	Acidic	1 : 2.5 Soil solution ratio using pH meter with glass electrode(Jackson, 1973)
2	Organic carbon (per cent)	1.13	High	Wet oxidation method (Walkley and Black, 1934)

3	Available N (kg ha^{-1})	279.81	Medium	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
4	Available P_2O_5 (kg ha^{-1})	30.23	Medium	Bray colorimetric method (Jackson, 1973)
5	Available K_2O (kg ha^{-1})	165.57	Medium	Ammonium acetate method (Jackson, 1973)
6	Available S (ppm)	3.05	Low	Turbidity method (Hesse, 1971)
7	Available Zn (ppm)	0.290	Low	DTPA method (Lindsay and Norvell, 1978)

3.1.6 Crop and Variety

The rice variety, 'Aiswarya' (PTB-52) released from Regional Agricultural Research Station, Pattambi was selected for the experiment. It has duration of 120-125 days. The grains are red, long and bold. The variety is suitable for first and second crop seasons and moderately resistant to blast and blight diseases and BPH.

3.1.7 Manures and Fertilizers

FYM containing 0.4 per cent N, 0.3 per cent P_2O_5 and 0.2 per cent K_2O is used as organic source. Fertilizer like urea (46 per cent N), single super phosphate (16 per cent P_2O_5 and 10 per cent S), zinc sulphate (17 per cent S and 36 per cent Zn), Rajphos (20 per cent P_2O_5) and Muriate of Potash (60 per cent K_2O) were used as the inorganic sources for the experiment.

3.2 METHODS

3.2.1 Design and Layout (Fig.3.2)

The experiment was laid out as a factorial experiment in Randomised Block Design. The layout of the experiments is given in Fig. 2.

Design	: Factorial RBD
Number of treatment combinations	: 14
Number of replications	: 3
Gross plot size	: 4 x 3 m^2
Total number of plots	: 42
Spacing	: 20 x 10 cm

3.2.2 Treatments

The treatments consisted of combinations of different forms of nitrogen, sulphur and zinc.

(i) Factor 1

Forms of nitrogen (N)

N_1: Full recommended dose of nitrogen as inorganic fertilizer

N_2: 50 per cent of recommended nitrogen as inorganic and 50 percent of recommended nitrogen as organic.

(ii) Factor 2

Levels of sulphur (S)

S_1 : 10 S kg ha^{-1}

S_2 : 20 S kg ha^{-1}

S_3 : 30 S kg ha^{-1}

T_1	T_5	T_{12}	T_8	T_9	T_6
T_3	T_{12}	T_6	T_{14}	T_4	T_{14}
T_{13}	T_6	T_9	T_4	T_{12}	T_5
T_{11}	T_4	T_2	T_3	T_1	T_{10}
T_2	T_{14}	T_5	T_7	T_{13}	T_{11}
T_9	T_8	T_1	T_{13}	T_3	T_8
T_7	T_{10}	T_{11}	T_{10}	T_7	T_2

R I **R II** **RIII**

FIG. 2. LAY OUT PLAN OF THE EXPERIMENT

Plate 1. Experimental field after preparation of land

Plate 2. Experimental field after transplanting of seedlings

Plate 3a. General view of the experimental field 1

Plate 3b. General view of the experimental field 2

Plate 4. Vegetative stage of the crop

Plate 5. Flowering stage of the crop

Plate 6. No fertilizer and manure plot (Control 1)

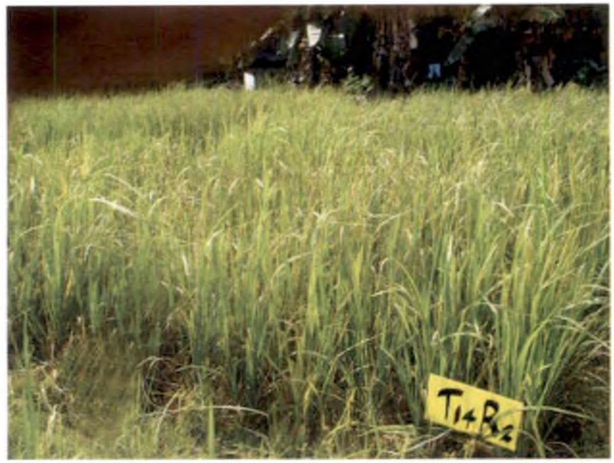

Plate 7. Package of Practice Recommendation plot (Control 2)

Plate 8. $N_2S_2Z_2$ (50 % N as organic + 50 % N as inorganic + S @ 20 kg ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1})

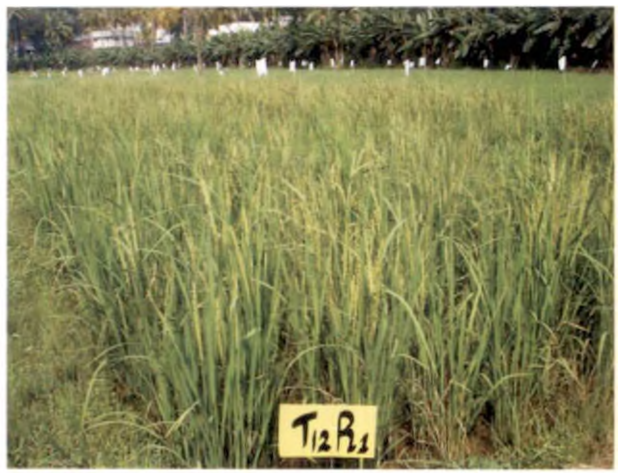

Plate 9. $N_2S_3Z_2$ (50 % N as organic + 50 % N as inorganic + S @ 30 kg ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1})

(iii) Factor 3

Levels of $ZnSO_4$ (Z)

Z_1 : 10 kg $ZnSO_4$ ha^{-1}

Z_2 : 20 kg $ZnSO_4$ ha^{-1}

(iv) Absolute control

a. No fertilizer and manure plot

b. POP recommendation (90: 45: 45 kg NPK ha^{-1} + 5 t ha^{-1} organic manure)

Treatment Combinations

T_1: $N_1S_1Z_1$ (100 per cent N inorganic + 10 kg S ha^{-1} + 10 kg $ZnSO_4$ ha^{-1})

T_2: $N_1S_1Z_2$ (100 per cent N inorganic + 10 kg S ha^{-1} + 20 kg $ZnSO_4$ ha^{-1})

T_3: $N_1S_2Z_1$ (100 per cent N inorganic + 20 kg S ha^{-1} + 10 kg $ZnSO_4$ ha^{-1})

T_4: $N_1S_2Z_2$ (100 per cent N inorganic + 20 kg S ha^{-1} + 20 kg $ZnSO_4$ ha^{-1})

T_5: $N_1S_3Z_1$ (100 per cent N inorganic + 30 kg S ha^{-1} + 10 kg $ZnSO_4$ ha^{-1})

T_6: $N_1S_3Z_2$ (100 per cent N inorganic + 30 kg S ha^{-1} + 20 kg $ZnSO_4$ ha^{-1})

T_7: $N_2S_1Z_1$ (50 per cent N inorganic + 50 per cent N organic +10 kg S ha^{-1} + 10 kg $ZnSO_4$ ha^{-1})

T_8: $N_2S_1Z_2$ (50 per cent N inorganic + 50 per cent N organic + 10 kg S ha^{-1} + 20 kg $ZnSO_4$ ha^{-1})

T_9: $N_2S_2Z_1$ (50 per cent N inorganic + 50 per cent N organic + 20 kg S ha^{-1} + 10 kg $ZnSO_4$ ha^{-1})

T_{10}: $N_2S_2Z_2$ (50 per cent N inorganic + 50 per cent N organic + 20 kg S ha^{-1} + 20 kg $ZnSO_4$ ha^{-1})

T_{11}: $N_2S_3Z_1$ (50 per cent N inorganic + 50 per cent N organic + 30 kg S ha^{-1} + 10 kg $ZnSO_4$ ha^{-1})

T_{12}: $N_2S_3Z_2$ (50 per cent N inorganic + 50 per cent N organic + 30 kg S ha^{-1} + 20 kg $ZnSO_4$ ha^{-1})

T_{13}: No fertilizer and manure plot

T_{14}: POP recommendation (90: 45: 45 kg NPK ha^{-1} + 5 t ha^{-1} organic manure)

FYM @ 5 t ha^{-1} was applied uniformly to all treatments.

3.3 CROP HUSBANDRY

3.3.1 Nursery

3.3.1.1 Land Preparation

The experimental area for nursery was ploughed, puddled and levelled after removing the weeds and stubbles.

3.3.1.2 Seeds and Sowing

Pre-germinated seeds @ 65 kg ha^{-1} were broadcast on the nursery area during the first week of October 2005. After 25 days, healthy seedlings were pulled out from the nursery and transplanted in the main field.

3.3.2 Main Field

3.3.2.1 Land Preparation

The experimental area was ploughed, puddled and levelled. Individual plots of size 4 x 3 m^2 were laid out and were perfectly levelled before transplanting.

3.3.2.2 Transplanting

Transplanting was done with a thin film of water in the field. Seedlings were transplanted at a spacing of 20 x 10 cm using two seedlings $hill^{-1}$.

3.3.2.3 Application of Manures and Fertilizers

Farmyard manure @ 5 t ha^{-1} was applied to all the plots and mixed well with topsoil. Full dose of P, S, $ZnSO_4$ and half dose of N and K were applied as basal and the remaining half dose of N and K was applied as top dressing at panicle initiation stage.

3.3.2.4 Maintenance of the Crop

The water level was maintained at about 1.5 cm during transplanting. Thereafter it was increased gradually to about five cm until maximum tillering stage. Thinning and gap filling were done five days after transplanting (DAT) to maintain uniform plant population. Two hand weedings were given at 20 and 45 DAT. The water was drained two weeks before harvest.

3.3.2.5 Plant Sampling

Ten hills were selected randomly from the net plot area to record biometric observations. Two rows from all sides were left as border rows.

3.3.2.6 Harvest

The crop was harvested at full maturity. The border and sampling rows were harvested separately. Net plot area of plots was harvested, threshed, winnowed and weight of grain and straw were recorded separately from individual plots.

3.4 OBSERVATIONS

3.4.1 Observations on Growth Characters

3.4.1.1 Height of the Plant

The mean value of the height of ten randomly selected plants from the net plot area was computed at 20, 40 DAT and at harvest and expressed in cm. The height of the plant was measured from the base to the tip of the top most leaf. At harvest, the height was recorded from the base of the plant to the tip of the longest panicle.

3.4.1.2 Tiller Number Hill^{-1}

Tiller number was counted at 20, 40 DAT and at harvest from sample hills, the mean values were worked out and recorded.

3.4.1.3 Leaf Area Index

Leaf area at 20, 40 DAT and at harvest was calculated using the length width method suggested by Gomez (1972).

$$\text{Leaf area} = k \times l \times w$$

where k is an adjustment factor, l is the length and w is the maximum width.

LAI was worked out using the formula,

$$\text{LAI} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Land area (cm}^2\text{)}}$$

3.4.1.4 Dry Matter Production

The sample plants were uprooted, washed, air-dried and oven dried at 70°C for 72 hours to constant weight. Dry matter production was computed for each treatment and expressed in kg ha^{-1}.

3.4.2 Observations on Yield Attributes and Yield

3.4.2.1 Number of Productive Tillers Hill^{-1} (Number of Panicles Hill^{-1})

Number of productive tillers in ten sample hills was counted and the mean number was worked out at harvest.

3.4.2.2 Length of Panicle

Ten panicles were collected from each plot and panicle length was measured from the neck to the tip and the average was expressed in cm.

3.4.2.3 Weight of Panicle

Ten panicles were separately weighed from each plot; the mean weight was worked out and expressed in grams.

3.4.2.4 Number of Spikelets Panicle^{-1} (Number of Grains Panicle^{-1})

The spikelets were removed from each panicle, counted and the mean number of spikelets panicle^{-1} was recorded.

3.4.2.5 Number of Filled Grains Panicle^{-1}

The filled grains were separated from each panicle, counted and the mean number was recorded.

3.4.2.6 Thousand Grain Weight (Test Weight)

Randomly selected thousand grains were counted from the cleaned and dried produce from net plot area of each treatment and the weight was expressed in grams.

3.4.2.7 Sterility Percentage

Number of spikelets and unfilled grains per panicle was counted and expressed as sterility percentage using the following formula:

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total grains per panicle}} \times 100$$

3.4.2.8 Grain Yield

The grains harvested from each net plot were dried to 14 per cent moisture content and expressed in kg ha^{-1}.

3.4.2.9 Straw Yield

The straw harvested from each net plot was dried to a constant weight under sun and the weight was expressed in kg ha^{-1}.

3.4.2.10 Harvest Index

Harvest index was calculated using the formula;

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.3 Physiological and Chemical Estimation

3.4.3.1 Chlorophyll Content of Leaves

The total chlorophyll content was estimated from the fully expanded second leaf from the top at panicle emergence stage by the method suggested by Arnon (1949) and expressed in mg g^{-1} fresh weight of leaves.

3.4.3.2 Plant Analysis

Sample plants collected from each plot at harvest were first sun dried, and then oven dried to a constant weight and the samples were ground, digested and used for analysis of nutrient content. The N content (Modified microkjeldahl method), P content (Vanado-molybdo-phosphoric yellow colour method), K content (Flame photometer method), S content (Turbidimetric method) and Zn content (Diacid digestion method) were estimated for plant samples from each plot separately (Jackson, 1973; Chesnin and Yien, 1950). Plant nutrient uptake was calculated by multiplying the nutrient content of plant samples with the DMP of that treatment at harvest stage and expressed in kg ha^{-1}.

3.4.3.3 Soil Analysis

Soil samples collected before and after the experiments were dried in shade, sieved through 2 mm sieve and analysed to determine the available N, available P_2O_5, available K_2O, available S and available Zn.

3.4.4 Economic Analysis

Economic analysis was done after taking into account the cost of cultivation and prevailing market price of rice grain and straw.

3.4.4.1. Benefit: Cost Ratio (BCR)

Benefit: cost ratio was worked out using the formula.

$$BCR = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

3.4.5 Pest and Disease incidence

Scoring of Major Pests like Rice Bug, Stem Borer and Leaf Roller and Diseases like Sheath Blight, Blast and Bacterial Leaf Blight was done and graded according to 0 to 9 scales.

3.4.6 Statistical Analysis

The data generated for the characters studied under different treatments were subjected to analysis of variance (Panse and Sukhatme, 1985). Whenever the results were significant, the critical difference was worked out at five or one per cent probability.

RESULTS

4. RESULTS

A field experiment on medium duration rice variety Aiswarya was conducted at the Cropping Systems Research Centre, Karamana, Thiruvananthapuram, of the Kerala Agricultural University during rabi season of the year 2005-06. The investigation was undertaken to study the response of sulphur and zinc and their interaction in integrated nutrition in wetland rice ecosystem. The experimental data collected were statistically analyzed and the results obtained are presented below

4.1 GROWTH CHARACTERS

Observations on growth characters like plant height, tiller number $hill^{-1}$, leaf area index and dry matter production were recorded from ten randomly selected plants or hills in the net plot area.

4.1.1 Height of Plant

Mean values of plant height at different growth stages, influenced by different treatments are presented in Table 4.1

The different levels of N, S and Zn recorded at 20 and 40 DAT had no significant effect on plant height though there was an increasing trend with highest level of these nutrients producing better results.

The plant height recorded at harvest stage was significantly influenced by N and S only. The highest plant height of 107.58 cm and 108.74 cm were recorded by N_2 and S_3 respectively. $ZnSO_4$ levels did not produce any significant effect on height at harvest stage.

There was no significant effect due to interaction between N and S, N and Zn, S and Zn, N, S and Zn in all growth stages (Table 4.5 and 4.6).

Treatment combinations produced significantly better results compared to controls.

TABLE 4.1. Effect of N, S and Zn on plant height

Treatment	Plant height (cm)		
	20 DAT	40 DAT	Harvest
Nitrogen			
N_1	48.58	71.71	105.94
N_2	49.95	72.88	107.58
SE_m	0.540	0.592	0.539
CD	ns	ns	1.568*
Sulphur			
S_1	48.56	71.42	104.41
S_2	49.49	72.64	107.12
S_3	49.75	72.82	108.74
SE_m	0.662	0.727	0.660
CD	ns	ns	1.920**
Zinc			
Z_1	48.76	72.08	106.66
Z_2	49.77	72.51	106.86
SE_m	0.540	0.594	0.539
CD	ns	ns	ns

ns - non- significant
* - significant at 5 per cent level
** - significant at 1 per cent level

4.1.2 Tiller Number hill^{-1}

The tiller number hill^{-1} as influenced by main effects of treatments during different stages of growth is presented in Table 4.2.

From the table it has been found out that the treatments produced significant effect on tiller number in all stages of growth stages except nitrogen nutrition, which could not effect significant influence on tiller number at 20 and 40 DAT. During harvest stage N applied as 50 per cent of recommended dose as organic and 50 per cent as inorganic is significantly superior than N applied as 100 per cent inorganic. S_3 (30kg ha^{-1}) recorded highest tiller number, which was on par with S_2 level (20kg ha^{-1}) at all growth stages. Between $ZnSO_4$ levels, Z_2 (20kg ha^{-1}) could produce significantly higher tiller number than Z_1 (10kg ha^{-1}).

The interaction effects in all growth stages have no significant effect on tiller number except interaction due to N and S at 20 DAT (Tables 4.5 and 4.6). An increasing trend was noticed upto N_2S_2 that produced maximum number of tiller hill^{-1} at 20 DAT.

Compared to control, treatment combinations produced significantly better results.

4.1.3 Leaf Area Index

The LAI of rice affected by main effects of different treatments are presented in Table 4.3.

At 20 DAT, there was no significant influence on LAI by main effects of treatments. In the other stages, the individual effects of treatments could produce a significant impact on LAI except by $ZnSO_4$ at 20 and 40 DAT. With regard to N nutrition recommended N applied 50 per cent as organic and 50 per cent as inorganic (N_2) recorded a significant effect on LAI than the 100 per cent N as inorganic fertilizer (N_1) in 40 DAT and at harvest stage. Among the sulphur levels, S_3 (30 kg ha^{-1}) was found to be significantly superior to S_1 (20 kg ha^{-1}) and was on

TABLE 4.2. Effect of N, S and Zn on tiller number $hill^{-1}$

Treatment	Tiller number $hill^{-1}$		
	20 DAT	40 DAT	Harvest
Nitrogen			
N_1	9.08	11.62	13.48
N_2	9.47	12.11	14.38
SE_m	0.179	0.238	0.239
CD	ns	ns	0.694*
Sulphur			
S_1	8.70	11.40	13.02
S_2	9.54	12.20	14.18
S_3	9.49	12.74	14.60
SE_m	0.220	0.292	0.292
CD	0.639*	0.849*	0.850**
Zinc			
Z_1	8.84	11.71	13.37
Z_2	9.64	12.52	14.69
SE_m	0.179	0.238	0.239
CD	0.521**	0.693*	0.694**

* - significant at 5 per cent level

** - significant at 1 per cent level

TABLE 4.3 Effect of N, S and Zn on leaf area index

Treatment	Leaf area index		
	20 DAT	40 DAT	Harvest
Nitrogen			
N_1	2.10	4.41	5.67
N_2	2.18	4.60	6.14
SE_m	0.087	0.067	0.136
CD	ns	0.195*	0.401*
Sulphur			
S_1	2.11	4.20	5.64
S_2	2.19	4.60	5.98
S_3	2.12	4.72	6.55
SE_m	0.310	0.082	0.169
CD	ns	0.239**	0.491**
Zinc			
Z_1	2.12	4.41	5.76
Z_2	2.16	4.59	6.35
SE_m	0.087	0.067	0.138
CD	ns	ns	0.401**

* - significant at 5 per cent level

** - significant at 1 per cent level

TABLE 4.4 Effect of N, S and Zn on dry matter production

Treatment	Dry matter production (kg ha^{-1})
Nitrogen	
N_1	9644.44
N_2	10175.00
SE_m	148.470
CD	431.695*
Sulphur	
S_1	9387.50
S_2	10062.50
S_3	10279.17
SE_m	181.838
CD	528.716**
Zinc	
Z_1	9777.78
Z_2	10041.67
SE_m	148.470
CD	ns

ns - non- significant
* - significant at 5 per cent level
** - significant at 1 per cent level

par with S_2 at 40 DAT and at harvest stage. $ZnSO_4$ applied @ 20 kg ha^{-1} was found to be significantly superior in recording LAI than 10 kg ha^{-1} at harvest stage.

Only the interaction due to N and S at 20 DAT had a significant impact on LAI, N_2S_2 recording the highest LAI at 20 DAT and was on par with N_2S_1 and N_1S_3 (Tables 4.5 and 4.6).

Significant positive effect was noticed with respect to treatments than controls.

4.1.4 Dry Matter Production

Results revealed that N and S exerted a significant influence on dry matter production (Table 4.4). But with respect to levels of $ZnSO_4$ the effect was not significant. Among the S levels, S_3 *i.e.* 30 kg ha^{-1} resulted in maximum dry matter production which was on par with S_2 (20 kg ha^{-1}). Substitution of 50 per cent N as organic and 50 per cent N as inorganic was significantly superior to treatment which received N dose as 100 per cent as inorganic (N_2).

All the interaction effects due to different treatments as given in Tables 4.5 and 4.6 were not significantly different with respect to this parameter.

All treatment combinations performed significantly better over control (Table 4.6).

4.2 YIELD ATTRIBUTES AND YIELD

4.2.1 Number of Panicles $hill^{-1}$

Number of panicles per hill as influenced by main effects of N, S and $ZnSO_4$ is given in Table 4.7.

On statistical scrutiny of data, significant difference was noticed by the nitrogen nutrition. N_2 *i.e.* 50 per cent N applied as inorganic and 50 per cent N applied as organic recorded significantly higher panicle

TABLE 4.5 Interaction effect of N, S and Zn on growth characters

Treatment	Plant height (cm)			Tiller number hill^{-1}			Leaf area index			Dry matter production (kg ha^{-1})
	20 DAT	40 DAT	Harvest	20 DAT	40 DAT	Harvest	20 DAT	40 DAT	Harvest	
N_1S_1	48.16	70.57	103.44	8.03	11.12	12.42	1.99	4.08	5.23	9108.33
N_1S_2	48.67	71.24	105.37	9.25	11.57	13.52	1.97	4.41	5.61	9650.00
N_1S_3	48.93	73.33	109.00	9.77	12.48	14.50	2.34	4.74	6.49	10175.00
N_2S_1	48.97	72.27	105.38	9.37	11.68	13.62	2.22	4.32	6.05	9666.67
N_2S_2	50.31	74.05	108.88	9.83	12.83	14.83	2.42	4.79	6.35	10475.00
N_2S_3	50.57	72.32	108.48	9.22	13.00	14.70	1.91	4.70	6.61	10383.33
SE_m	0.936	1.028	0.903	0.311	0.413	0.413	0.151	0.116	0.239	257.158
CD	ns	ns	ns	0.903**	ns	ns	0.436**	ns	ns	ns
N_1Z_1	48.71	71.73	105.51	8.59	11.23	13.02	2.18	4.31	5.52	9511.11
N_1Z_2	48.46	71.70	106.37	9.44	12.21	13.93	2.02	4.50	6.02	9777.78
N_2Z_1	48.82	72.43	107.81	9.10	12.18	13.71	2.07	4.52	6.00	10044.44
N_2Z_2	51.08	73.33	107.36	9.84	12.83	15.06	2.29	4.69	6.67	10305.56
SE_m	0.764	0.839	0.738	0.254	0.337	0.338	0.123	0.094	0.195	209.968
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S_1Z_1	48.27	71.39	104.80	8.17	11.10	12.38	2.15	4.16	5.30	9283.33
S_1Z_2	48.86	71.45	104.03	9.23	11.70	13.65	2.07	4.24	5.98	9491.67
S_2Z_1	48.25	72.52	106.74	9.32	11.65	13.45	2.21	4.47	5.55	9858.33
S_2Z_2	50.73	72.77	107.51	9.77	12.75	14.90	2.18	4.72	6.41	10266.67
S_3Z_1	49.77	72.33	108.44	9.05	12.37	14.27	2.02	4.61	6.45	10191.67
S_3Z_2	49.73	73.32	109.05	9.93	13.12	14.93	2.23	4.83	6.65	10366.67
SE_m	0.936	1.028	0.903	0.311	0.413	0.413	0.151	0.116	0.239	257.158
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns – non-significant ** - significant at 1 per cent level

TABLE 4.6 Effect of treatment combinations on growth characters

Treatment	Plant height (cm)			Tiller number $hill^{-1}$			Leaf area index			Dry matter production (kg ha^{-1})
	20 DAT	40DAT	Harvest	20 DAT	40DAT	Harvest	20 DAT	40DAT	Harvest	
$N_1S_1Z_1$	48.99	70.55	103.28	7.37	10.80	12.07	2.13	4.06	5.07	9033.33
$N_1S_1Z_2$	47.32	70.59	103.60	8.70	11.43	12.77	1.86	4.10	5.38	9183.33
$N_1S_2Z_1$	47.28	71.67	104.96	9.10	10.97	12.97	2.09	4.25	5.12	9433.33
$N_1S_2Z_2$	50.06	70.80	105.77	9.40	12.17	14.27	1.84	4.56	6.09	9866.68
$N_1S_3Z_1$	49.85	72.97	108.27	9.30	11.93	14.23	2.33	4.62	6.38	10066.67
$N_1S_3Z_2$	48.01	73.69	109.73	10.23	13.03	14.77	2.35	4.85	6.59	10283.33
$N_2S_1Z_1$	47.55	72.23	106.31	8.97	11.40	12.70	2.16	4.26	5.53	9533.33
$N_2S_1Z_2$	50.39	72.31	104.45	9.77	11.97	14.53	2.27	4.38	6.57	9800.00
$N_2S_2Z_1$	49.22	73.37	108.51	9.53	12.33	14.13	2.33	4.70	5.97	10283.33
$N_2S_2Z_2$	51.40	74.72	109.25	10.13	13.33	15.53	2.51	4.87	6.73	10666.67
$N_2S_3Z_1$	49.69	71.70	108.60	8.80	12.80	14.30	1.71	4.60	6.51	10316.67
$N_2S_3Z_2$	51.45	72.94	108.34	9.63	13.20	15.10	2.11	4.81	6.70	10450.00
SE_m	1.323	1.454	1.278	0.439	0.584	0.585	0.213	0.164	0.338	363.676
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control 1	42.36	65.28	99.80	6.97	10.23	11.53	1.27	3.13	3.91	7750.00
Control 2	45.66	69.11	103.29	7.93	10.70	12.53	1.80	3.85	5.16	8483.33
Control mean	44.01	67.20	101.55	7.45	10.47	12.03	1.54	3.49**	4.54*	8116.67
Treatment mean (Including controls)	48.52**	71.64**	106.01**	8.98**	11.88**	13.66**	2.05*	4.36**	5.84**	9653.57**

ns – non-significant *- significant at 5 per cent level ** - significant at 1 per cent level

number hill^{-1} than N_1 (100 per cent N applied as inorganic form). An increasing trend was noticed with S levels and the maximum number of panicles hill^{-1} was recorded with highest level of S (S_3) and was significantly superior to S_2 and S_1. $ZnSO_4$ applied @ 20 kg ha^{-1} could record significantly higher panicle number hill^{-1} than the lower level (10 kg ha^{-1}).

None of the interactions showed any significant effect (Tables 4.17 and 4.18) with respect to number of panicles hill^{-1}.

All treatment combinations turned out to be significantly superior compared to control.

4.2.2 Length of Panicle

Data with respect to main effects are presented in Table 4.8 and data due to the interaction effects are presented in Tables 4.17 and 4.18.

On the scrutiny of data it was found that the main effects and interaction effects of N, S and Zn did not exert any significant influence on the length of panicle. Even though the effect was not significant, substitution of 50 per cent of inorganic N with organic N (N_3) had produced higher panicle length over 100 per cent N (N_1).

All treatments showed significantly better effect over control.

4.2.3 Weight of Panicle

The data related to the main effects of nitrogen, sulphur and zinc are presented in Table 4.9.

Only the sulphur and zinc application exhibited significant effect on this character. Highest panicle weight (2.42g) was recorded by S_3 (30 kg ha^{-1}), which was significantly superior to S_1 and was on par with S_2. Similarly application of 20 kg ha^{-1} of $ZnSO_4$ also increased the weight of panicle significantly than 10 kg ha^{-1}.

TABLE 4.7 Effect of N, S and Zn on number of panicles $hill^{-1}$

Treatment	Number of panicles $hill^{-1}$
Nitrogen	
N_1	10.69
N_2	11.87
SE_m	0.278
CD	0.808 *
Sulphur	
S_1	10.28
S_2	11.50
S_3	12.37
SE_m	0.340
CD	0.989**
Zinc	
Z_1	10.93
Z_2	11.84
SE_m	0.278
CD	0.808 *

* - significant at 5 per cent level
** - significant at 1 per cent level

TABLE 4.8 Effect of N, S and Zn on length of panicle

Treatment	Length of panicle (cm)
Nitrogen	
N_1	20.67
N_2	20.90
SE_m	0.159
CD	ns
Sulphur	
S_1	20.83
S_2	20.73
S_3	20.77
SE_m	0.194
CD	ns
Zinc	
Z_1	20.80
Z_2	20.77
SE_m	0.159
CD	ns

ns - non- significant

TABLE 4.9 Effect of N, S and Zn on weight of panicle

Treatment	Weight of panicle (g)
Nitrogen	
N_1	2.24
N_2	2.36
SE_m	0.042
CD	ns
Sulphur	
S_1	2.18
S_2	2.30
S_3	2.42
SE_m	0.051
CD	0.148 **
Zinc	
Z_1	2.22
Z_2	2.38
SE_m	0.042
CD	0.121*

ns - non- significant
* - significant at 5 per cent level
** - significant at 1 per cent level

The interaction effect of nitrogen and sulphur, nitrogen and zinc, sulphur and zinc (Table 4.17) and interaction effect of nitrogen, sulphur and zinc (Table 4.18) revealed that they were not able to make any significant influence on panicle weight.

Treatment combinations produced significantly superior results compared to controls.

4.2.4 Number of Grains Panicle^{-1}

Number of grains panicle^{-1} as influenced by main effects of nitrogen, sulphur and zinc sulphate are presented in Table 4.10.

The data show that main effects of N, S and Zn had no significant effect on the number of grains panicle^{-1}. But an increasing trend was noticed with higher levels of sulphur application and maximum number of grains panicle^{-1} was recorded with S_3 (30 kg ha^{-1}). Similarly N_2 recorded higher number of grains panicle^{-1} over N_1.

The interaction effect given in Tables 4.17 and 4.18 were not statistically significant.

Treatment group showed significantly superior effect on grains panicle^{-1} compared to control group.

4.2.5 Number of Filled Grains Panicle^{-1}

The mean of number of filled grains panicle^{-1} as influenced by treatments are presented in Table 4.11.

Number of filled grains panicle^{-1} was not influenced by different forms of N though N_2 showed a better trend. The effect of sulphur levels on the number of filled grains panicle^{-1} recorded by S_3 (30 kg ha^{-1}), was significantly superior to S_2 and S_1. Application of $ZnSO_4$ also had a significant influence on this character with Z_2 (20 kg $ZnSO_4$ ha^{-1}) producing maximum number of filled grains panicle^{-1} compared to Z_2 (10 kg $ZnSO_4$ ha^{-1}).

TABLE 4.10 Effect of N, S and Zn on number of grains $panicle^{-1}$

Treatment	Number of grains $panicle^{-1}$
Nitrogen	
N_1	106.44
N_2	108.69
SE_m	2.003
CD	ns
Sulphur	
S_1	104.83
S_2	107.80
S_3	110.08
SE_m	2.453
CD	ns
Zinc	
Z_1	107.58
Z_2	107.56
SE_m	2.003
CD	ns

ns - non- significant

TABLE 4.11 Effect of N, S and Zn on number of filled grains panicle^{-1}

Treatment	Number of filled grains panicle^{-1}
Nitrogen	
N_1	88.42
N_2	90.23
SE_m	1.280
CD	ns
Sulphur	
S_1	83.78
S_2	89.18
S_3	93.50
SE_m	1.567
CD	4.557 **
Zinc	
Z_1	86.46
Z_2	91.17
SE_m	1.280
CD	3.721 *

ns - non- significant
* - significant at 5 per cent level
** - significant at 1 per cent level

TABLE 4.12 Effect of N, S and Zn on sterility percentage

Treatment	Sterility percentage
Nitrogen	
N_1	18.30
N_2	18.01
SE_m	1.466
CD	ns
Sulphur	
S_1	19.79
S_2	18.01
S_3	16.67
SE_m	1.795
CD	ns
Zinc	
Z_1	19.61
Z_2	16.70
SE_m	1.466
CD	ns

ns -non- significant

Table 4.17 and 4.18 revealed that interaction effects of treatments did not significantly influence this attribute.

However all treatments differed significantly with respect to control.

4.2.6 Sterility Percentage

As shown in the Table 4.12 main effects of N, S and Zn had not made any significant impact on this attribute.

Similarly none of the interactions were able to make any significant influence on sterility percentage (Tables 4.17 and 4.18).

4.2.7 Thousand Grain Weight

Data with respect to main effects of different levels of nitrogen, sulphur and zinc sulphate are presented in Table 4.13.

Only sulphur application had significantly influenced the thousand-grain weight. S_3 recorded the highest values thousand-grain weight and this was on par with S_2 level.

Interaction effect due to N X S, N X Zn, S X Zn and N X S X Zn as shown in the Tables 4.17 and 4.18 were insignificant.

Significant increase was observed in treatment group over control group.

4.2.8 Grain Yield

Mean grain yield as affected by main effects of treatments is given in Table 4.14.

On statistical scrutiny of data, significant difference was noticed by the two levels of nitrogen nutrition. Higher grain yield was recorded by N_2 *i.e.* 50 per cent N applied as inorganic and 50 per cent N applied as organic and it was significantly superior than N_1 (100 per cent N applied as inorganic form). Sulphur and $ZnSO_4$ application also made a

TABLE 4.13 Effect of N, S and Zn on thousand grain weight

Treatment	Thousand grain weight (g)
Nitrogen	
N_1	27.04
N_2	27.24
SE_m	0.374
CD	ns
Sulphur	
S_1	24.72
S_2	27.99
S_3	28.69
SE_m	0.458
CD	1.331**
Zinc	
Z_1	26.52
Z_2	27.35
SE_m	0.374
CD	ns

ns - non- significant
** - significant at 1 per cent level

TABLE 4.14 Effect of N, S and Zn on grain yield

Treatment	Grain yield (kg ha^{-1})
Nitrogen	
N_1	3136.81
N_2	3445.14
SE_m	76.300
CD	221.851**
Sulphur	
S_1	3042.71
S_2	3431.25
S_3	3398.96
SE_m	93.448
CD	271.711*
Zinc	
Z_1	3169.44
Z_2	3412.50
SE_m	76.300
CD	221.851*

* - significant at 5 per cent level
** - significant at 1 per cent level

TABLE 4.15 Effect of N, S and Zn on straw yield

Treatment	Straw yield (kg ha^{-1})
Nitrogen	
N_1	4831.25
N_2	5270.14
SE_m	95.640
CD	278.084**
Sulphur	
S_1	4691.67
S_2	5143.75
S_3	5316.67
SE_m	117.134
CD	340.582**
Zinc	
Z_1	4882.64
Z_2	5218.75
SE_m	95.640
CD	278.084*

* - significant at 5 per cent level

** - significant at 1 per cent level

TABLE 4.16 Effect of N, S and Zn on harvest index

Treatment	Harvest index
Nitrogen	
N_1	0.391
N_2	0.396
SE_m	0.007
CD	ns
Sulphur	
S_1	0.387
S_2	0.394
S_3	0.390
SE_m	0.008
CD	ns
Zinc	
Z_1	0.394
Z_2	0.397
SE_m	0.007
CD	ns

ns - non- significant

significant impact. S_2 level showed maximum grain yield production, which was significantly superior to S_1 and was on par with S_3. Similarly Z_2 showed significant increase in grain yield over Z_1.

Grain yield as influenced N X S, N X Zn and S X Zn interactions are given in Tables 4.17. Interaction due to N X S alone was found to be significant with respect to grain yield. N_2S_2 recorded highest grain yield, which was significantly superior to all other combinations.

Interaction due to N X S X Zn as presented in Table 4.18 was not significantly different with respect to grain yield.

All treatment combinations performed better than control.

4.2.9 Straw Yield

Data shown in Table 4.15 revealed that all the individual effects of N, S and Zn influenced the straw yield significantly.

N and S levels had made highly significant effect with an increasing trend observed in both these treatments. Among the different S levels, S_3 level recorded maximum straw yield which was on par with S_2 level. The higher straw yield recorded by S_2 was significantly higher than S_1. Higher level (Z_2) of $ZnSO_4$ application proved to be significantly superior over lower level (Z_1).

The interaction effect due to N X S, N X Zn, S X Zn and N X S X Zn was not significant (Tables 4.17 and 4.18).

Control treatments recorded significantly inferior straw yield than other treatment combinations.

4.2.9 Harvest Index

Data in Table 4.16 shows that different levels of nitrogen, sulphur and zinc sulphate did not make any significant impact on this character.

Similary none of the interactions showed any significant effect as given in Tables 4.17 and 4.18.

TABLE 4.17 Interaction effect of N, S and Zn on yield and yield attributes

Treatment	Number of panicles hill^{-1}	Length of panicle (cm)	Weight of panicle (g)	Number of grains panicle^{-1}	Number of filled grains panicle^{-1}	Sterility percentage	Thousand grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
N_1S_1	9.87	20.68	2.12	103.08	81.78	20.25	23.93	2800.00	4512.50	0.383
N_1S_2	10.72	20.42	2.29	106.10	87.35	19.33	28.09	3160.42	4889.58	0.392
N_1S_3	12.10	20.90	2.32	110.15	93.12	15.32	29.10	3450.00	5091.67	0.404
N_2S_1	10.70	20.99	2.25	106.57	85.78	19.32	25.55	3285.42	4870.83	0.403
N_2S_2	12.28	21.05	2.32	109.50	91.02	16.69	27.88	3702.08	5397.92	0.407
N_2S_3	12.63	20.67	2.52	110.02	93.88	18.02	28.28	3347.92	5541.67	0.376
SE_m	0.481	0.275	0.072	3.470	2.216	2.539	0.647	132.16	165.653	0.012
CD	ns	ns	ns	ns	ns	ns	ns	384.257**	ns	ns
N_1Z_1	10.54	20.59	2.15	106.28	83.81	20.69	26.72	2981.94	4643.06	0.391
N_1Z_2	11.24	20.74	2.34	106.61	91.02	15.91	27.36	3291.67	5019.45	0.395
N_2Z_1	11.31	20.99	2.30	108.89	89.10	18.54	26.32	3356.94	5122.22	0.396
N_2Z_2	12.43	20.80	2.42	108.50	91.36	17.48	28.15	3533.33	5418.06	0.394
SE_m	0.393	0.224	0.059	2.833	1.810	2.073	0.529	107.904	135.255	0.009
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S_1Z_1	9.80	20.84	2.08	103.98	82.22	20.51	24.90	3037.50	4575.00	0.398
S_1Z_2	10.77	20.82	2.29	105.67	85.35	19.06	24.58	3047.92	4808.33	0.387
S_2Z_1	10.85	20.85	2.22	108.90	85.43	21.12	26.59	3264.58	4897.92	0.399
S_2Z_2	12.15	20.62	2.38	106.70	92.93	14.90	29.38	3597.92	5389.58	0.400
S_3Z_1	12.13	20.70	2.37	109.87	91.72	17.21	28.08	3206.25	5175.00	0.384
S_3Z_2	12.60	20.87	2.47	110.30	95.28	16.13	29.31	3591.67	5458.33	0.397
SE_m	0.481	0.275	0.072	3.470	2.217	2.539	0.647	132.155	165.653	0.012
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns – non-significant ** - significant at 1 per cent level

TABLE 4.18 Effect of treatment combinations on yield and yield attributes

Treatment	Number of panicles hill^{-1}	Length of panicle (cm)	Weight of panicle (g)	Number of grains panicle^{-1}	Number of filled grains panicle^{-1}	Sterility Percentage	Thousand grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
$N_1S_1Z_1$	9.50	20.67	2.03	101.87	79.37	21.48	24.273	2754.17	4470.83	0.382
$N_1S_1Z_2$	10.23	20.69	2.20	104.30	84.20	19.03	23.583	2845.83	4554.17	0.384
$N_1S_2Z_1$	10.30	20.36	2.19	109.97	82.83	24.29	27.270	2954.17	4612.50	0.390
$N_1S_2Z_2$	11.13	20.48	2.39	102.23	91.87	14.37	28.910	3366.67	5166.67	0.394
$N_1S_3Z_1$	11.83	20.74	2.21	107.00	89.23	16.29	28.623	3237.50	4845.83	0.401
$N_1S_3Z_2$	12.37	21.06	2.43	113.30	97.00	14.35	29.580	3662.50	5337.50	0.407
$N_2 S_1Z_1$	10.10	21.00	2.18	106.10	85.07	19.55	25.523	3320.83	4679.17	0.415
$N_2 S_1Z_2$	11.30	20.97	2.38	107.03	86.50	19.10	25.573	3250.00	5062.50	0.391
$N_2 S_2Z_1$	11.40	21.33	2.25	107.83	88.03	17.95	25.910	3575.00	5183.33	0.408
$N_2 S_2Z_2$	13.17	20.76	2.38	111.17	94.00	15.43	29.850	3829.17	5612.50	0.405
$N_2 S_3Z_1$	12.43	20.66	2.53	112.73	94.20	18.12	27.537	3175.00	5504.17	0.366
$N_2 S_3Z_2$	12.83	20.68	2.51	107.30	93.57	17.91	29.030	3520.83	5579.17	0.387
SE_m	0.680	0.388	0.102	4.907	3.134	3.590	0.915	186.90	234.269	0.017
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control 1	23.74	1.72	19.08	87.97	72.63	17.47	9.20	2308.33	3708.33	0.385
Control 2	23.91	1.95	19.52	97.33	80.33	17.29	9.57	2641.67	4375.00	0.376
Control mean	23.82	1.83	19.30	92.65	76.48	17.38	9.38	2475.00	4041.67	0.380
Treatment mean (Including controls)	26.66**	2.23**	20.57*	105.44	93.35**	18.06	11.10**	3174.40**	4906.55**	0.392

ns – non-significant *- significant at 5 per cent level ** - significant at 1 per cent level

4.3 CHEMICAL ESTIMATION

4.3.1 Chlorophyll content

Total chlorophyll content of leaves at 40 DAT as affected by different treatments is given in Table 4.19.

The results revealed that S application had a significant effect on chlorophyll content. S_2 (30 kg ha^{-1}) level recorded maximum chlorophyll content. An increasing trend was noticed upto S_2, which was statistically on par with S_3. S_1 was significantly inferior to S_2 and S_3.Though an increasing trend was seen, N levels was not significant. The effect of $ZnSO_4$ on influencing this character was not significant.

Similarly interactions between treatments were not significant as shown in Tables 4.24 and 4.25.

But with respect to control treatments all other treatment combinations recorded significantly higher results.

4.3.2 Uptake of Nitrogen

Uptake of nitrogen as influenced by the main effects of different treatments is given in table 4.20.

With respect to individual effects, N, S and Zn influenced the uptake of N significantly. Here N_2 (50 per cent organic + 50 per cent inorganic) recorded highest N uptake compared to N_1 (100 per cent as inorganic N). In case of S, highest N uptake of 122.64 kg ha^{-1} was recorded by S_3 and it was significantly superior to S_2 and S_1. Increased application of $ZnSO_4$ @ 20 kg ha-1 also had a significant influence on N uptake when compared to lower dose, viz. 10 kg ha-1.

The interaction effect due to N X S, N X Zn and S X Zn presented in Table 4.24 revealed no significant influence with respect to N uptake. Similar trend was also noticed in the case of interaction due to combinations N X S X Zn (Table 4.25).

TABLE 4.19. Effect of N, S and Zn on chlorophyll content

Treatment	Chlorophyll content (mg g^{-1})
Nitrogen	
N_1	2.61
N_2	2.72
SE_m	0.050
CD	ns
Sulphur	
S_1	2.50
S_2	2.77
S_3	2.70
SE_m	0.061
CD	0.177**
Zinc	
Z_1	2.64
Z_2	2.69
SE_m	0.050
CD	ns

ns - non- significant

** - significant at 1 per cent level

TABLE 4.20. Effect of N, S and Zn on N, P and K uptake

Treatment	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
Nitrogen			
N_1	106.45	17.23	109.37
N_2	122.58	19.46	116.74
SE_m	2.277	0.538	2.060
CD	6.626**	1.564**	5.990*
Sulphur			
S_1	102.58	17.87	108.13
S_2	118.33	17.84	113.91
S_3	122.64	19.31	117.13
SE_m	2.791	0.659	2.523
CD	8.115**	ns	ns
Zinc			
Z_1	109.47	18.99	111.60
Z_2	119.58	17.70	114.51
SE_m	2.279	0.5380	2.060
CD	6.626 **	ns	ns

ns - non- significant
* - significant at 5 per cent level
** - significant at 1 per cent level

4.3.3 Uptake of Phosphorus

Data presented in table 4.20 revealed that only N had a significant influence on phosphorus uptake.

N applied as organic-inorganic integration (N_2) has effected a significantly higher uptake of P_2O_5 than recommended dose of N applied as inorganic fertilizer.

Data pertaining to interaction effects due to the treatments are presented in tables 4.24 and 4.25, which showed that results were not statistically significant in influencing P_2O_5 uptake.

4.3.4 Uptake of Potassium

Data presented in table 4.20 revealed that S and $ZnSO_4$ application could not produce any significant influence on uptake of K_2O.

Nitrogen nutrition in different forms could effect a marked influence on potassium uptake. When N was applied as inorganic fertilizer alone the uptake of K_2O was lower and the difference was significant than the uptake of K_2O when N was applied 50 per cent as organic and 50 per cent as inorganic.

Interactions among different nutrients tested were not significantly different with regard to K uptake as shown in tables 4.24 and 4.25.

4.3.5 Uptake of Sulphur

The uptake of S affected by application of different nutrients and their interactions are presented in Tables 4.21, 4.24 and 4.25.

The perusal of data given in table showed that main effects of the treatments contributed significantly to S uptake. N_1 (100 per cent as inorganic) was significantly inferior to N_2 (50 per cent as organic+50 per cent as inorganic). Highest S dose (30 kg ha^{-1}) was significantly superior

TABLE 4.21. Effect of N, S and Zn on S and Zn uptake

Treatment	S uptake (kg ha^{-1})	Zn uptake (g ha^{-1})
Nitrogen		
N_1	6.71	223
N_2	8.62	263
SE_m	0.374	6.670
CD	1.088**	19.320*
Sulphur		
S_1	5.33	208
S_2	8.30	252
S_3	9.38	270
SE_m	0.458	8.150
CD	1.333*	23.670**
Zinc		
Z_1	7.09	231
Z_2	8.25	255
SE_m	0.374	6.670
CD	1.088*	19.320*

* - significant at 5 per cent level

** - significant at 1 per cent level

to lower dose (10 kg ha^{-1}) but was on par with 20 kg ha^{-1} (S_2). Similarly the higher dose of $ZnSO_4$ @ 20 kg ha^{-1}significantly produced a higher uptake of S than lesser dose of 20 kg ha^{-1}.

Significant increase was observed in treatment group over control group.

4.3.6 Uptake of Zinc

Data pertaining to the uptake of zinc by the main effects of treatments is presented in table 4.21.

The statistical scrutiny of data revealed that the individual treatment effect had resulted in significant difference in the uptake of zinc. Higher uptake of zinc was recorded by N_2 (50:50 organic-inorganic integration), which was significantly different than N_1 (100 per cent inorganic fertilizer).

Although increase in levels of S has progressively increased the uptake of zinc; the highest uptake of zinc (270 g) recorded by highest S levels (30 kg ha^{-1}) was found to be statistically on par with S_2 but it was significantly superior than lower dose of S (10 kg ha^{-1}). Higher dose of $ZnSO_4$ application resulted in significantly higher uptake of zinc.

Data related to different interactions of treatments as presented in tables 4.24 and 4.25 shows that only the interaction between S and Zn had a significantly positive impact on uptake of zinc. S_3Z_2, which produced the maximum uptake of zinc, was found to be on par with S_3Z_1 and S_2Z_2 but the interaction among these treatment combinations was found to be significantly superior to remaining three S and Zn combination (S_2Z_1 S_1Z_2 and S_1Z_1)

4.3.7 Available Nitrogen

The mean data on soil nitrogen as affected by main effects of N, S and Zn status is presented in Table 4.22.

TABLE 4.22. Effect of N, S and Zn on available N, P_2O_5 and K_2O in the soil

Treatment	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
Nitrogen			
N_1	268.65	31.62	176.51
N_2	279.45	32.50	186.51
SE_m	3.234	1.458	2.670
CD	9.385*	ns	7.762*
Sulphur			
S_1	266.30	30.98	174.39
S_2	273.36	32.76	183.20
S_3	282.50	32.43	186.94
SE_m	3.961	1.7858	3.270
CD	11.494*	ns	9.507*
Zinc			
Z_1	272.48	32.51	179.278
Z_2	275.62	31.60	183.742
SE_m	3.234	1.458	2.670
CD	ns	ns	ns

ns - non- significant
* - significant at 5 per cent level

Significant difference was noticed with N_2 (50 per cent N applied as inorganic and 50 per cent N applied as organic) compared to N_1 (100 per cent N applied as inorganic form). The effect of S application was also significant with S_3 recording highest available N content of 282.50 kg ha^{-1}, which was on par with S_2.

. Only interaction due to N X S was found significant in influencing available N of soil with N_2S_3 registering highest N content (Table 4.24). The interaction effect due to N X S X Zn was also not significant (Table 4.25).

4.3.8 Available Phosphorus

Data with respect to main effects are presented in Table 4.22and data due to the interaction effects are presented in Tables 4.24 and 4.25.

On the scrutiny of data the main effects and interaction effects of N, S and Zn did not exert any significant influence on the available P content of soil.

4.3.9 Available Potassium

Availability of soil potassium as influenced by different treatment is presented in table 4.22.

Among the main effects N and S levels affected K_2O availability significantly. Higher available K_2O was recorded by N_2 *i.e.* 50 per cent N applied as inorganic and 50 per cent N applied as organic and it was significantly superior to N_1 *i.e.* 100 per cent N applied as inorganic form. S application increased K_2O availability in soil with S_3 level recording highest one (186.94 kg ha^{-1}) and this was on par with S_2 level.

The interaction effect due to N X S, N X Zn, S X Zn and N X S X Zn was not significant (Tables 4.24 and 4.25).

4.3.10 Available Sulphur

Data presented in Table 4.23 revealed that application of sulphur and zinc sulphate had a significant impact on available S status of soil.

Higher dose of S *i.e.* (30 kg ha^{-1}) recorded significantly higher available S content than lowest level of 10 kg ha^{-1} and S_3 was on par with S_2. Application of $ZnSO_4$ @ 20 kg ha^{-1} (Z_2) resulted in significantly higher S status over 10 kg $ZnSO_4$ ha^{-1} (Z_1).

Among interactions N X S and S X Zn turned out to be significant in influencing the available sulphur content as shown in Table 4.24. Here maximum S was recorded with S_3Z_2 level (5.8 kg ha^{-1}). The three-way interaction between N, S and Zn was insignificant (Table 4.25).

Significant variation was observed in treatment combinations including controls and the mean of treatments was significantly better than the two controls tested.

4.3.11 Available Zinc

The average soil zinc as affected by main effects of N, S and Zn status is presented in Table 4.23.

Between different nitrogen forms, no significant variation was observed in soil zinc status. Significant influence of sulphur and zinc sulphate application was noticed with an increasing trend towards higher levels. Among S levels, S_3 recorded highest Zn status of soil followed by S_2. Similarly highest level of $ZnSO_4$ application (Z_2) proved to be significantly superior over lower level (Z_1).

The interaction effect due to N X S, N X Zn, S X Zn and N X S X Zn as shown in Tables 4.24 and 4.25 were not statistically significant. But all treatment combinations including controls differed significantly.

TABLE 4.23. Effect of N, S and Zn on available S and Zn in the soil

Treatment	Available S (ppm)	Available Zn (ppm)
Nitrogen		
N_1	4.36	0.344
N_2	4.76	0.349
SE_m	0.184	0.006
CD	ns	ns
Sulphur		
S_1	4.06	0.324
S_2	4.76	0.349
S_3	4.87	0.367
SE_m	0.225	0.008
CD	0.655*	0.022**
Zinc		
Z_1	4.06	0.330
Z_2	5.07	0.364
SE_m	0.184	0.006
CD	0.535**	0.018**

ns - non- significant
* - significant at 5 per cent level
** - significant at 1 per cent level

TABLE 4.24 Interaction effect of N, S and Zn on chlorophyll content, plant nutrient uptake and available nutrients in soil

Treatment	Chlorophyll content (mg g^{-1})	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	Available S (ppm)	Available Zn (ppm)	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})	S uptake (kg ha^{-1})	Zn uptake (g ha^{-1})
N_1S_1	2.48	270.22	29.89	171.53	4.36	0.324	93.09	16.33	104.97	4.97	191
N_1S_2	2.75	264.47	32.77	175.28	4.47	0.341	109.66	17.44	108.31	6.74	225
N_1S_3	2.60	271.27	32.20	182.72	4.26	0.368	116.62	17.91	114.84	8.42	253
N_2S_1	2.52	262.38	32.06	177.26	3.77	0.325	112.07	19.42	111.28	5.68	225
N_2S_2	2.82	282.24	32.76	191.12	5.05	0.357	127.00	18.25	119.51	9.86	278
N_2S_3	2.80	293.74	32.67	191.17	5.48	0.366	128.67	20.70	119.43	10.33	287
SE_m	0.086	5.602	2.526	4.624	0.319	0.011	3.947	0.932	3.568	0.648	11.530
CD	ns	16.256*	ns	ns	0.926*	ns	ns	ns	ns	ns	ns
N_1Z_1	2.568	266.91	31.85	176.99	4.08	0.333	100.10	18.24	106.98	6.02	212
N_1Z_2	2.652	270.39	31.39	176.02	4.64	0.355	112.80	16.21	111.77	7.40	236
N_2Z_1	2.711	278.06	33.16	181.56	4.03	0.326	118.82	19.74	116.23	8.15	252
N_2Z_2	2.719	280.85	31.83	191.46	5.50	0.372	126.34	19.18	117.26	9.09	275
SE_m	0.070	4.574	2.062	3.775	0.260	0.009	3.223	0.761	2.913	0.529	9.420
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S_1Z_1	2.58	269.70	31.80	173.50	4.175	0.310	99.70	18.75	107.84	5.04	218
S_1Z_2	2.42	262.90	30.15	175.29	3.950	0.339	105.45	16.99	108.42	5.61	199
S_2Z_1	2.68	268.65	32.81	181.43	4.067	0.325	111.16	18.76	110.80	7.72	221
S_2Z_2	2.90	278.06	32.72	184.96	5.450	0.373	125.50	16.93	117.03	8.88	283
S_3Z_1	2.66	279.11	32.90	182.91	3.933	0.355	117.52	19.45	116.18	8.50	255
S_3Z_2	2.74	285.90	31.97	190.97	5.800	0.380	127.77	19.16	118.09	10.25	285
SE_m	0.086	5.602	2.526	4.624	0.319	0.011	3.947	0.932	3.568	0.648	11.530
CD	ns	ns	ns	ns	0.926**	ns	ns	ns	ns	ns	33.470**

ns – non-significant *- significant at 5 per cent level ** - significant at 1 per cent level

TABLE 4.25 Effect of treatment combinations on chlorophyll content, nutrient uptake and available nutrients in soil

Treatment	Chlorophyll content (mg g^{-1})	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	Available S (ppm)	Available Zn (ppm)	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})	S uptake (kg ha^{-1})	Zn uptake (g ha^{-1})
$N_1S_1Z_1$	2.54	274.92	31.12	173.66	4.57	0.311	90.79	17.59	104.87	5.19	202
$N_1S_1Z_2$	2.43	265.52	28.66	169.40	4.15	0.336	95.39	15.07	105.08	4.76	179
$N_1S_2Z_1$	2.64	262.38	33.99	176.44	4.20	0.323	99.78	19.91	103.62	5.82	192
$N_1S_2Z_2$	2.86	266.56	31.55	174.11	4.73	0.359	119.54	14.97	113.00	7.65	258
$N_1S_3Z_1$	2.53	263.43	30.45	180.89	3.48	0.366	109.74	17.21	112.45	7.04	237
$N_1S_3Z_2$	2.66	279.10	33.95	184.55	5.03	0.371	123.49	18.60	117.22	9.80	269
$N_2 S_1Z_1$	2.63	264.47	32.49	173.33	3.78	0.309	108.61	19.91	110.81	4.89	233
$N_2 S_1Z_2$	2.41	260.29	31.63	181.18	3.75	0.342	115.52	18.93	111.76	6.47	218
$N_2 S_2Z_1$	2.71	274.92	31.65	186.42	3.93	0.326	122.55	17.61	117.97	9.61	249
$N_2 S_2Z_2$	2.93	289.56	33.88	195.81	6.17	0.387	131.45	18.89	121.06	10.10	307
$N_2 S_3Z_1$	2.79	294.79	35.35	184.93	4.38	0.344	125.29	21.69	119.90	9.96	273
$N_2 S_3Z_2$	2.81	292.69	29.98	197.40	6.57	0.389	132.04	19.72	118.95	10.70	301
SE_m	0.122	7.922	3.572	6.539	0.450	0.015	5.582	1.318	5.046	0.917	16.310
CD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Control 1	2.06	249.83	26.27	137.09	3.35	0.265	74.29	11.87	83.51	3.14	158
Control 2	2.23	261.33	29.07	164.62	3.42	0.272	91.10	17.47	97.37	4.12	183
Control mean	2.14	255.58	27.67	150.86	3.38	0.269	82.69	14.67	90.44	3.63	170
Treatment mean (including controls)	2.59**	271.41*	31.43	190.34**	4.39**	0.336**	109.97*	17:82**	109.83**	7.09**	223**

ns – non-significant   *- significant at 5 per cent level   ** - significant at 1 per cent level

4.4 PEST AND DISEASE INCIDENCE

Leaf roller and earhead bug infestation was noticed and scoring of intensity of their attack was recorded and has been presented in table 4.26.

No statistical analysis was done with respect to this observation and the attack of leaf roller was high in treatments $N_2S_2Z_2$ and $N_2S_3Z_1$. Earhead bug attack was found to be high in treatments combination of $N_1S_2Z_2$, where full doe of N was applied as inorganic and was followed by $N_1S_3Z_1$ and $N_2S_3Z_1$.

4.5 ECONOMICS OF CULTIVATION

Data related to economics of cultivation as influenced by different treatments are presented in table 4.27.

The data was not statistically analysed and highest BC ratio of 1.34 was recorded by the treatment combination $N_1S_3Z_2$ *i.e.* S @ 30 kg ha^{-1} and $ZnSO_4$ @ 20 kg ha^{-1} along with full dose of N applied as inorganic source and it was followed by treatment combinations of $N_2S_2Z_2$ and $N_1S_2Z_2$.

The two control treatments were found to be inferior with respect to BC ratio and absolute control with zero level of all nutrients resulted in negative net returns with a BC ratio of 0.98. The control treatments in which Package of Practices recommendations were followed yielded lower BC ratio than the treatments.

Table 4.26. Scoring of pest and disease incidence

Treatment	Leaf roller	Earhead bug
T_1 ($N_1S_1Z_1$)	1	3
T_2 ($N_1S_1Z_2$)	3	1
T_3 ($N_1S_2Z_1$)	5	3
T_4 ($N_1S_2Z_2$)	1	7
T_5 ($N_1S_3Z_1$)	3	5
T_6 ($N_1S_3Z_2$)	5	3
T_7 ($N_2S_1Z_1$)	1	1
T_8 ($N_2S_1Z_2$)	3	3
T_9 ($N_2S_2Z_1$)	1	3
T_{10} ($N_2S_2Z_2$)	5	1
T_{11} ($N_2S_3Z_1$)	5	5
T_{12} ($N_2S_3Z_2$)	1	3
T_{13} (Control 1)	1	1
T_{14} (Control 2)	1	3

* Data not statistically analysed

Earhead bug

Scale	Percentage damage
0	no damage
1	1-10 % damage
3	11-20 % damage
5	21-30 % damage
7	31-50% damage
9	> 50 % damage

Leaf roller

Scale	Percentage damage
0	no damage
1	<1% damage
3	1-15% damage
5	16-30% damage
7	31-50% damage
9	> 51 % damage

Table 4.27 Economics of cultivation

Treatment	Total cost (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	Benefit: Cost (ratio)
T_1 ($N_1S_1Z_1$)	29244	30975	1731	1.06
T_2 ($N_1S_1Z_2$)	29435	31875	2440	1.08
T_3 ($N_1S_2Z_1$)	29411	32858	3447	1.12
T_4 ($N_1S_2Z_2$)	29601	37267	7666	1.26
T_5 ($N_1S_3Z_1$)	29578	35592	6014	1.20
T_6 ($N_1S_3Z_2$)	29768	39975	10207	1.34
T_7 ($N_2S_1Z_1$)	32634	35925	3291	1.12
T_8 ($N_2S_1Z_2$)	32725	36125	3400	1.10
T_9 ($N_2S_2Z_1$)	32701	38967	6266	1.19
T_{10} ($N_2S_2Z_2$)	32891	41858	8967	1.27
T_{11} ($N_2S_3Z_1$)	32868	36408	3540	1.11
T_{12} ($N_2S_3Z_2$)	33058	39325	6267	1.19
T_{13} (Control 1)	26539	25883	-656	0.98
T_{14} (Control 2)	28888	29884	996	1.03

* Data statistically not analysed

Cost of inputs

Seeds	- Rs. 10 kg^{-1}
Farmyard manure	- Rs. 300 kg^{-1}
N (Urea)	- Rs. 5 kg^{-1}
P_2O_5 (Rajphos)	- Rs. 4.50 kg^{-1}
K_2O (MOP)	- Rs. 7 kg^{-1}
$ZnSO_4$	- Rs. 22 kg^{-1}
SSP	- Rs. 5 kg^{-1}
PP chemicals	- Rs. 899 kg^{-1}

Wage rate - Rs. 195 per day

Price of grain - Rs. 8 kg^{-1}
Price of straw - Rs. 2 kg^{-1}

DISCUSSION

5. DISCUSSION

A field investigation was conducted at Cropping Systems Research Centre, Karamana, to study the response of sulphur and zinc application under integrated nutrient supply system on the growth and yield of rice. The results obtained are discussed below.

5.1. GROWTH CHARACTERS

The scrutiny of plant height recorded at different phases revealed that plant height was influenced only during the harvest stage and in that stage also nitrogen nutrition and sulphur level only could exert a marked change on the height. When nitrogen was applied in integrated way (organic and inorganic source), significant difference was noticed on the plant height than the nitrogen applied only as inorganic form. Nitrogen being a growth element, vegetative characters like plant height is influenced by nitrogen. The loss of nitrogen was comparatively less in the treatment where there was integration of organic and inorganic form that resulted in better availability and uptake leading to increased plant height. This was clearly evident from the perusal of data of nitrogen uptake by this treatment. This is also corroborated by Vasantharao *et al.* (2004) and Bhoite (2005).

There was progressive increase in height of plant due to increase in levels of sulphur with highest level (S_3- 30 kg S ha^{-1}) recording maximum plant height. The same trend was also reported by Nair (1995) and Sudha (1999). Increase in plant height due to zinc sulphate application was not found to be significant. The results of Ghatak *et al.* (2005) showed a significant increase by $ZnSO_4$ application in laterite soils could be mainly attributable to the graded levels of $ZnSO_4$ at 0, 10, 20, 30 and 40 kg ha^{-1} but non-significance in our experiment may be due to limited levels tried. The control treatments mainly zero levels of nutrients and Package of Practices (POP) recommendation levels produced were evidently inferior to the treatments with respect to plant height.

As in the case of plant height the tiller number was favourably influenced by integrated application of nitrogen (N_2) at harvest stage. The loss of nitrogen in the soil by various means may be the reason for poor tiller production when full dose of nitrogen was applied as inorganic fertilizer (N_1).

The effect of sulphur and zinc could produce significance in tiller number in all growth stages. Contribution of $ZnSO_4$ to higher tiller production was due to involvement of zinc in auxin metabolism, which led to higher hormonal activity at critical growth stages. Significant tiller number at 20 and 40 DAT coincides with active and maximum tillering stages and this implies the importance of zinc application for the availability of nutrients during these phases. These results were in conformity with findings of Chaphale and Badole (1999) and Kulandaivel et al. (2004). The increased tiller number with sulphur application was also reported by Nair (1995), Sudha (1999) and Chandel *et al.* (2003).

Significant effect by the interaction of nitrogen and sulphur on tiller production might be due to the fact that the supply of one nutrient in higher quantities favourably influences the absorption, distribution and function of another nutrient and the concentration of nutrients in plants had taken place as a result of variation in the level of supply of one of interacting nutrients (Cakmak and Marschner, 1987). The experimental soil being deficient in sulphur due to continuous application of non-sulphur containing fertilizers in an intensively rice-cropped area may be the reason for the response of sulphur and interaction effect between nitrogen and sulphur. N_2S_2 (nitrogen integration at 50:50 dose as organic-inorganic along with 20 kg S ha^{-1}) produced maximum tiller number $hill^{-1}$.

Tiller production was significantly less in control treatments and it showed that recommended fertilizer application without any sulphur and zinc was insufficient to effect better growth parameters.

As in the other growth parameters, leaf area index was significantly influenced by the main effects of treatments tested. The higher availability of nitrogen from the integrated application of nitrogenous fertilizers and reduced loss of nitrogen during the critical stages of crop improved the leaf area index and was evident from the data pertaining to uptake and availability of nitrogen. Integration of organics with inorganics resulted in more root penetration due to improvement in physical condition of soil allowing better utilization of plant nutrients and this was in close conformity to that of Singh et al (2000) who reported that combined application of organics and inorganics produced 75 per cent higher root biomass than NPK applied as fertilizers. Conducive soil conditions during the initial stages of rice crop might have resulted in increased plant height and subsequent formation of new leaves. Similar increase in LAI with nutrient substitution was also given by Sindhu (2002) and Vasantharao *et al.* (2004).

Higher LAI with higher levels of sulphur was reported by Nair (1995) and Sudha (1999). Farmyard manure application contributed directly to nutrient pool of soil, and increased availability of nutrients including zinc through chelation or mobilizing some of active soil zinc and this, along with addition of zinc sulphate might have increased the available zinc content resulting in better growth characters including LAI. Increasing zinc availability due to zinc sulphate application was also reported by Kulandaivel *et al.* (2004).

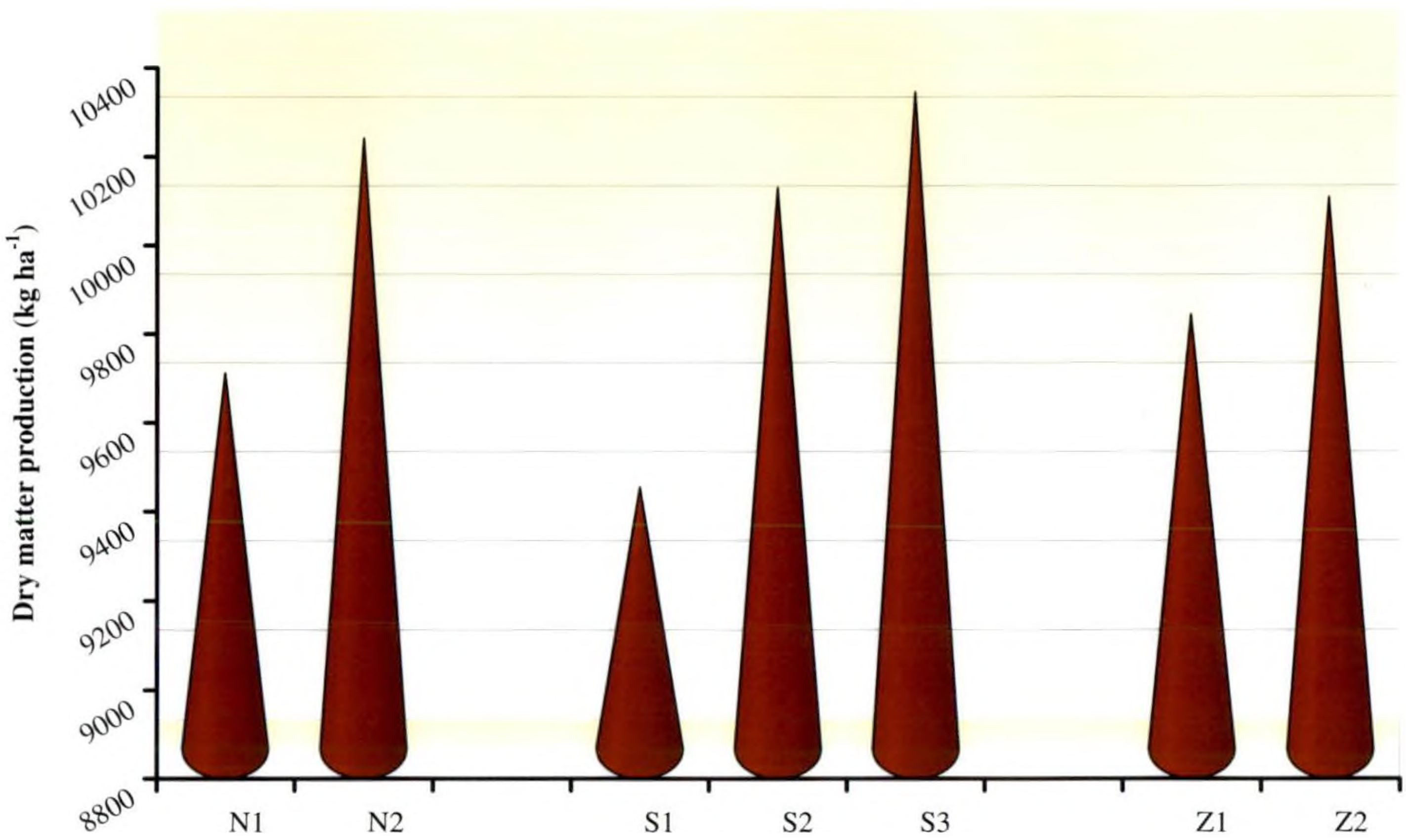

Fig. 3. Effect of N, S and Zn on DMP (kg ha^{-1})

With respect to interaction effect the same trend as that of tiller number was noticed *i.e.*; interaction between nitrogen and sulphur was found significant with N_2S_2 recording higher LAI than other treatments.

The performance of controls over treatments was significantly inferior with respect to leaf area index. Enhanced availability of nutrients in integrated condition along with supplementation of sulphur fertilizer and $ZnSO_4$ in a nutrient deficient soil might have contributed to higher leaf area index in treatment plots.

Significant trend noticed in growth characters was also seen in dry matter production since increase in DMP is the cumulative effect of improved growth characters. Favorable environment in rhizosphere created by optimum use of organic and inorganic source of nitrogen which in turn resulted in slow release of nitrogen during growth stages and this might have resulted in better availability and uptake of nitrogen. This along with optimum concentrations of sulphur and zinc in the soil solution facilitate better photosynthetic activity leading to higher dry matter production than the control treatments. Within the treatments the main effects of nitrogen and sulphur had remarkable effect on dry mater production. This was in conformity with findings of Dubey and Verma (1999), Sindhu (2002), Vasantharao *et al.* (2004), Banerjee *et al.* (2006) and Singh *et al* (2006).

Increase in sulphur levels also contributed to dry matter production with higher levels (S_3-30kg ha^{-1}) producing maximum dry matter production. Balanced nutrient supply would have contributed to increased availability and uptake of these nutrients, which added to overall vigour of plant resulting in rapid photosynthetic rate and consequently higher dry matter production. Increase in DMP with sulphur application was also reported by George (1989), Nair (1999), Sudha (1999), Chandel *et al.* (2003) and Mini (2005).

Though increased values were recorded by application of zinc sulphate the reason for absence of statistical significance may be due to the fact that only two levels are tested without zero and higher levels. However significant increase in dry matter production due to zinc sulphate application was reported by Mani *et al.* (2001) and Kulandaivel *et al.* (2004).

5.2 YIELD ATTRIBUTES

Among the yield parameters number of panicles hill^{-1} alone is significantly improved by nitrogen nutrition though all other yield parameters are showing an increasing trend. As in the case of growth characters organic nutrition played an appreciable role when compared to inorganic nutrition in the sense that when the recommended fertilizer was applied equally as organic and inorganic form (N_2), it significantly produced higher panicle number hill^{-1}. This may be attributed to favourable physical conditions of soil, and nutrient availability and increased nitrogen use efficiency in all growth phases as well as reproductive phase. This was clearly evident from better tiller production and dry matter production. Better yield parameters with organic – inorganic integration in rice have been established by Mishra *et al.* (2003), Parihar (2004), Vasantharao *et al.* (2004), Bhoite (2005) and Singh *et al.* (2006).

Significant difference was noticed by S application on yield parameters like thousand grain weight, weight of panicle, filled grains panicle^{-1} and number of panicles hill^{-1}. Remarkable increase on these parameters corresponds to the increased levels of sulphur and higher values were recorded with 30 kg S ha^{-1}. The reason for this increase might be due to increased availability of sulphur, a major nutrient required in more quantities and its role in crop physiology and nutrient balance which in turn resulted in better uptake of sulphur and other nutrients. This was in conformity with the findings of Nair (1995) and Sudha (1999).

Yield attributes like weight of panicle, filled grains panicle^{-1} and number of panicles hill^{-1} were favourably increased by higher applications of zinc sulphate (20 kg ha $^{-1}$) while zinc sulphate had no marked effect on thousand grain weight, length of panicle, total grains panicle^{-1}. Improvement in these parameters with zinc application may be ascribed to its involvement in metalloenzyme system regulatory function and in growth promoting auxin production. Similar results were obtained by Binod Kumar and Singh (1996), Chaphale and Badole (1999) and Kumar *et al.* (1999). Ghatak *et al.* (2005) and Naik and Das (2006) also reported improvement in yield parameters of rice with application of zinc.

The two control treatments were clearly inferior to all other treatment combinations. This proved the superiority of treatments over recommended fertilizer dose and non- application of fertilizers in nutrient deficient soils and we could infer that even the recommended package of practices (POP) were insufficient in exhibiting a better yield characters. The interactions among the treatments with respect to yield attributes were not found to be significantly different. Testing with further levels of nitrogen, sulphur and zinc would have resulted in significant interaction effects at higher levels.

5.3 YIELD

5.3.1 Grain yield

Statistical scrutiny of yield data revealed that the main effects of treatments had a profound influence on grain yield of rice. In this context it has to be mentioned that because of heavy incidence of ear head bug during later stages of crop had declined the yield of rice in almost all the treatments (Table 4.26).

Integrated application of nitrogen through organic-inorganic sources recorded significantly improved yield compared to inorganic source alone. Since this was reflected in yield attributing characters the grain yield increase due to improvement of yield attributes owing to slow and steady release of nitrogen throughout the crop period and it was evident from the data with respect to growth parameters also. Better physico –chemical conditions resulting in a favourable soil environment in the rhizosphere due to organic matter addition in N_2 (50 per cent N as organic form) increased the availability of macro and micronutrients. All of these contributed to better yield attributes, which finally resulted in increased yield. It was also evident from the perusal of data with respect to uptake and availability of nutrients.

Sengar *et al.* (2000) explained the superior performance of the organic-inorganic nitrogen integration might be owing to the improvement in physical, chemical and biological environment of soil favouring increased availability of macro and micronutrients. It was also pertinent to note the yield decline in control treatments when compared to integrated application of nutrients. As a sustainable means of production the importance of this treatment may be emphasized than the normal practice being adopted by the farmers. Similar increase in rice yields through substitution of inorganic nitrogen by farmyard manure was reported by Singh *et al.* (1996). Higher grain yields were obtained by Parihar (2004) with application of 50 per cent of nitrogen each through farmyard manure and urea to that of urea alone.

Progressive yield increase was noticed by sulphur application and yield at 30 kg S ha^{-1} obtained was comparable to 20 kg ha^{-1} but significantly superior to 10 kg S ha^{-1}. The experimental soil being

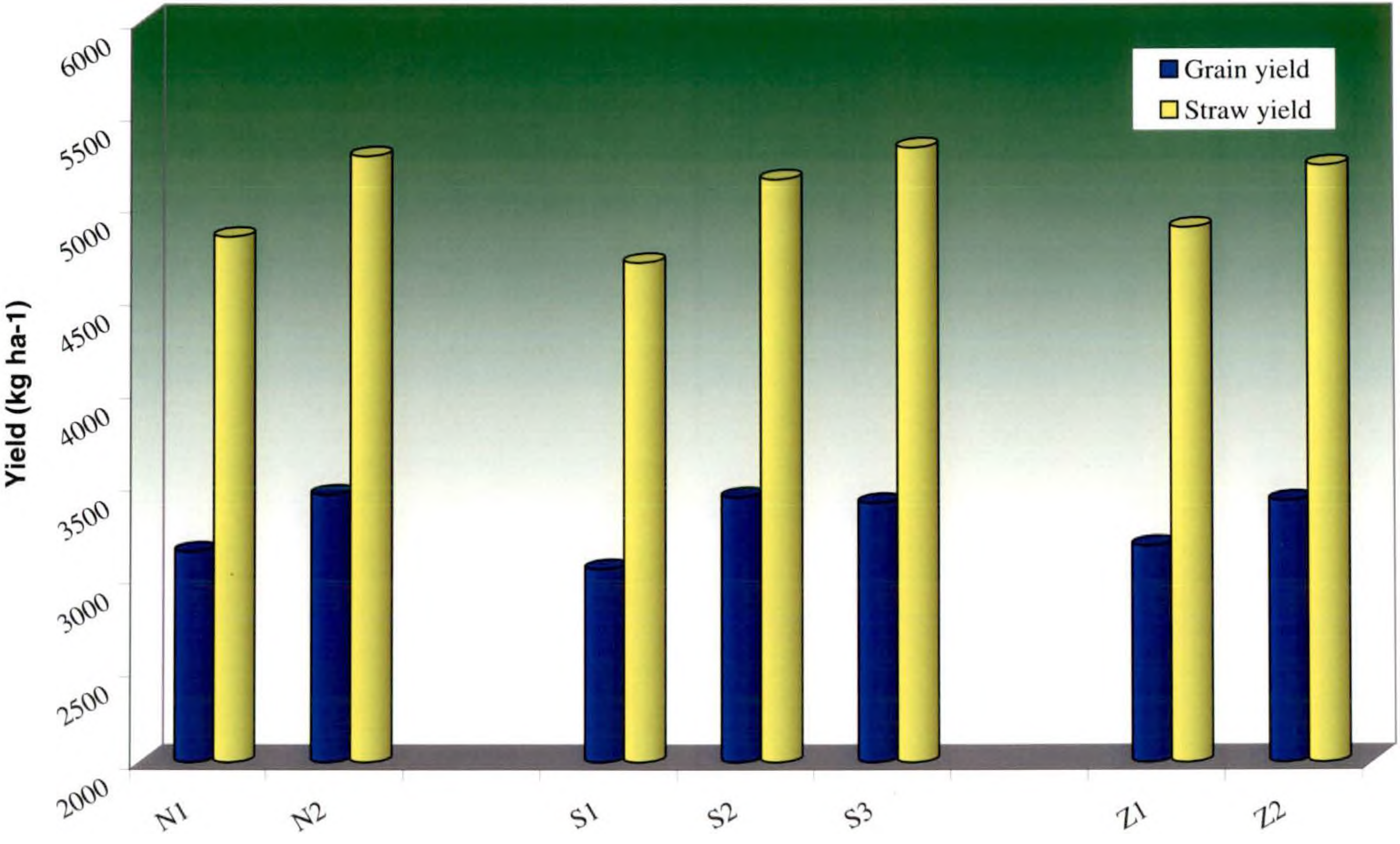

Fig. 4. Effect of N, S and Zn on yield (kg ha^{-1})

deficient in sulphur responded favourably to the applied sulphur, which is one of the most important nutrients. Owing to the important role-played by sulphur in metabolism of carbohydrates and proteins and as component of enzymes involved in photosynthesis might have contributed to improvement in yield attributing characters, which finally reflected in yield. The present results were in conformity with findings of Nair (1995) and Sudha (1999). Sakal *et al.* (2001) also reported maximum yield response in rice to the tune of 14.3-q ha^{-1} at 45 kg S ha^{-1} dose. This linear response could pave the way for experimenting with higher levels of sulphur so as to ascertain the potential yield by enhanced application of sulphur. Increase in rice yield with increase in sulphur levels was reported by workers like Rajendra rai (2003), Mahapatra *et al.* (2003), Misra *et al.* (2003), Sen *et al.* (2003) and Sheela (2005).

Perusal of data on grain yield by zinc sulphate application showed a marked positive influence and significant yield increase by 20 kg ZnSO4 ha^{-1} over 10 kg ZnSO4 was mainly due to improvement in yield attributing characters. The experimental site being intensively rice grown area and soil with zinc deficiency could express positive response for zinc and higher yield attributable to the role of zinc in diverse enzymatic activity along with synthesis of protein, indole acetic acid (IAA), transformation of carbohydrate and photosynthesis. This was corroborated by findings of Chapale & Badole (1999), Kumar et al. (1999) Rao and Shukla (1999), Kulandaivel *et al.* (2004) Patel and Meshri (2003). Udayasoorian (1998) ascribed the improvement in yield and yield components with zinc to its involvement in metalloenzyme system regulatory function and in growth promoting auxin production. Prasad (1997) explained that zinc sulphate @ 40 $kgha^{-1}$ in the presence of adequate organic matter content, availability of zinc was increased because of formation of natural soluble organo–zinc complexes which release complexed zinc slowly in the root vicinity.

Only the interaction between nitrogen and sulphur was found to be significant with regard to grain yield N_2S_2.*i.e.* 50 per cent N as organic and 50per cent N as inorganic in combination with sulphur @ 20kg ha^{-1} recorded highest grain yield. This clearly showed the synergistic relationship between nitrogen and sulphur and this has been reported by (Singh *et al.*, 1994 and Sakal *et al.*, 1999). Regular application of S free fertilizers for past many years in the field has resulted in reduction in available sulphur status of soil and it was the reason for high response for main effect of sulphur and its interaction effect with other major nutrients namely nitrogen.

Mean grain yield of treatment combinations were significantly superior to two control treatments. This further strengthens the role of zinc and sulphur under integrated nitrogen management in rice based cropping system. Mythili *et al.* (2003) also obtained higher grain yield in rice due to combined application of sulphur and zinc under integrated condition.

5.3.2 Straw yield

The effect similar to that of grain yield was also seen in the straw yield. With respect to nitrogen nutrition, nitrogen applied in an integrated manner has exhibited better growth parameters including dry matter production and this could be the attributable factor for increase in yield by this treatment. This was in confirmation with findings of Dubey and Verma (1999) and Vasantharao *et al.* (2004).

Higher straw yield obtained by application of 30 kg S ha^{-1} (S_3) was found to be on par with S_2 but significantly higher than S_1 (10 kg ha^{-1}). Application of sulphur ensured the balanced nutrition leading to higher nutrient availability, which could have resulted in higher growth and yield parameters resulting in higher straw yield. Higher straw yield with higher dose of suphur application was also obtained by Sen *et al.* (2003) and Sheela (2005).

Positive influence of zinc sulphate was also noticed at 20 kg $ZnSO_4$ ha^{-1}. This was corroborated by Kulandaivel *et al.* (2004) and Ghatak *et al.* (2005) .The same trend as that of grain yield was also obtained in straw yield by control treatments in relation to treatment combinations.

5.4 CHEMICAL ESTIMATION

5.4.1 Chlorophyll Content

Chemical estimation of chlorophyll showed that there was significant effect on chlorophyll content by sulphur application. Increase in chlorophyll content was observed up to 20 kg ha^{-1} and a slight reduction was noticed at 30 kg ha^{-1}. Sulphur is an essential ingredient of chlorophyll and required for synthesis of chlorophyll. Significant increase in chlorophyll content with sulphur application was reported by Sudha (1999) and Mini (2005).

5.4.2 Uptake of Nutrients

Substitution of 50 percent of nitrogen through farmyard manure had a significant impact on uptake of N, P, K, S and Zn. Higher availability of nitrogen in the rhizosphere coupled with enhanced dry matter production might have contributed to higher uptake of nitrogen. This confirmed the findings of Vasantharao *et al.* (2004). Conversion of available form of phosphorus from fixed form due to organic acids produced and organo-humic complex formed due to decomposition of organic matter in N_2 treatment might have contributed to better P uptake. Soil solution K may have increased owing to better soil environment in the rhizosphere in the organic manure applied plots (N_2) could be the

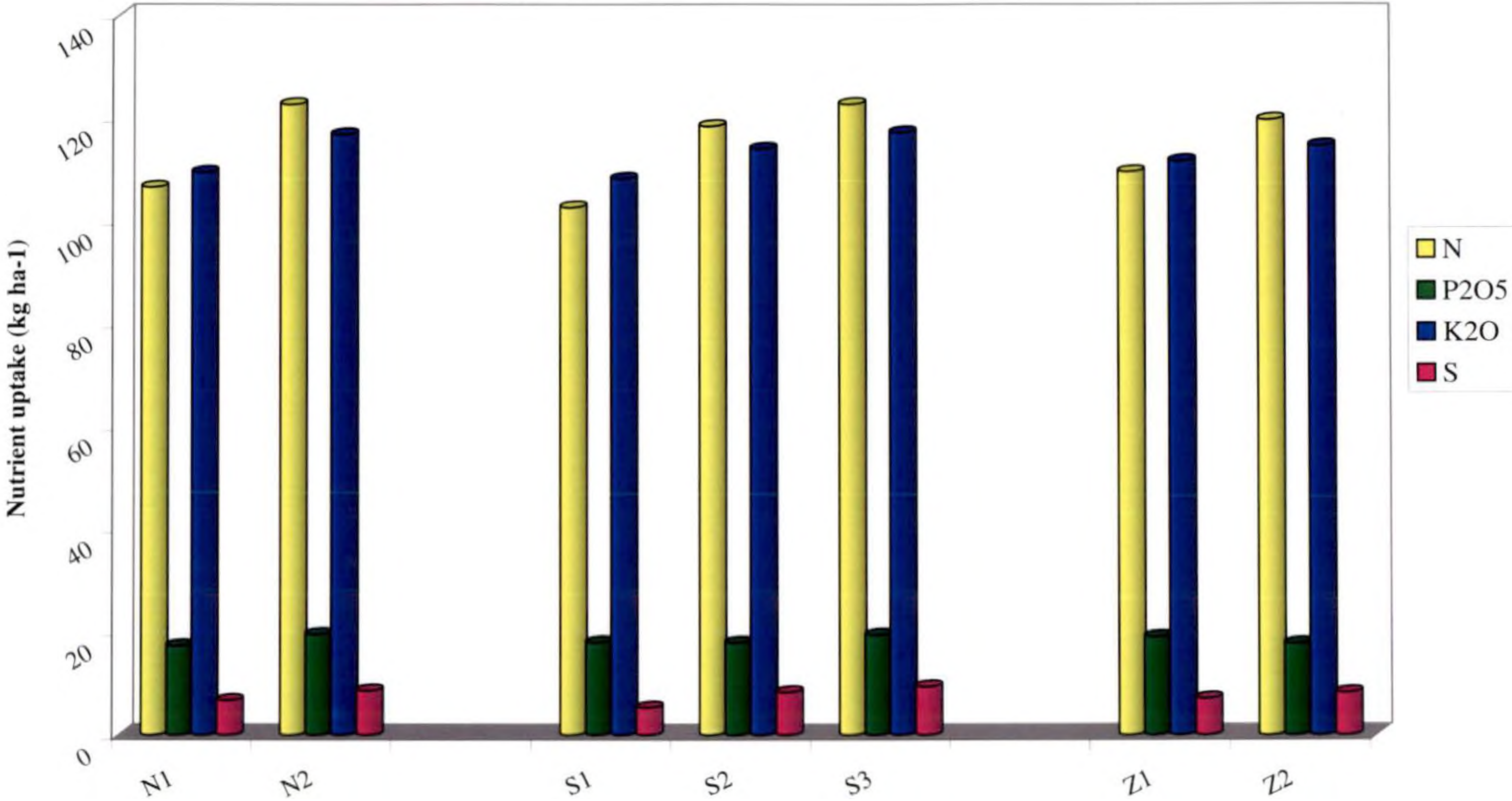

Fig. 5. Effect of N, S and Zn on uptake of N, P, K and S (kg ha^{-1})

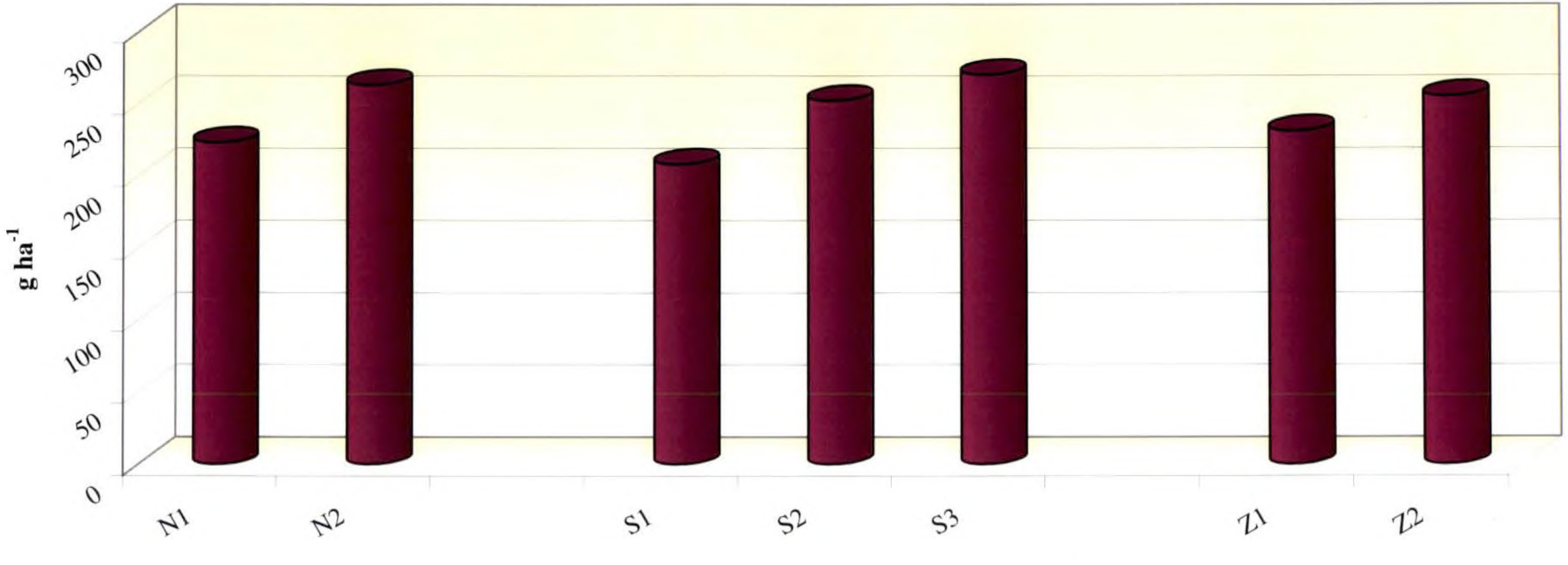

Fig. 6. Effect of N, S and Zn on uptake of Zn (g ha^{-1})

reason for better uptake of K. Similar increase in N, P, and K under integrated nutrient management were reported by Parihar (2004), Yadav *et al.* (2005) and Patro *et al.* (2005).

Organic manures are rich in major and micronutrients when applied along with chemical fertilizers ensured steady supply of nutrients for longer period of crop growth thereby positively influencing the availability may be the reason for higher uptake of sulphur. Higher levels (30 kg ha^{-1}) contributed to maximum uptake. Mondal and Chettri (1998) and Sudha (1999) also obtained higher sulphur uptake when FYM was applied along with inorganic fertilizers. Higher Zn uptake was also noticed under nutrient substituted condition. This may be attributed to the increased availability of Zn in soil due to chelating action of organic materials (Devarajan and Krishnaswamy, 1996 and Prasad, 1997). Vinay singh (2006) also reported significant increase in total uptake of N, P, K, S and Zn with the application of combined use of organics and inorganics.

Sulphur application significantly influenced N, S and Zn uptake. The increase in uptake of N, S and Zn may be due to the synergistic action of sulphur on these nutrients. Higher uptake of N and S due to S application was earlier reported by Nair (1995) and Sudha (1999). Significant increase in uptake of nutrients with higher S levels application was also reported by Chandel *et al.* (2003) and John *et al.* (2005).

$ZnSO_4$ also played a similar role in the uptake of nutrients as that of sulphur. Uptake of N, S and Zn was significantly influenced with higher level of $ZnSO_4$. Higher nitrogen uptake by zinc sulphate application was mainly due to synergistic relationship between N and Zn (Kumar *et al.* (1999). Rao and Shukla (1999) ascribed better N, P, K and Zn uptake by zinc sulphate application mainly due to favourable effect of zinc sulphate on the efficient use of N, P, K and Zn. Our soil being zinc deficient with the history of inadequate organic manure application was another reason for zinc uptake by the addition of zinc sulphate. Increase in zinc uptake by $ZnSO_4$ application was highlighted by Ghatak *et al.* (2005) and Kumar *et al.* (1999).

Interactions had no impact on uptake of nutrients except interactions due to S and Zn. Complimentary effect of zinc and sulphur as reported by Islam *et al.* (1985) may be another reason for higher zinc uptake. It was noticed that interaction effect was more pronounced in higher levels of S than the lower level and is evident from the maximum uptake of zinc by S_3Z_2 (S @ 30 kg ha^{-1}+ $ZnSO_4$ @ 20 kg ha^{-1}) combination, which was found to be on par with S_3Z_1 and S_2Z_2. But these three combinations were significantly superior to S_2Z_1, S_1Z_2 and S_1Z_1. However this interaction effect could not produce a favourable effect on grain yield. Detailed investigation with higher sulphur and zinc levels could throw more light in this aspect. Significantly lower uptake of nutrients was recorded in the two controls namely absolute control (zero levels of nutrients and POP (package of practice) recommendations as in the case of all other parameters.

5.4.3 Available Nutrients in Soil

Available nutrient status of soil after the experiment also exhibited significant variations with respect to nitrogen substitution, sulphur and zinc sulphate application. Combined use of both organic and inorganic source had resulted in positive nutrient status of soil with respect to nitrogen and potassium. Slow decomposition of farmyard manures throughout the crop period and better physico-chemical and biological conditions attributed to creation of favourable environment in the rhizosphere facilitated the release of P and K from native and organic sources might be the reason. Similar reports were given by Deepa (1998)

Mondal and Chettri (1998) and Roy *et al.* (2001). Dutta and Bandyopadhyaya (2003) reported considerable improvement in organic carbon and available nutrient (N, P and K) after harvest of rice.

Available nutrient status was also influenced by sulphur application. The effect was significant with respect to N, K, S and Zn. Again, the increased availability of these nutrients may be due to synergistic relation between sulphur and these nutrients. Mini (2005) found out that sulphur application had a significant influence on available N, P, K and S content of soil after experiment. Arvind Verma *et al.* (2005) reported that application of combination of sulphur and zinc along with 100 percent NPK significantly increased the zinc content of the soil.

Zinc sulphate application significantly influenced the available sulphur and zinc content of the soil. Higher levels of zinc sulphate contributed higher S and Zn status of the soil after the experiment. This may be due to the complimentary effect of sulphur and zinc on each other. The higher solubility, diffusion and mobility of applied inorganic zinc fertilizer along with effect of farmyard manure might be the reason for increased zinc status of soil. Zinc sulphate application showed an increasing trend with respect to available N and K content but showed an opposite trend in the case of P. This can be attributed to antagonistic effect of P and zinc. At higher levels of zinc application, P content of soil decreased though the effect was not significant. Kumar *et al.* (1999) also obtained similar decrease in P content of soil when zinc sulphate was supplied alone.

Among interaction, N X S and S X Zn turned out to be significant in influencing available sulphur content of soil. Combination of N_2S_3 (50 per cent of N as organic and 50 per cent of N as inorganic + 30 kg S ha^{-1}) recorded highest S content, which was followed by N_2S_2 (50 per cent of

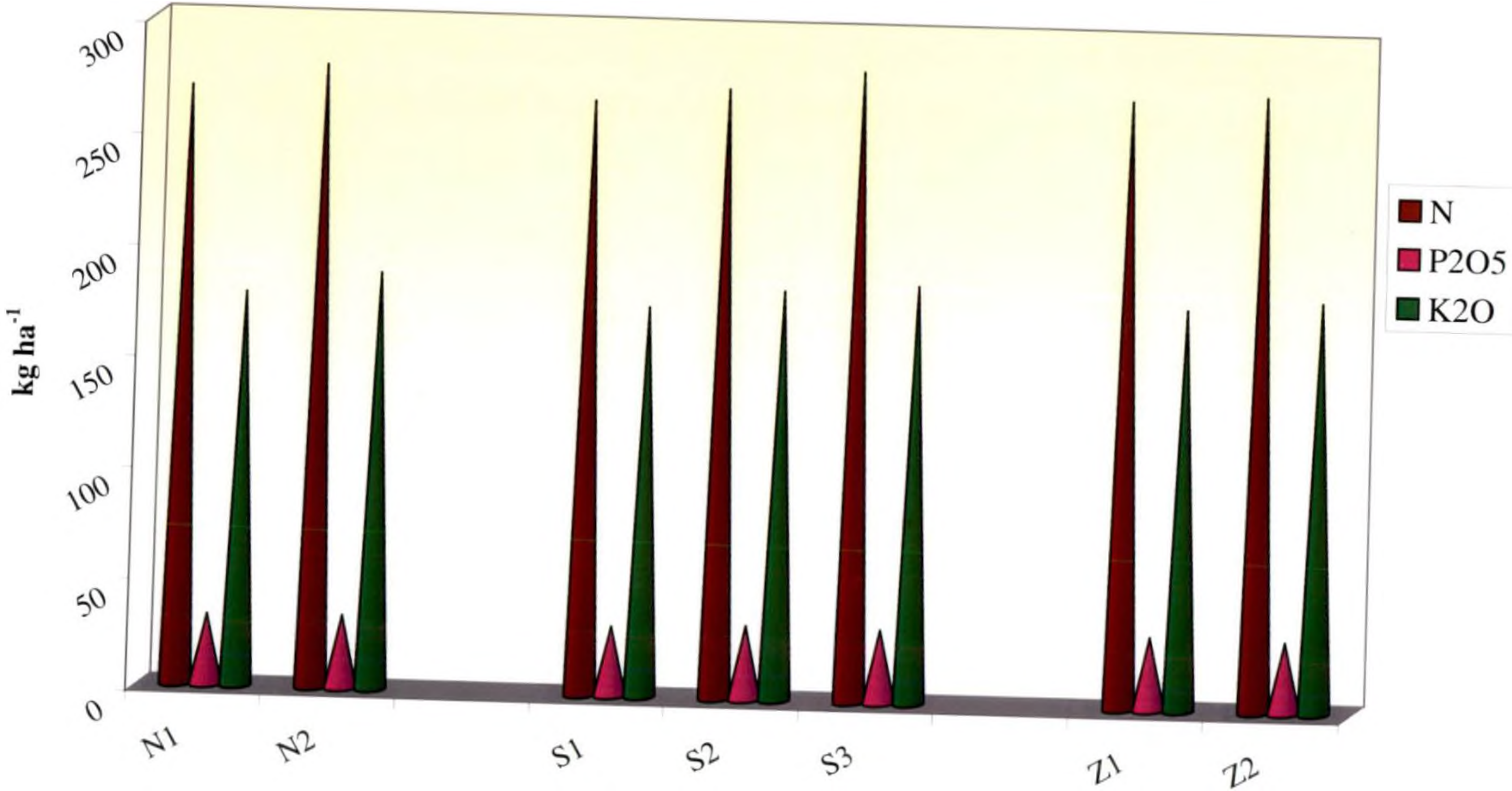

Fig.7. Effect of N, S and Zn on available N, P_2O_5 and K_2O(kg ha^{-1})

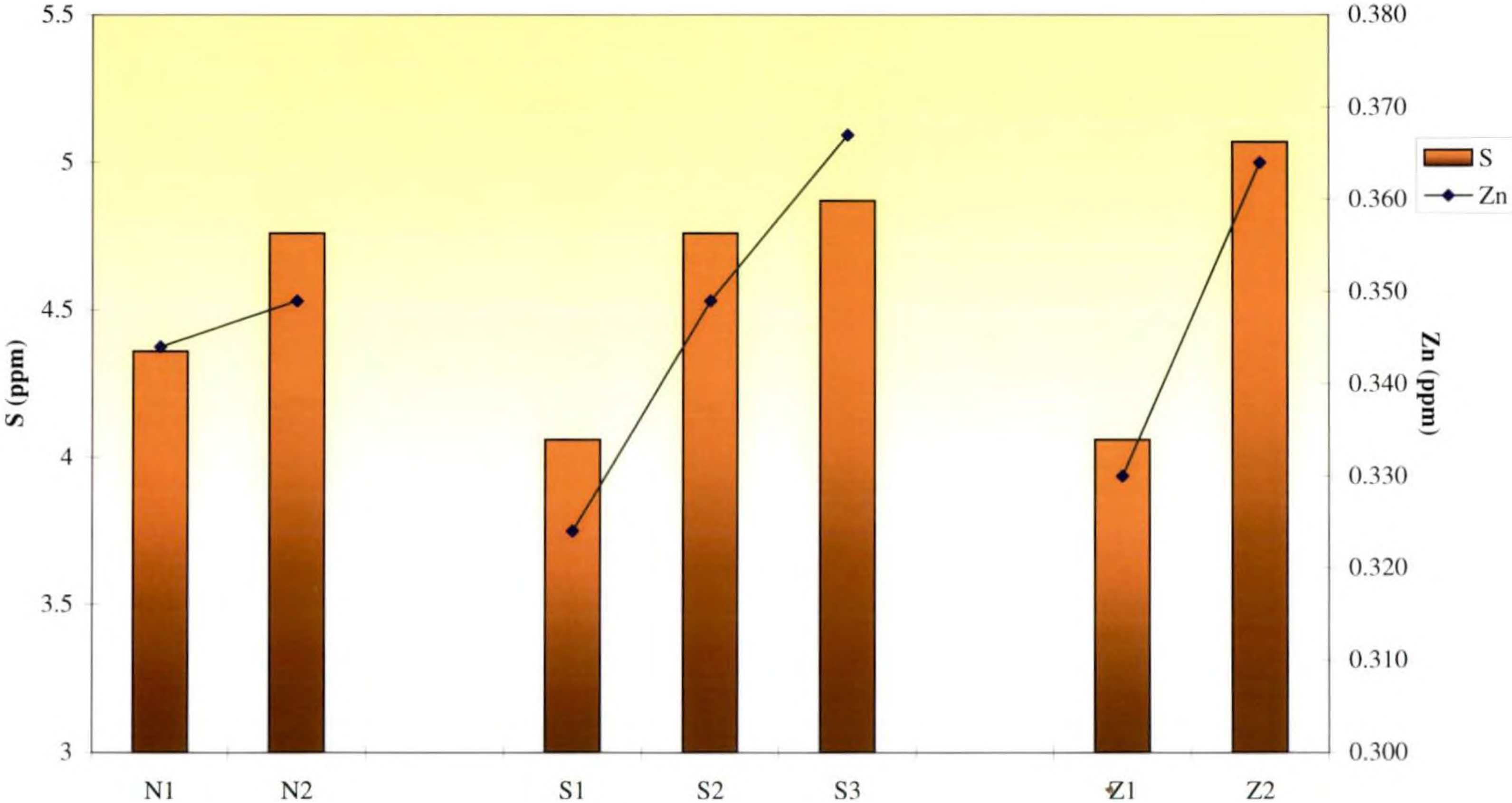

Fig. 8. Effect of of N, S and Zn on avialable S and Zn in the soil

N as organic and 50 per cent of N as inorganic + 20 kg S ha^{-1}). Regarding SZ interaction, combined application of S @ 30kg ha^{-1} with ZnSO4 @ 20 kg ha^{-1} (S_3Z_2) turned out to be higher in contributing to the available S in soil. The results were in agreement with findings of Arvind Verma *et al.* (2005) who found out that application of S alone or in combination with Zn significantly increased the available S content of soil.

5.4 PEST AND DISEASE INCIDENCE

The treatment. which received N as 100 per cent as inorganic, S @ 20 kg ha^{-1} and $ZnSO_4$ @ 20 kg ha^{-1} was found to be severely affected by earhead bug. Inspite of control measures taken, the incidence of earhead bug was noticed throughout the earhead stage in all treatmental plots which had resulted in yield reduction in almost all treatments. The attack by the pest to the general yield decline and it was reflected in the sterility percentage also.

5.5 ECONOMICS OF CULTIVATION

It was found that 30 kg S ha^{-1} and 20 kg ZnSO4 ha^{-1} along with full dose of N applied as inorganic source recorded highest benefit cost ratio of 1.34. This might be attributable to lesser cost of cultivation owing to the low cost of inorganic fertilizers when compared to FYM on nitrogen basis. It was evident from the fact that in terms of grain yield this treatment is inferior to T_{10} ($N_2S_2Z_2$), which has a grain yield of 3829.17 kg ha^{-1} with a benefit cost ratio of 1.27. Hence we could infer that from the sustainability point of view $N_2S_2Z_2$ (S @ 20 kg ha^{-1} + ZnSO4 @ 20 kg ha^{-1} and N applied equally as organic-inorganic integration) would be the better treatment when compared to T_6 ($N_1S_3Z_2$) with a benefit cost ratio of 1.34.

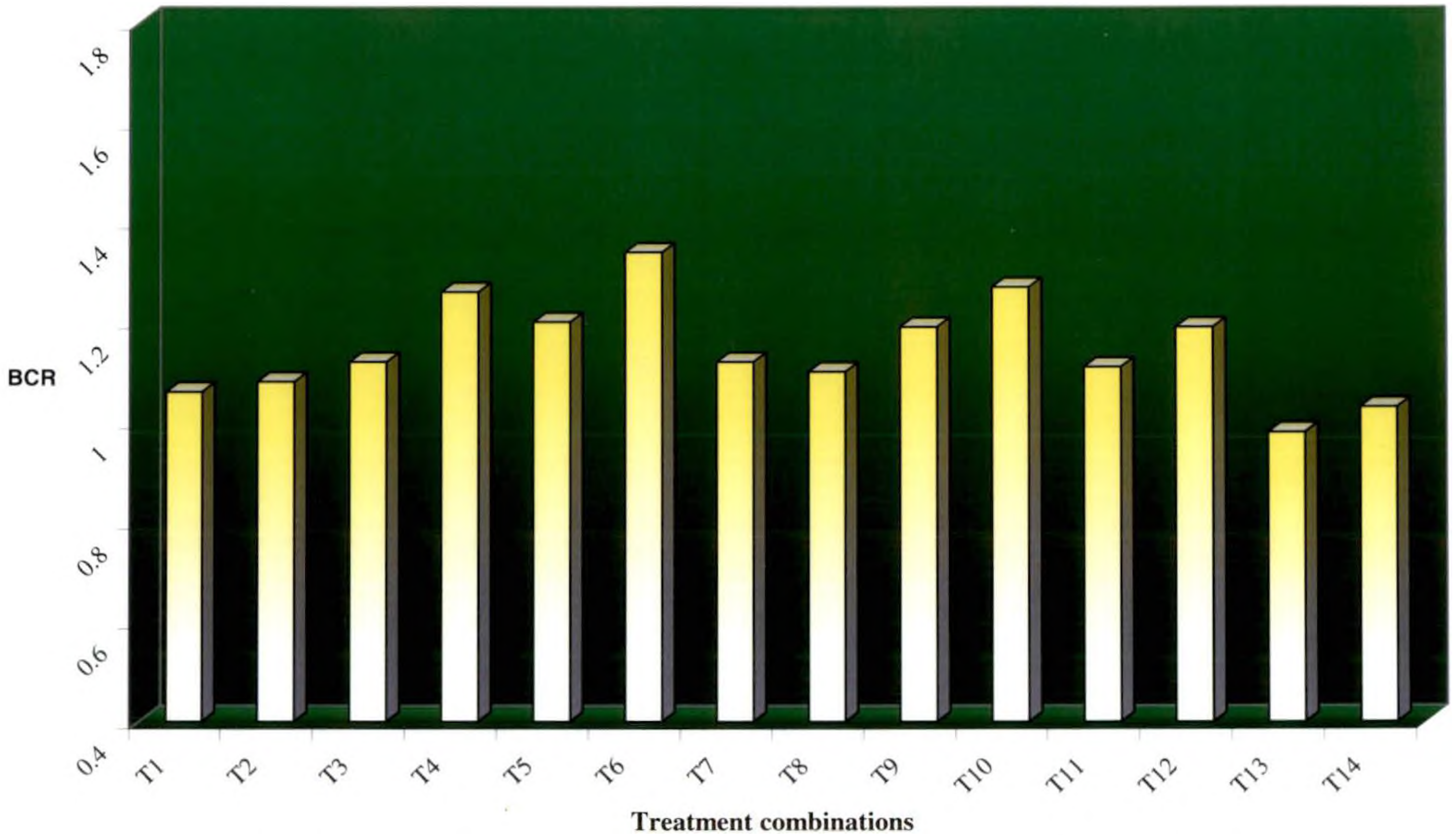

Fig.10. Effect of treatment combinations on BCR

SUMMARY

6. SUMMARY

A field investigation was conducted during rabi season of 2005-06 at Cropping Systems Research Centre, Karamana, Thiruvananthapuram to study the effect of sulphur and zinc under integrated nutrition on growth and yield of wetland rice. The soil of the experimental site was medium in available nitrogen, phosphorus, potassium and deficient in sulphur and zinc.

The experiment was laid out in factorial randomized block design with three replications. The treatments consist of combinations of two levels of nitrogen (N_1-100 percent of N as inorganic and N_2-50 per cent of N each as organic-inorganic integration), three levels of sulphur (S_1-10 kg S ha^{-1}, S_2-20 kg S $ha^{-1}$and S_3-30 kg S ha^{-1}) and two levels of $ZnSO_4$ (Z_1-10 kg $ZnSO_4 ha^{-1}$and Z_2-20 kg $ZnSO_4$ ha^{-1}) along with two controls. The treatment with no nutrients and treatment with package of practice recommendation form two control treatments. Farmyard manure @ 5 t ha^{-1} was applied uniformly to all plots. Observations on growth characters, yield attributes, yield, nutrient uptake and nutrient status of the soil after the experiment was collected, statistically analyzed and the results obtained are summarized below.

Organic-inorganic integration of nitrogen significantly influenced the plant height at harvest stage only while S applied @ 30 kg ha^{-1} was found to be significantly superior to lower level at all the stages. Treatment combinations also influenced the plant height significantly at all the stages. Similarly significantly higher tiller number $hill^{-1}$ was obtained at harvest stage by integrated application of nitrogen fertilizers both through organic and inorganic source. Sulphur and $ZnSO_4$ application at higher levels significantly contributed to higher tiller number $hill^{-1}$ compared to lower levels at all growth stages.

Higher LAI was observed in integration of organic and inorganic N source at 40 DAT and at harvest. Application of S at higher levels positively enhanced the LAI at 40 DAT and at harvest. Eventhough the effect was insignificant an increase in LAI was found at 20 DAT. $ZnSO_4$ @ 20 kg ha^{-1} found significantly superior to 10 kg ha^{-1} at harvest stage of the crop. Significant variation in dry matter production was noticed in treatment which received 50 percent of N as organic and 50 per cent of N as inorganic compared to those received inorganic N alone. Among the S levels, S_3 *i.e.* 30 kg ha^{-1} resulted in maximum dry matter production. Even though the effect was not significant, increase in DMP was observed with increase in $ZnSO_4$ level. Treatment combinations produced significantly superior results compared to control with respect to all growth characters studied.

Integrated nitrogen nutrition, though showed an increasing trend in most of the yield parameters, significantly influenced only number of panicles $hill^{-1}$. But significant difference was noticed by S application @ 30 kg ha^{-1} on yield parameters like thousand grain weight, weight of panicle, filled grains $panicle^{-1}$ and number of panicles $hill^{-1}$. Yield attributes like weight of panicle, filled grains $panicle^{-1}$ and number of panicles $hill^{-1}$ were favourably increased by higher applications of $ZnSO_4$ @ 20 kg ha^{-1}.Treatment combinations found superior in yield characters like thousand grain weight, weight of panicle, length of panicle, total grains $panicle^{-1}$, filled grains $panicle^{-1}$ and number of panicles $hill^{-1}$ over control treatments.

Grain yield and straw yield were also significantly influenced by the treatments. Higher grain and straw yields were recorded by N_2 *i.e.* 50 per cent N applied as inorganic and 50 per cent N applied as organic and it was significantly superior than N_1 (100 per cent N as inorganic). S @ 20 kg ha^{-1} obtained highest grain yield and it was on par with 30 kg ha^{-1} while application of S @ 30 kg ha^{-1}had recorded highest straw yield.

Addition of $ZnSO_4$ @ 20 kg ha^{-1} recorded highest yield in terms of grain and straw. Among treatment interactions, substituted application of 50 per cent of N as organic and 50 per cent of N as inorganic along with S @ 20 kg ha^{-1} recorded highest grain yield production. Compared to control treatments, all treatment combinations produced significantly superior results. However harvest index was not influenced by treatments and their interactions. Though there was general yield decline due to earhead bug, there was no marked variation in the treatmental effect by pest attack.

Chlorophyll content was significantly increased with sulphur application with 20 kg ha^{-1} recording higher values. Uptake of N, P, K, S and Zn was found to be significantly influenced with substitution of 50 percent of nitrogen through farmyard manure. Sulphur application also significantly influenced N, S and Zn uptake with higher level of sulphur (30 kg ha^{-1}). Uptake of N, S and Zn was significantly influenced with higher level of $ZnSO_4$. Sulphur and zinc interaction had made a positive impact on zinc uptake with combination of S @ 30 kg ha^{-1} along with $ZnSO_4$ @ 20 kg ha^{-1} produced highest uptake. Treatment combinations also significantly increased the uptake of all nutrients compared to controls.

Available soil nutrients were also significantly affected by treatments. Organic-inorganic integration of N sources had resulted in positive nutrient status of soil with respect to nitrogen and potassium. Higher soil status of N, K, S and Zn was noticed with higher levels of sulphur application. $ZnSO_4$ application significantly increased the available sulphur and zinc content of the soil after the experiment. Nitrogen and sulphur interaction was significant in affecting the available N and S content of soil with combination of sulphur @ 30 kg ha^{-1} along with application of 50 per cent of N as organic and 50 per cent of N as inorganic producing highest values. S X Zn interaction also played significant role in increasing available S content of soil. Highest benefit cost ratio of 1.34 was recorded by T_6 which combined S @ 30 kg ha^{-1} and $ZnSO_4$ @ 20 kg ha^{-1} along with full recommended dose of N as inorganic fertilizer.

Future line of work

- Higher levels of zinc and sulphur could be tested under integrated nitrogen nutrition with different proportion of organic and inorganic nitrogen in different rice based cropping systems and their residual effect on subsequent crops in the system has to be investigated in detail
- Interactions of zinc and sulphur with other micronutrients can also be studied

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* originals not seen

SULPHUR-ZINC INTERACTION IN INTEGRATED NUTRIENT SUPPLY SYSTEM OF WETLAND RICE (*Oryza sativa* L.)

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Abstract of the
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ABSTRACT

An experiment was conducted at Cropping Systems Research Centre (CSRC), Karamana, Thiruvananthapuram during rabi season of 2005-06 to study the response of wetland rice to sulphur and zinc under integrated nutrient condition using the variety Aiswarya.

The experiment was laid out in factorial randomized block design with three replications. The treatments consist of combinations of two levels of nitrogen (N), three levels of sulphur (S) and two levels of $ZnSO_4$ (Z) along with two controls (zero level of fertilizer treatment and Package of Practice recommendation treatment). Recommended dose of nitrogen applied as 100 per cent inorganic (N_1) and 50 per cent N applied equally as organic-inorganic integration (N_2) constitutes the N levels. Sulphur applied @ 10 kg ha^{-1} (S_1), 20 kg ha^{-1} (S_2) and 30 kg ha^{-1} (S_3) were the three sulphur levels. The two $ZnSO_4$ fertilizer levels are10 kg $ZnSO_4$ ha^{-1} (Z_1) and 20 kg $ZnSO_4$ ha^{-1} (Z_2) and farmyard manure @ 5 t ha^{-1} was applied uniformly to all treatments.

Results of the experiment revealed that the main effects of nitrogen, sulphur and $ZnSO_4$ as well as their combinations exerted positive significant influence on the growth and yield attributing characters of rice. Organic- inorganic integration (N_1) significantly influenced growth characters like plant height, tiller number $hill^{-1}$, leaf area index and dry matter production and yield character like number of panicles $hill^{-1}$ and yield while higher sulphur (S_3) level upto 30 kg ha^{-1} were found significantly superior in influencing all growth, yield attributing characters and yield of rice to lower level (S_1). $ZnSO_4$ @ 20 kg ha^{-1} (Z_1) recorded significantly higher plant height, tiller number $hill^{-1}$ leaf area index, number of panicles $hill^{-1}$, weight of panicle, filled grains $panicle^{-1}$ and yield of rice. Treatment combinations also significantly

influenced most of the growth, yield attributing characters and yield of rice compared to controls.

Chlorophyll content was significantly influenced by S application only. Nutrient uptake was also influenced by treatments and their combinations. Organic- inorganic integration (N_1) significantly favoured the uptake of N, P, K, S and Zn while S application at higher levels contributed significantly to uptake of N, S and Zn. Uptake of N, S and Zn was significantly influenced with higher level of $ZnSO_4$ @ 20 kg ha^{-1} (Z_2). Combination of S @ 30 kg ha^{-1} along with $ZnSO_4$ @ 20 kg ha^{-1} produced highest uptake of Zn.

Available N and K exhibited significant variation with combined use of both organic and inorganic source of nitrogen. Available nutrient status of N, K, S and Zn was significantly increased by S application at higher levels. Again, there was increase in availability of S and Zn content of the soil with higher level of $ZnSO_4$ (20 kg ha^{-1}) application. N X S and S X Zn interactions also played significant role in increasing available N and S content of soil. Treatment combinations recorded significantly better results in uptake and availability of nutrients compared to control treatments. Highest benefit cost ratio was recorded by a combination of S @ 30 kg ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1} along with full recommended dose of N as inorganic fertilizer.

APPENDIX I

Weather parameters during the cropping period
(September 2005 to February 2006)

Standard weeks	Maximum temperature,°C	Minimum temperature,°C	Rainfall, mm	RH, %
36	29.6	22.9	112.0	95.1
37	29.8	23.6	27.0	89.9
38	31.7	24.1	0.0	83.0
39	32.5	24.0	0.0	80.3
40	32.8	23.8	0.0	79.0
41	30.6	23.4	99.0	87.3
42	32.0	23.5	12.0	90.9
43	30.1	23.5	118.0	95.0
44	30.9	24.1	25.0	91.3
45	30.7	23.3	90.0	94.4
46	30.4	23.2	119.0	94.3
47	30.6	23.4	88.4	93.3
48	32.1	23.4	60.6	95.0
49	31.7	23.1	61.2	93.7
50	29.5	22.7	90.8	95.6
51	30.8	23.4	4.9	95.1
52	31.4	21.6	0.0	95.3
1	32.1	22.8	0.0	95.9
2	32.2	23.7	13.2	92.1
3	28.6	20.8	9.3	93.4
4	31.2	21.7	0.0	96.0
5	31.8	22.4	0.0	93.0
6	32.2	22.4	0.0	90.3
7	32.2	22.5	0.0	91.0
8	32.4	23.2	0.0	91.1