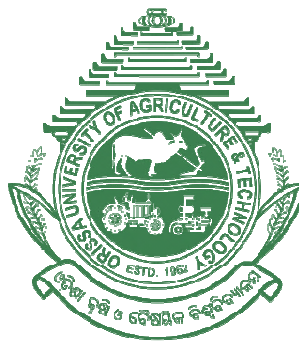


Integrated nutrient management in rice-rice cropping system

*A Thesis submitted to the
Orissa University of Agriculture and Technology
in Partial fulfilment of the Requirements for the Degree of
Doctor of Philosophy in Agriculture
(Agronomy)*

By

*Mohima Prasad Behera
Adm. No. 01Agro./Ph.D./07*



**DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
ORISSA UNIVERSITY OF AGRICULTURE & TECHNOLOGY
BHUBANESWAR – 751 003, ODISHA
2015**



**ORISSA UNIVERSITY OF AGRICULTURE & TECHNOLOGY
DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
BHUBANESWAR – 751 003**

Dr. Jogeswar Sahoo
Former Professor

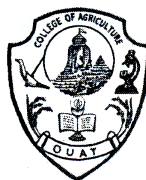
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CERTIFICATE - I

This is to certify that the thesis entitled “**Integrated nutrient management in rice-rice cropping system**” submitted in partial fulfilment of the requirement for the award of degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURE (AGRONOMY)** to the Orissa University of Agriculture and Technology is a faithful record of *bona fide* and original research work carried out by **MOHIMA PRASAD BEHERA** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

(Jogeswar Sahoo)
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Advisory Committee



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DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
BHUBANESWAR – 751 003**

CERTIFICATE - II

This is to certify that the thesis entitled “**Integrated nutrient management in rice-rice cropping system**” submitted by **MOHIMA PRASAD BEHERA** to the Orissa University of Agriculture and Technology, Bhubaneswar in the partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURE (AGRONOMY)** has been approved by the students’ advisory committee and the external examiner.

Advisory Committee

Chairman

Dr. Jogeswar Sahoo
Former Professor

Members

1. **Dr. Basudev Behera**
Professor and Head

2. **Dr. Bijoy Kumar Mishra**
Associate Professor and Head
Department of Plant Physiology

3. **Dr. Antaryami Mishra**
Associate Professor
Dept. of Soil Science and Agril. Chem.

External Examiner

(Name and Designation)

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I dedicate this piece of work to Lord Jagannath.

Bhubaneswar
Date :

(Mohima Prasad Behera)
Adm. No. 01 Agro/Ph.D/07

ABSTRACT

The experiment was conducted in the Instructional Farm, Department of Agronomy, College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar during Kharif (wet) and rabi (dry) seasons of 2010-11 and 2011-12. The soil was sandy loam in texture with pH of 5.8, medium in N, P, K content and deficient in available S (8 ppm), Zn (0.33 ppm) and B (0.43 ppm). There were eleven treatments i.e., T₁ = RFD (80-40-40 kg N-P₂O₅ ha⁻¹), T₂ = RFD + FYM @ 5 t ha⁻¹, T₃ = RFD + ZnSO₄ @ 25 kg ha⁻¹, T₄ = RFD + Zn-EDTA @ 1 kg ha⁻¹, T₅ = RFD + S @ 30 kg ha⁻¹, T₆ = RFD + B @ 1 kg ha⁻¹, T₇ = RFD + Zn-EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹, T₈ = RFD + Zn-EDTA @ 1 kg ha⁻¹ + B @ 1 kg ha⁻¹, T₉ = RFD + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹, T₁₀ = RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ and T₁₁ = RFD + Zn-EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹.

The treatments were tested in randomized block design with three replications. The rice variety 'Lalat' was grown with 15 cm x 10 cm spacing during Kharif season. The study was made to assess the effect of integrated nutrient management on growth, yield, nutrient uptake and economics of rice during Kharif season.

During rabi season rice variety 'Lalat' was grown in these treatment plots with a common dose of N-P₂O₅-K₂O @ 80-40-40 kg ha⁻¹ to study the residual effect of FYM, S, Zn and B on growth, yield, nutrient uptake and economics of rice, as well as the effect on rice-rice cropping system.

During Kharif season, application of RFD along with ZnSO₄ @ 25 kg ha⁻¹ and B @ 1 kg ha⁻¹ produced the maximum grain (5.28 t ha⁻¹) and straw yield (6.33 t ha⁻¹). This treatment also ensured highest uptake of nutrients i.e., N (135.5 kg ha⁻¹), P (33.1 kg ha⁻¹), K (178.1 kg ha⁻¹), S (13.3 kg ha⁻¹), Zn (256.0 g ha⁻¹) and B (177g ha⁻¹), net return (₹ 39,312 ha⁻¹) and B:C ratio (1.65).

During rabi season, the same treatment (T₁₀) produced maximum grain (6.21 t ha⁻¹) and straw yield (7.45 t ha⁻¹) with highest uptake of nutrients N (195.5 kg ha⁻¹), P (49.7 kg ha⁻¹), K (204.9 kg ha⁻¹), S (20 kg ha⁻¹), Zn (439 g ha⁻¹) and B (276 g ha⁻¹), net return (₹ 47231 ha⁻¹) and B:C ratio (1.75), which was due to residual effect of ZnSO₄ (25 kg ha⁻¹) and B (1 kg ha⁻¹) applied to Kharif rice.

Integrated application of RFD along with ZnSO₄ (25 kg ha⁻¹) and B (1 kg ha⁻¹) to Kharif rice produced the maximum grain (11.49 t ha⁻¹) and straw yield (13.78 t ha⁻¹) in the rice-rice cropping system. This treatment also exhibited maximum nutrient uptake i.e., N (331 kg ha⁻¹), P (82.8 kg ha⁻¹), K (383 kg ha⁻¹), S (33.3 kg ha⁻¹), Zn (695 g ha⁻¹) and B (453 g ha⁻¹), net return (₹ 86543 ha⁻¹) and B:C ratio (1.70) in rice-rice- cropping system.

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INTRODUCTION

Rice is cultivated in about 160 million hectares globally with a produce of 685 million tonnes (DRR, 2011). Asian countries produce about 90 per cent of this production. India is one of the leading rice producing countries of the world along with China, Thailand, Vietnam, USA and Pakistan. It has the world's largest area under rice with 43.95 million hectare with an annual production of 106.54 million tonnes and an average yield of 2424 kg ha⁻¹ (GOI, 2014). India's share in global rice production is 21.5 per cent. Rice crop alone contributes to about 40 to 43 per cent of the total food grain production and that is why the crop plays a vital role in national food and livelihood security mission. Rice export contributes nearly 25 % of total agriculture export from the country.

The major rice growing states are Uttar Pradesh with an area (5.98 M ha), production (14.63 MT) and average yield of 2447 kg ha⁻¹ followed by West Bengal (5.50 M ha, 15.31 MT and 2786 kg ha⁻¹) and Andhra Pradesh (4.51 M ha, 13.03 MT and 2891 kg ha⁻¹). Uttar Pradesh, West Bengal and Andhra Pradesh contribute about 14.63, 14.37 and 10.25 % to total rice area of the country. Odisha cultivates rice in 4.18 million ha with an annual production of 7.58 million tonnes and average yield of 1815 kg ha⁻¹. The area of rice in Odisha contribute to 8.51 % of gross rice cultivated area of the country. However its productivity is 33.55 % less than the national productivity (GOI, 2014).

Rice is a staple food of majority of Indians and its demand in future is bound to increase with growing population, which is projected to be 1.301 and 1.378 billion by 2020 and 2030 respectively (DRR, 2011). It covers 69 % of the gross cultivated area and 63 % of the total area under food grain in Odisha. The state economy is directly linked with improvements in production and productivity of rice in the state (Das, 2012).

The reasons for low productivity of rice in the state are many. Imbalanced fertilizer use and low fertilizer use efficiency are the main reasons in achieving higher productivity in the coastal alluvial soils of Odisha. With introduction of high yielding and fertilizer responsive varieties of rice, the supply of nutrients in adequate quantities at right time has assumed considerable importance in a rice-rice cropping system for sustainable production, which is lacking in the state. Most of the soils of Odisha are deficient in some or other nutrients including micronutrient owing to intensive cropping system for obtaining higher yields per unit area. Introduction of high yielding varieties and indiscriminate use of high analysis fertilizers has led to imbalances in soil fertility.

As cropping intensity and yield levels go up, so is the mining of plant nutrients through harvested crops. This has caused the deficiency of micronutrients in the state, which are indispensable for normal plant growth and development. Its deficiency is one of the major problem in achieving targeted yield of rice.

Among the micronutrients, boron deficiency is found wide spread in soils of Odisha. Boron deficiency in soils ranged from 4.4 to 89 % with an average of 44 %, Out of 30 districts, 14 districts are having more than 50 % B deficient soils. Coarse textured red, laterite, mixed red and yellow soils are prone to B deficiency. The boron content in these soils ranged from 0.18 to 5.1 mg/kg with a mean value of 1.41 mg/kg. Sulphur is deficient in 28% of the soils of Odisha (Jena *et al.*, 2008).

Zinc has been identified as the third most important nutrient element after N and P in low land rice limiting growth and yield of crop. Soil is the principal source of Zn from which plants draw their requirements. But at present, nearly half of the Indian soils including the coastal tracts suffer from zinc deficiency of varying magnitude. About 50 per cent of Indian soils are deficient in zinc and 20 per cent soils have hidden deficiency symptoms (Singh, 1999). About 8 million hectares of flooded rice is affected by zinc deficiency in India (Katyal and Ponnampereuma, 1974).

Sporadic deficiency of Zn in fine textured soils in irrigated command areas of the state is observed. Analysis of soil samples from 30 district of Odisha showed that the DTPA (diethylene triamine pentaacetic acid) extractable Zn in soils ranged from 0.24 to 2.08 mg/kg with a mean value of 1.10 mg/kg. The Zn deficiency of 25 districts in the state ranged from 0 to 76 %. The deficiency in alluvial and laterite soils ranged from 7.0 to 76.0 and 2-12 % respectively but it was 42 % in black soils (Jena et al., 2008).

In Odisha, about 19 per cent of total soils are deficient in zinc. The problem seems to be more acute in rice and it is aggravated by many fold in rice-rice cropping system in the irrigated ecosystem. Zinc fertilization has become an essential component to the package of practice for ensuring high rice productivity (Singh, 1999).

Sulphur is increasingly being recognized as the fourth major plant nutrient after Nitrogen, Phosphorus, and Potassium. Sulphur deficiency in the soils of Odisha ranges between 7.0 to 98% with a mean value of 28%. Its status in the soils of the intensive rice growing districts of Odisha is alarming. Available sulphur contents in soils of Balasore, Kalahandi, Bargarh and Bhadrak district ranged between 4.5 – 27.0, 2-22.8, 1.2-23.8 and 1.2-103.5 mg kg⁻¹, respectively with a deficiency of 27.8, 81.1, 88.0 and 20.0 per cent respectively. Considering 0.15 % as critical limit of sulphur deficiency in leaves of rice plant, 33-94. % of plant samples of Balasore, Kalahandi, Bargarh and Bhadrak district were found to be deficient in sulphur. As studied under long term experiments, heavy depletion of soil sulphur due to rice-pulse and rice-oilseeds systems in the coastal district aggravate the sulphur deficiency. These are the leading cropping systems in Odisha and the removal of sulphur will definitely decline the rice, pulse and oilseed yields in the coming years.

Application of recommended dose of major nutrients with FYM is crucial to obtain the desired yield of rice. Imbalanced fertilizer application with little or no organic manure and use of high analysis fertilizers without micro-nutrients in

intensively practiced rice-rice cropping system, deficiencies or hidden hunger of secondary and micronutrients especially S, Zn and B have also been observed.

Rice-rice cropping system is the second largest system in India next to rice-wheat system. Increasing productivity in rice-rice system can't be sustained unless the declining trends in soil fertility due to nutrient mining is replenished properly from outside sources. An integrated approach to nutrient management involving inorganic fertilizers, organic manures and micronutrient fertilizers are the right step in this context.

As rice is grown under submerged anaerobic conditions, integrated management of nutrients offer a wide scope for harnessing the efficiency of different nutrients, and their combinations. Information on management of S, Zn and B for rice in lateritic soils of Odisha is lacking for which the present study is proposed to assess the direct, residual and interactive effects of S, Zn and B along with FYM on rice-rice cropping system, with the following objectives.

- i) To study the effect of INM on growth and yield of rice-rice system.
- ii) To assess the residual effect of FYM, S, Zn and B on succeeding crop of rice during *rabi* season.
- iii) To estimate the nutrient uptake.
- iv) To work out the economics of the system.



REVIEW OF LITERATURE

Next to nitrogen and phosphorus, zinc deficiency is considered to be most important one limiting the growth and yield of rice. It necessitates immediate attention for zinc management. Application of zinc through organic and inorganic sources make it cost effective. Further, the residual effect of zinc in the succeeding crop also reduces its application cost for two to three seasons.

Sulphur has been widely recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium for some years. Since 40-45 % soils of India are found to be deficient in available sulphur, it has become impossible to achieve higher rice yield with superior grain quality without sulphur application.

Boron deficiencies are becoming increasingly observed in India. Among micronutrients, boron deficiency is found wide spread in soils of Odisha limiting the potential yield of HYV rice. Besides the effect of FYM have also been observed for improving the growth and yield of rice.

Here an attempt has been made to review the research findings available in India and abroad on the above essential elements along with FYM related to the present investigation entitled “Integrated nutrient management in rice-rice cropping system”.

2.1 Zinc deficiency

Zinc deficiency was wide spread in Indian soils. Nearly 8 million hectares of flooded rice is affected by zinc deficiency in India (Katyial and Sharma, 1989). In Odisha nearly 19 % of the soils are deficient in zinc (Jena *et al.*, 2008). Among the soil groups black, black mixed red and black and alluvial soil appears to be more deficient. The problem seems to be more acute in rice soil and it is aggravated to many fold in rice-rice system. Zinc fertilization has become an essential component in the package of practices for ensuring high crop productivity (Singh, 1999).

2.1.1 Zinc nutrition

In 1919, Maze first reported the essentiality of zinc in plant nutrition. Zinc deficiency appears to be one of the important nutritional disorders limiting crop growth and yield. Zinc is essential for normal, growth and yield of in plants. It has particular functions in the plants such as maintenance of structural and functional integrity of biological membranes and facilitation of protein synthesis and gene expression (Shukla and Behera., 2011)

Havlin *et al.* (2010) reported that zinc was involved in synthesis of tryptophan, a compound needed for production of growth hormone auxin and indole-acetic acid. It is also involved in chloroplast synthesis, enzyme activation and cell membrane integrity.

Zinc is also vital for oxidation process in plant cells and helps in transformation of carbohydrates and regulates sugar metabolism in plant. Its deficiency retards photosynthesis and nitrogen metabolism (Tandon, 2009).

2.1.1.1 Zn deficiency in India

Zinc deficiency was observed in intensively rice growing regions of Odisha. The DTPA extractable Zn content in soils of Odisha ranged from 0.24-2.18 mg/kg with mean value of 1.10 mg/kg. The magnitude of Zn deficiency in the state ranged from 0-76 % with mean value of 19 % (AICRPMSE, 2009-10). The zinc deficiency in black, alluvial and laterite soils of Odisha was found to be 42 %, 7 to 76 % and 2 to 12 % respectively (Jena *et al.*, 2008).

Zinc deficiency is now considered to be the most wide spread nutrient disorder in low land rice (Frageria *et al.* (2002).

2.1.1.2 Zinc status and availability in soil

Total zinc in Indian soils ranges from 2 to 1,600 ppm, but in most cases it is within 10-300 ppm. Coarse textured alluvial soils are very low in Zn while fine textured red and black clay soils are rich in Zn, Similarly highly weathered coarse textured red and lateritic and calcareous soils are poor in zinc (Tandon, 2009).

Total zinc content of soil depend on the type of parent material, age and organic matter content of the soil. According to Swain (1995), the average value of the total zinc content of most of the mineral soil varies between 10 and 300 ppm. The zinc content of Orissa soils ranges between 0.3 to 4.6 ppm (Sahu and Mitra, 1992).

The available Zn content in the soils of in Odisha ranged between 0.04-25.38 mg kg⁻¹ with a mean value of 1.16 mg kg⁻¹ (AICRPMSPE, 2008).

2.1.3 Critical level of zinc in soil and plant

Dubey *et al.* (1981) reported that the critical limit was 0.6 ppm DTPA extractable zinc in soil for rice crop. The AICRP on MSPE has been using uniform critical level of deficiency as 0.6 mg kg⁻¹ across the country as a database that has been accepted in administering Zn (Shukla and Behera,2011).

According to Sakal and Singh (1982) the critical limit of zinc in soil below which plant responded to zinc application was 0.78 ppm. The soil available zinc for rice was 0.50, 0.70, 0.80 and 1.00 ppm for *entisols*, *inceptisols*, *alfisols* and *vertisols* respectively (Katyal, 1985).

Biswas and Tewatia (1988) reported that the critical limits of DTPA extractable zinc in soil for deficiency, sufficiency and toxicity were 0.39, 1.80 and 12 ppm respectively.

2.1.4 Deficiency and toxicity symptoms of Zn in rice.

Under zinc deficiency, the mid rib of lower leaves towards the base become chlorotic. These leaves develop brown rusty spots which join together and form continuous areas. In case of severe deficiency, the entire leaf becomes rusty. Zinc deficiency in rice is termed as Khaira disease in India (Alloway, 2008). Characteristic symptoms in rice is bronzing starting with young leaves and later spreading to other leaves and stem (Tandon, 2009).

Zinc toxicity in cereals is normally 60-80 ppm on dry weight basis but tolerance of much higher concentration is reported. A survey of international literature shows that on zinc sensitive crops, the threshold values of toxicity were in the range of 150-200 ppm (Alloway, 2008).

Zinc toxicity can result in reduction in root growth and leaf expansion followed by chlorosis (Tandon, 2009).

2.1.5 Response of rice to sources of zinc.

Zinc sulphate which is most extensively used zinc fertilizer because of its higher water solubility and relative low cost (Jayaraman and Ramiah, 1989).

Zincated super, zinc phosphate ($Zn_3(PO_4)_2$) and zinc ammonium phosphate ($Zn(NH_4)PO_4$) proved as effective as Zinc sulphate on calcareous soils of Bihar (Singh and Singh, 1983).

Several sources of zinc available in the country have been evaluated for their relative efficiency and effectiveness for correcting Zn deficiencies in crops or cropping system. Among various chemical sources, Zinc sulphate heptahydrate ($ZnSO_4 \cdot 7H_2O$) containing 21-22 % Zn is the major source of Zn in India and has proved most effective compared with other Zn sources in correcting Zn deficiency. Zn-EDTA was found at par with Zinc sulphate in combating Zinc deficiency of rice, however its high cost over $ZnSO_4$ made it most uneconomical and less effective.

The efficiency of sparingly soluble Zn sources such as ZnO, ZnCO₃, Zinc frits in fine textured soils was at par with highly soluble ZnSO₄·7H₂O (Jena *et al.*, 2008).

2.1.6 Response of rice to time and method of zinc application

Soil and foliar application and sometimes even dipping of the planting material in micronutrient slurry can be used for applying micronutrient

Soil application is mostly recommended method for zinc application (Tandon, 2009). Regular and small application have been advocated by than a single large application, due to strong fixation of added soluble Zn (Swarup, 2003), Katyal and Rattan (1990) found that the best time of zinc application was at sowing or transplanting of rice.

Residual effects of zinc application are common and each crop in rotation is not to be treated with micronutrients, unlike N. Zinc applied at 10 kg Zn/ha in black clay soil leaves residual effect for 4-6 succeeding crops (Singh, 2003).

If zinc fertilizer, is not available before sowing of crop, results show that a delayed application can help the farmer to cut down loss in yield as compared to no application (Tandon, 2009).

Katyal (1985) reported that among various method of zinc application like soil application as broadcast, band placement, top dressing and foliar application. Coating of seeds with zinc suspension, nursery enrichment with zinc, dipping the seedlings roots in zinc suspension and amending zinc with organic manures before adding in soil, soil treatments and foliar sprays are more effective. Broadcasting ZnSO₄ on the surface of the soil followed by mixing appeared to be the best method of zinc application. Drilling ZnSO₄ below the seed row was equally effective like that of broadcast application, while its band placement away from the seed row was some what inferior to broadcasting or drilling or soaking seeds in ZnSO₄ solution or coating seeds with zinc powder or application of zinc to the nursery did not prove

better. However, dipping rice seedling roots in 2-4 % zinc suspension was found to be quite effective in correcting zinc deficiency and increasing yield of rice.

Although Zinc sulphate is commonly advocated for soil application for field crops, the usefulness of spray application can not be ignored and the recommendation is given in cases when soil application has been skipped for any reason or zinc deficiency is noticed in a growing crop.

In rice spray applications were effective and 5.6 kg Zn/ha applied to the soil produced 97% of the yield obtained with 3 sprays of 1% Zinc sulphate. (Tandon, 2009).

Sakal *et al.* (1993) found that split application of 25 kg ZnSO₄/ha @ 12.5 kg each at transplanting and tillering proved as effective as 25 kg ZnSO₄ applied once at transplanting. Application of 25 kg ZnSO₄ in three splits (10 kg at transplanting + 10 kg at tillering + 5 kg at PI stage) was also at par to its single application at transplanting or two split application (12.5 kg at transplanting + 12.5 kg at tillering).

Sahoo and Sahoo (2001) reported that soil application of 25 kg ZnSO₄/ha at puddling integrated with in situ green manuring in rice (cv. Lalat) was significantly superior to other method of application.

2.1.7 Residual effect of Zinc in rice-rice cropping system

Continuous application of zinc for 15 years was associated with substantial build up of available zinc in soil. At Bhubaneswar, increase in zinc content has been noticed from initial 1.40 mg/kg to 7.47 mg/kg after 15 years of continuous application of zinc under long term fertilizer experiment (Nambiar, 1994).

Response to grain yield after four seasons (one direct and three residuals) was highest (21.9 %) with 50 kg ZnSO₄/ha when compared to the other levels. The

yield response with 50 kg ZnSO₄/ha was highest (19.9 %) even after eight seasons indicating the existence of strong residual effect (Pattanaik and Bhujapalraj, 1999).

Grain yield increased 33.2 % due to residual effect of 5 kg Zn/ha applied to kharif season (Sahoo, 2005).

Residual effect of FYM, S, Zn and B recorded 2.10, 1.40, 7.97 and 1.4 % increase in mean rice yield respectively over the control. But their combined application were more effective than their single use.

2.1.8 Zinc use efficiency

According to Randhawa and Takkar (1975) response of rice to zinc in different states of India largely varies from 0.10 to 5.6 t ha⁻¹ of grain with variable levels of zinc application (10 to 100 kg ZnSO₄/ha).

2.1.9 Effect of zinc on growth and yield attributes

Srinivasan (1984) reported that plant height was increased by Zn application. Higher shoot length in Zn treated plants might be due to high auxin production in these plants. Similar results were reported by Khanda *et al.*, 1997.

Biswal (2007) found that application of ZnSO₄ @ 25 kg ha⁻¹ to soil before planting produced maximum plant height (87.7 cm) at harvest. Among the sources, ZnSO₄ proved significantly superior to Zn-EDTA.

Sahoo (2005) found that application of 5 kg Zn/ha to soil was found to be superior to 2.5 kg Zn/ha or foliar application of Zn-EDTA the plants become taller during kharif (62-75 cm) than that of rabi season (56 to 66 cm)

Sahoo (2005) found that highest LAI was recorded at 45 DAT (4.9 to 5.0) with soil application of 5 kg Zn/ha where kharif rice was grown with green manuring or FYM @ 5 t/ha.

Mohapatra (2003) found maximum plant height of 104.65 cm with use of S + Zn + B in rice.

Maximum number of tillers per hill was obtained with residual use of S+Zn+B followed by either S + Zn or Zn + B. Residual use of Zn alone recorded more number of tillers per hill than that of FYM, S, B and S + B in all the growth stages (Mohapatra, 2003).

Dixit and Khanda (1989) found that increasing levels of zinc application increased number of tillers significantly.

Khanda and Dixit (1991) reported that application of ZnSO₄ @ 25 kg/ha significantly produced higher dry matter than Zn-EDTA applied either through soil or foliar.

Sahoo and Sahoo (2001) reported that integrated application of 25 kg ZnSO₄/ha along with green manuring produced higher dry matter/hill than application of same dose of ZnSO₄ or Zn-EDTA either to soil or as foliar application.

Sharma and Singh (1985) found that application of 16 kg Zn ha⁻¹ as soil application and 5 kg Zn ha⁻¹ as foliar spray increased the weight of grains significantly over control (No zinc).

Application of Zn increased the growth parameters possibly due to inter relationship with auxin, (an important growth parameter) regulating stem elongation and cell enlargement .

Zinc @ 10 kg ha⁻¹ registered favourable effect on yield attributes viz., number of panicles m⁻², panicle weight, panicle length, number of filled spikelet (grain/panicle) and grain filling per cent and test weight (Devarajan and Krishnaswamy, 1996).

Tabassum *et al.* (2013) found that the yield attributes increased significantly with increasing levels of zinc and organic manures, over control (no zinc). The plant height increased by 7.0 to 15.4 %, number of tillers by 12.6 to 36.3 %, number of effective tillers by 14.8 to 45.3 %, length of ear head by 5.4 to 19.5 % and test weight by 3.3 to 11.3 % with increasing levels of zinc over control.

The yield of rice increased significantly with application of zinc @ 2.5, 5 and 10 kg ha⁻¹ recording 17.5, 26.3 and 29.9 % increase in grain and 21.0, 31.9 and 42.7 % in straw yield respectively over control (Tabasum *et al.*, 2013).

Zinc application increased paddy yield by 200-500 kg/ha in 39 % trials and 500-1000 kg/ha in 23 % trials (Singh, 1999 and Katyal, 1985).

Application of zinc increased the number of panicles per m² and ZnSO₄ recorded more panicles per m² than Zn-EDTA (Khanda and Dixit, 1991).

Sahoo and Sahoo (2001) reported that irrespective of methods of application ZnSO₄ produced significantly longer and heavier panicles than Zn-EDTA .

Biswal (2007) found that soil application of ZnSO₄ @ 25 kg ha⁻¹ recorded maximum test weight (24.6 g). Among the sources, ZnSO₄ was significantly superior over Zn-EDTA.

Sahoo (2005) found that application of 5 kg Zn/ha integrated with green manuring recorded maximum test weight (23.78 g) which was at par with application of 5 kg Zn/ha integrated with FYM. Application of 2.5 kg Zn/ha both in kharif and rabi improved test weight (23.68) as compared to foliar application of Zn-EDTA (22.9 g) and control (22.2 g).

2.1.10 Effect of zinc on grain and straw yield

Maharana (1992) conducted field experiment in coastal districts of Odisha and reported that application of ZnSO₄ to rice both in kharif and rabi season significantly increased the grain and straw yield.

Sharma and Rathore (1986) reported that soil application of ZnSO₄ @ 10 kg ha⁻¹ increased the rice yield by 16.2 per cent over control. Das (1981) reported that application of Zn at 0, 15, 20 and 25 kg ha⁻¹ as ZnSO₄ produced grain yields of 3.28, 3.65, 4.12 and 3.94 t ha⁻¹, respectively.

Biswal (2007) reported maximum grain yield (4790 kg ha⁻¹) with soil application ZnSO₄ @ 25 kg ha⁻¹. Grain yield increased 39.8 per cent over control.

Sahoo (2005) reported that maximum yield of 42.07 q/ha was obtained by application of green manure with 5 kg Zn/ha followed by FYM 5 t ha⁻¹ + 5 kg Zn/ha (41.80 q/ha). Grain yield increased 45.5 and 47.6 % over control by the above treatments respectively.

Chandrapala *et al.* 2010 reported that rice responded significantly to the application of Zn, S and FYM. Lowest grain yield of 4.10 t/ha was recorded with the treatment of NPK alone. However, NPK + Zn + S treatment recorded highest grain yield of 5.30 t/ha and remained at par with the treatment NPK + FYM.

Mishra *et al.* (1993) reported higher grain yield with NPK and Zn combination in Zn-deficient soils of Odisha under farmers field condition.

Khanda *et al.* (1997) reported that straw yield did not increase conspicuously with application of zinc in lateritic soil. Of the two sources, ZnSO₄ recorded 4.21 % higher straw yield than Zn-EDTA. Soil application increased straw yield by 2.2 % over foliar application.

Premkumar *et al.* (1979) and Bhuiya *et al.* (1981), observed that application of zinc either soil or foliar increased the straw yield.

Sahoo (2005) recorded highest kharif rice straw yield of 50.37 q ha⁻¹ with application of 5 kg Zn ha⁻¹ integrated with green manuring before planting.

Biswal (2007) reported highest straw yield 54.15 q ha⁻¹ with soil application of ZnSO₄ @ 25 kg/ha.

2.2 Sulphur deficiency

Singh (2000) has reported that about 45% districts of the country showed more than 40% S deficient soils. Sulphur deficiency is more acute in coarse textured soils having low organic matter.

Sulphur deficiency is increasing with each passing year, which is restricting crop yields, quality of produce, nutrient use efficiency and economic returns (Tandon, 2011)

In Odisha, S deficiency in soils ranges from 7 to 98 % with an average value of 28%. S deficiency is more prone in light textured, red and lateritic soils but coastal saline soils are sufficient in S. (AICRPMSPE,2008)

Singh *et al.* (2013) reported that out of 1191 soil samples of New Tehri district in Garhwali region, more than 40% soil having low OC content were deficient in available S. Hence S deficiency is associated with soil OC content.

2.2.1 Sulphur nutrition

S is involved in the synthesis of protein, oils and vitamins. Sulphur containing aminoacids are methionine (21% S), Cysteine (26 % S) and cystine (27% S). S is also component of Fe-S protein known as ferredoxin. Vitamins biotin and thiomine also contain S (Prasad, 1999)

S is needed for synthesis of coenzyme A, which is involved in oxidation and synthesis of fatty acids, and oxidation of intermediates of citric acid cycle. S is required for synthesis of chlorophyll (Havlin *et al.*, 2010).

2.2.2 Effect of sulphur

The results of sulphur trials on rice conducted in different locations indicate that HYV rice benefit markedly from its application. This indicates that increasing occurrence of sulphur deficiencies in soil, makes it difficult to supplement adequate amount of sulphur required for high rice yields under intensive crop rotation (Mohapatra, 2003).

Rice crop absorbs 2.5-3.5 kg S t⁻¹ of paddy produced, thus an uptake of 15-21 kg S is associated with a 6 t ha⁻¹ paddy harvest (Tandon, 1986b).

2.2.3 Critical level of sulphur in soils and plants

Critical concentration of available sulphur for soils under DTPA analysis method of extractable micronutrient content (mg kg⁻¹) categorized that soil have been

found to be < 5.00 ppm (very low), 5.0-10.00 ppm (low), 10.00-20.00 ppm (marginal) and >20.00 ppm (adequate) (Jena *et al.*, 2008).

Islam *et al.* (1997) studied sulphur concentration of rice plant at different stages of growth and suggested that sulphur concentration of 0.144, 0.091 and 0.071 % at tillering, flowering and harvesting stages were adequate to get optimum yield. He also reported that S-concentration less than 0.13 and 0.09 %, respectively at tillering and grain maturity stages caused appreciable yield reduction.

2.2.4 Growth and yield attributes

Bhuvanewari *et al.* (2007) reported that application of sulphur alone or in combination with FYM significantly increased the physiological characters over control (no sulphur). The CGR, RGR, NAR, LAI and chlorophyll content were least, which did not receive sulphur and FYM. LAI was significantly higher with application of 40 kg S ha⁻¹ and 12.5 t ha⁻¹ FYM.

Application of sulphur @ 40 kg/ha with FYM on rice recorded 296 number of panicles/m², 45 number of filled grains per panicle and 20.9 g per 1000-grain weight (Bhubaneswari *et al.*, 2007).

Favourable effects of S on yield characters and rice yield could be due to its stimulating effect in the synthesis of chloroplast protein resulting greater photosynthetic efficiency which in turn resulted in increased yield (Biswas and Tewatia, 1991).

Islam *et al.* (1887) reported favourable response to sulphur fertilization under sub-merged condition and plants were full with good vegetative growth than no sulphur application.

Bhuiyan and Islam (1989) reported reduction in panicle number in sulphur deficient plots. The number of panicle was markedly reduced to 4.1 per hill as against 14.9 per hill in sulphur treated plots.

Soren (2003) reported that application of S @ 40 kg/ha to the soil recorded higher plant height (71.73 cm) than 20 kg S/ha (71.27 cm) and foliar application (65.82 cm). It was also reported that application of elemental S @ 40 kg/ha produced 9.2 tillers per hill which was significantly superior to foliar application of sulphur (8.28 /hill). It was observed that soil application of sulphur @ 40 kg/ha recorded higher LAI (4.57) than application of 20 kg S/ha (4.37). Further, sulphur application @ 40 kg/ha was more effective on dry matter production (23.28 g/hill) than at 20 kg S/ha (23.20 g/hill) and foliar spray of S (22.51 g/hill). Soil application of S 40 kg/ha recorded higher panicle length (24.49 cm) than application of 20 kg S/ha (23.52 cm) and foliar application (20.59 cm).

2.2.5 Grain and straw yield

Biswal *et al.* (1991a, 1991b) reported that in a set of trials conducted under the FAO sulphur trials network during 1987, 1990, the yield increase due to application of 10 kg, 20 kg and 30 kg S/ha to rice were 10.6, 19.5 and 25.5 % respectively. Trials conducted on rice indicated that average yield increase due to S application ranged from 14 % to 60%.

Recent studies by ICAR's coordinated research project on Secondary and Micronutrients, trials on rice reported a good response of S to rice application. Averaged over several reports, sulphur application increased the grain yield of rice (as paddy) by 702-920 kg/ha. Average increase in the yield of rough rice due to S application was 869 kg/ha at ten location, however an increase in yield of average 734 kg/ha of rice had been reported at the rate of application of 37.5 kg S/ha (Tandon, 2011).

Takkar (1987) based on economic analysis of a large number of crop response data recommended 20-40 kg S ha⁻¹ as economical dose for enhancing rice grain yield. However, Islam *et al.* (1987) suggested application of 30 kg S ha⁻¹ as gypsum for higher grain and straw yield.

The sulphur use efficiency (SUE), relative agronomic efficiency and apparent sulphur recovery in gypsum treatments were higher than S-95 and elemental S for equal dose of S (Jena *et al.*, 2006 and Jena *et al.*, 2008).

Rice responds up to 40 kg S ha⁻¹ in various field trials on S conducted by OUAT. In rice-sunflower cropping sequence sulphur applied @ 30 kg ha⁻¹ each to rice and sunflower recorded higher cumulative yield (10.22 t ha⁻¹) which was 33% higher than control (Jena *et al.*, 2008)

Biswas and Tewatia (1992) reported that an average increase in yield due to application of S @ 20 kg ha⁻¹ was 672 kg ha⁻¹ (14 per cent yield increase over control) and on an average 27 kg of rice grain was obtained per kg of applied sulphur.

Tiwari *et al* (2006) reported that in rice-rice cropping system , a study on estimation of residual response to sulphur, application, S @ 30 kg/ha resulted in response of rice of 990 kg/ha and an overall increase in yield of 23.4 per cent in rice based cropping system (rice-rice). Almost an average yield gains due to carry over of effect of S was almost one tonne paddy/ha.

Soren (2003) reported that among different levels of S, application of 40 kg S/ha produced higher grain yield (39.30 q/ha) than the 20 kg S/ha (38.60 q/ha) and foliar application of sulphur (34.45 q/ha) . Similarly application of 40 kg S/ha produced higher straw yield (45.95 q/ha) than with 20 kg S/ha (45.25 q/ha) and foliar spray of liquid S (41.65 q/ha).

2.3 Boron nutrition

Boron is involved in cell differentiation, development and growth of pollen grains, sugar translocation, movement of growth regulators with in the plant and lignin synthesis. It is responsible for carbohydrate metabolism and synthesis of nucleic acids (DNA and RNA)and tissue development (Sakal & Singh, 1995).

Havlin *et al.*, 2010 reported that the primary function of B is in plant cell wall structure integrity that is essential for normal transport of water, nutrients and organic compounds to new growth and cell wall stability which is important for pollen tube growth that is responsible or seed development in plants.

Boron is essential for the development of reproductive tissues, and its deficiency results in low grain set or poor quality seed (Dell *et al.*, 2002)

2.3.1 Boron deficiency

Boron deficiencies are becoming increasingly important in India and are next to Zn from practical point of view. Sharma and Katyal (2006) reported that out of 57 benchmark soils of the country, B deficiency was suspected in 17.

B has emerged as an important micronutrient in Indian agriculture ,next to only Zn in the context of spread of deficiency (Sathya *et al.*, 2009). In India ,B deficiency was initially 2% in the year 1980 (Katyal and Vlek,1995) which has now increased to 52% (Singh,2012)

In Odisha, more than 50 % soils of 14 districts are deficient in B. Coarse textured, red, laterite ,mixed red and yellow soils are more prone towards B deficiency (Jena *et al.*,2008).

Sixty nine per cent of the acid soils of Odisha are reported to be deficient in B (Sarkar and Singh, 2003).

2.3.2 Critical level of boron in soil and its concentration in rice plant

In India ,hot water extractable B is the accepted procedure for determining available B in soils and the critical deficiency level (CDL) is 0.5 mg kg⁻¹ soil or 0.5 ppm (Rattan *et al.*, 2008)

Boron deficiency is found to be wide spread in soils of Odisha. Analysis of 10,142 soil samples collected from 30 district revealed that hot water soluble boron content in soils ranged from 0.18 to 5 mg/kg with a mean value of 1.41 mg/kg. Boron deficiency in soils varied from 4.4 to 89 % with state average of 44 % (Jena *et al.*, 2008).

The status of B availability in soils of Odisha revealed by AICRP on MSPE, Bhubaneswar, reported the total status of B (mg kg⁻¹) ranged from 2.0-42.0 with a mean value of 13.0. Similarly the available boron status of the soils of Odisha ranged from 0.01-2.96 mg kg⁻¹ with a mean value of 0.60 mg kg⁻¹.

Sakal and Singh (1995) reported the critical levels of boron (mg/kg or ppm) for rice to be 18 ppm (deficiency), 18-150 ppm (sufficiency) and 400 (toxicity) .

Katyal and Agrawala (1982) concluded that 0.5 ppm hot-water soluble boron could be the critical limit for deficiency and 1.00 ppm for toxicity .

Out of 30 districts in Odisha, 14 districts have more than 50 % B deficient soil. Course textured red, laterite, mixed red and yellow soils are prone to B deficiency (Jena *et al.*, 2008).

2.3.3 Growth and yield attributes

Mohapatra (2003) found direct effect of boron application in rice @1.5 kg ha⁻¹ recorded plant height at harvest of 89.10 cm, number of tillers per hills of 14.38, leaf area index of 3.94 (90 DAT), total dry matter of 29.14 g plant⁻¹ (90 DAT), crop growth rate (g d⁻¹ m⁻²) of 9.45, panicle length of 25.32, panicles m⁻² of 310.20, number of grains per panicle of 156.84 and 1000-grain weight of 21.33 g.

Premila and Dale (1984) reported significant increase in plant height and number of tillers per plant with boron fertilization.

2.3.4 Grain and straw yield

Tiwari *et al.* (2006) reported that with rice-wheat and rice-rice cropping system, boron produced significant yield increases in both the crops although B @ 5 kg borax/ha was applied in kharif season. In rice-rice system, boron applied to kharif rice increased paddy yield by 260 kg/ha followed by 234 kg/ha in rabi rice.

Shukla *et al.* (2009) reported the fertilization to rice without boron nutrient resulted in a potential yield loss of 9-12 per cent on boron deficient soil.

Tandon (2009) reported grain yield in rice due to borax application in Odisha was 570 kg/ha (15 %) in rabi season .

Response of rice to boron application in laterite soils of Bhubaneswar was studied. The range of response of rice to boron application was 0.5-4.25 q/ha with an average response of 3.86 q/ha with a B:C ratio of 5.1:1 (Jena *et al.*, 2008).

For Odisha condition, boron application @ 1.0 kg/ha through borax is recommended for rice to boron deficient soil.

Mohapatra (2003) reported that application of boron @ 1.5 kg/ha (Borax) to rabi rice resulted in residual effect on kharif rice with a grain yield of 48.14 q/ha and straw yield of 67.67 q/ha.

2.4 Residual effect of zinc, sulphur and boron on yield and yield attributing characters

2.4.1 Residual effect of zinc

Sahoo (2005) observed that residual effect of 5 kg Zn/ha + green manuring during rabi season proved superior to residual effect of FYM + 5 kg Zn/ha and sole application of zinc. Organic sources of zinc (green manure/FYM) applied to kharif rice benefitted the succeeding rabi rice due to residual effect which resulted in higher grain yield as compared to sole application of zinc.

Mohapatra (2003) reported that residual use of FYM, S, Zn and B recorded 2.10, 1.40 and 7.97 and 1.40 % mean yield increase respectively over control. Residual use of S + Zn + B recorded maximum grain yield of 52.97 q ha⁻¹.

Singh *et al.* (1983) reported marked residual effect of Zn fertilizer when applied along with farm yard manure. Application of Zn with FYM significantly increased grain and straw yield, Zn content in grain and straw over application of either Zn or FYM alone.

Nambiar (1994) reported that continuous application of zinc for 15 years in rice-rice system was associated with substantial build up of available zinc in soil. At Bhubaneswar, increase in zinc content has been noticed from on initial 1.40 mg/kg to 7.47 mg/kg after 15 years of continuous application of zinc under long term fertilizer experiment .

Devaranjan and Ramanathan (1995) reported on red loam soils of Bhubaneswar continuous application of 25 kg ZnSO₄/ha to each rice crop up to six season maximized the average rice yields and uptake of zinc and enhanced the available zinc status from initial 0.48 mg/kg to 3.85 mg/kg .

2.4.2 Residual effect of boron

Tandon (2011) reported that in rice-rice system, boron applied to kharif rice increased paddy yield by 260 kg/ha, followed by 234 kg/ha of rabi rice or total of annual yield increase of 494 kg paddy/ha as an average over 3 locations and 2 years.

Boron leaves residual effect on subsequent crops with the application of B may be omitted in subsequent crop depending on the rate of B application. Singh and Goswami (2014) reported application of 0.5 – 2.0 kg B/ha increased rice yields by 460, 500, 570 and 270 kg ha⁻¹ in acid soils of Assam, Jharkhand, Odisha and West Bengal.

Dwivedi *et al.* (1990) reported appreciable residual effect of boron fertilizer in rice-based cropping sequence. Increasing rate of boron application to kharif rice increased B content in plants and seeds of succeeding crop and in turn helped on increasing grain yield.

Mohapatra (2003) reported that application of boron recorded 2.1 % more mean grain yield in rice as residual effect over control.

2.4.3 Residual effect of sulphur

Tandon (2001) reported that in rice-rice cropping system, study on estimation of residual response to sulphur revealed that application of S @ 30 kg/ha resulted an increase in rice yield of 990 kg/ha and overall increase in yield of 23.4 %.

Chowdhury and Majumdar (1994) reported residual effect of sulphur applied to kharif rice on increase in yield attributes and yield of subsequent summer rice.

2.3.4 Residual effect of sulphur, zinc and boron

Mohapatra (2003) reported that maximum grain yield of 52.97 q ha⁻¹ was obtained in rice cv. Lalata with residual effect of S + Zn + B treatment which was at par with the yields recorded either with S + Zn (52.42 q ha⁻¹) or Zn + B (51.75 q ha⁻¹).

Application of Zn + S and Zn + B to rice-rice cropping system under Bhubaneswar location in long term fertilizer experiments did not have any

significant effect on grain and straw yield over the recommended doses (AICRP on LTF, Annual Report 2013-14).

Akhter *et al.* (1994) reported residual effect of Zn and S when applied at higher rates to first crop of the sequence. Initial application of 50 kg S + 5 kg Zn ha⁻¹ resulted in increasing grain yield of the next crop but their lower rates were not effective.

2.4 Nutrient uptake and removal

2.4.1 Sulphur uptake and removal

A large number of sulphur response data showed that S application results in a greater increase in S uptake as compared to increase in yield of biomass. There is thus a significant enrichment in the plant sulphur content which is observed in grain as well as straw (Tandon, 2011).

John *et al.* (2006a) reported that on rice rice system in Kerala, production of 10.6 tonne paddy/ha resulted in a total S uptake of 20 kg/ha through grain plus straw and more sulphur was retained in the straw than on grain.

In a long term fertilizer trial at IARI, New Delhi, sulphur uptake on rice-rice cropping system was found to be 6.5 kg ha⁻¹ in kharif and 10 kg ha⁻¹ in rabi season.

Under Bhubaneswar location in rice-rice cropping system, highest total S uptake of 3.06 kg ha⁻¹ in grain in kharif and 7.54 kg/ ha⁻¹ in grains in rabi seasons have been reported in long term fertilizer experiment (AICRP on LTF, 2013).

Long term fertilizer experiments conducted at Bhubaneswar locations in 2013 revealed that for every tonne rice production, the rate of absorption of S was 3.32 – 4.54 kg t⁻¹ in rabi season (AICRP on LTF, Bhubaneswar 2013)

2.4.2 Zinc uptake and removal

Sahoo (2005) reported that at higher levels of zinc application through ZnSO₄ (5 kg/ha) higher content of zinc was recorded in grain (39.93 ppm) and straw (66.33 ppm) as compared to lower levels (2.5 kg/ha) recording 38.81 ppm in grain and 64.61 ppm in straw.

Mohapatra (2003) reported residual use of nutrients affected Zn content both in grain and straw and their total uptake. Higher Zn content of grain and straw was marked in Zn treatments.

Sahu *et al.* (1994) correlated Zn-uptake with rate of Zn-fertilization and observed maximum Zn-uptake with 5 ppm Zn-application as ZnSO₄.

2.4.3 Boron uptake and removal

Mohapatra (2003) reported that higher content of boron both in grain and straw was found with residual effect of boron in kharif season.

De Datta (1981) reported a total uptake of 90 g/ha of Boron per/tonne of grain production of paddy.

Boron content in grain of rice ranged from 12.86 to 16.50 ppm whereas in straw ranged from 13.17 to 17.13 ppm to various doses of boron application to rice-rice cropping system under Bhubaneswar location. Highest uptake of 0.182 kg/ha of B was recorded from the treatment of boron application @ 1.0 kg ha to all crops (AICRP on MSNPE, Annual Report, 2009-10).

Nayar *et al.* (1984) reported from CRRI, Cuttack that during dry season, HYV rice varieties had low requirement of B but its uptake increased with the rates of boron application.

Combined application of Zn, S and B to rice resulted in synergistic effect on uptake of these nutrients as well as uptake of N and K also but P-uptake was adversely affected (Muralidharan and Jose, 1995)

2.5 Integrated nutrient management (INM)

Integrated nutrient management (INM) or integrated plant nutrient supply (IPNS) is defined as maintenance or adjustment of soil fertility and supply of plant nutrient to an optimum level for sustaining the desired crop productivity from all possible resources of plant nutrients in an integrated manner (Das *et al.*, 2015 and Prasad *et al.*, 2014).

Integration of organics and inorganics has been found to be quite promising not only in maintaining higher productivity but also providing greater stability to crop production (Nambiar and Abrol, 1992).

Fertilizers, inorganic manures, legumes, crop residues, industrial by-products and bio-fertilizers are the main ingredients of INM (Das *et al.*, 2015).

2.5.1 Growth parameters

Application of 1/3rd recommended dose of nitrogen (100 % RDN i.e., 120 kg N/ha) through chemical fertilizer, FYM and Azolla registered the highest plant height and leaf area index in rice (*Oryza sativa* L.). Higher yield component (viz., number of panicles/m², number of filled grains/panicle) and grain and straw yield of rice were also achieved from the same treatment as compared to 100 % recommended dose of fertilizer and control (Mohanty *et al.*, 2013).

Application of inorganic fertilizer level of N₁₀₀ P₂₀O₅ 60 K₂O₄₀ + FYM + Zn produced significantly higher panicles/m² than other nutrient management practices. It could be due to slow release of nutrients for longer period after decomposition of FYM which favoured better plant growth and yield of hybrid rice (Pandey *et al.*, 2007). Parihar (2004) also reported similar effect of FYM on rice.

Nitrogen applied after treating with neem extract under inorganic fertilizer level of N₁₀₀ P₆₀ K₄₀ produced more yield attributes than untreated nitrogen due to reduced loss of nitrogen (Pandey *et al.*, 2007).

Mohapatra (2003) reported application of S + Zn + B along with RFD @ 120-60-60 N-P-K kg ha⁻¹ resulted in vigorous crop growth at all phases of growth and produced maximum dry matter followed by application of S + Zn + RFD which remained at par with Zn + B + RFD. Application of Zn @ 5 kg ha⁻¹ along with RFD was found to be superior in recording all higher growth parameters than application of FYM @ 5 t ha⁻¹+RFD.

Sahoo (2005) reported green manuring along with Zn 5 kg ha⁻¹(ZnSO₄) + RFD @ 60-30-30 N-P-K kg ha⁻¹ recorded highest growth parameters than foliar application of Zn-EDTA +RFD.

2.5.2 Yield attributed and yield

Mohapatra (2003) recorded highest grain yield of 68.79 q ha⁻¹ with application of S+Zn+B along with RFD @ 120-60-60 kg ha⁻¹ which remained at par with application of Zn+B with RFD. It was found to be superior over application of FYM @ 5 t ha⁻¹, along with RFD.

Sahoo(2003) recorded highest grain and straw yield with application of green manuring with 5 kg Zn ha⁻¹(ZnSO₄) along with RFD @ 60-30-30 kg N-P₂O₅-K₂O ha⁻¹, which was found to be superior over foliar application of Zn-EDTA+ RFD.

Field experiment conducted for three years in alluvial soils of RRTTS, Ranital to study the integrated effect of Zn and green manuring on rice-rice cropping system. The data revealed that application of 2.5 kg Zn/ha + green manuring with dhanicha recorded 20.69 % higher yield over control (Jena *et al.*, 2008).

Maximum rice yield was obtained from green manuring (GM) with 5 kg Zn/ha (4190-4224 kg/ha) followed by that of with FYM @ 5 t/ha (4170-4190 kg/ha) (Sahoo, 2005). In kharif, maximum yield of rice (4207 kg/ha) was obtained by green manuring with 5 kg Zn/ha followed by FYM @ 5 t/ha with 5 kg Zn/ha (4180 kg/ha) (Sahoo, 2005).

Application of ZnSO₄ @ 20 kg/ha incubated or blended with press mud or FYM increase grain and straw yield of rice over recommended NPK alone (Kumar *et al.*, 1999).

Sahoo and Sahoo (2001) reported that application of 5 kg Zn/ha as ZnSO₄ integrated with FYM 5 t/ha increased the grain yield of rice to 4170 kg/ha (cv. Lalat) as compared to sole application of Zinc to soil (3930 kg).

Application of 100-60-40 kg N-P₂O₅- K₂O along with 10 tonnes of FYM gave the grain yield and B-C ratio comparable to that of 100-60-40 kg N-P₂O₅-K₂O + FYM + 25 kg ZnSO₄ ha⁻¹. (Pandey *et al.*, 2007).

Application of 1/3rd recommended dose (RD) of N through chemical fertilizer, FYM and Azolla reported higher yield components i.e., number of panicles m⁻², number of filled grain panicle⁻¹, grain and straw yield of rice as compared to 100 % recommended dose of fertilizer and control (Mohanty *et al.*, 2013).

Basal application of ZnSO₄ @ 50 kg to rice-rice cropping system along with farmers practices increased the grain yield by 6 % (6.23 t ha⁻¹) and 10.8% (7.43 t ha⁻¹) during dry season 2007-08 and 2008-09 respectively and 4.46 % (6.44 t ha⁻¹) and 9.4% (7.26 t ha⁻¹) respectively during wet seasons of 2008 and 2009. The results indicated that zinc application is required for both rice crops in the cropping system as against existing recommendation of zinc application once in three seasons in Nellore district of Andhra Pradesh (Sujathamma *et al.*, 2013). Similar results were reported earlier by Rajendra Prasad *et al.*, 2000.

Yadav and Kumar, 2009 reported that in rice-wheat system, application of Zinc to both rice and wheat was found more beneficial than its single application to any single crop. The result of site-specific nutrient management experiment indicated that maximum grain & economic yield can be achieved by including micro and macronutrients (N₁₅₀ P₂₀ O₅ 60 K₂O 120 S₄₀ B₅ ZnSO₄ 25).

2.5.3 Nutrient uptake

Ram *et al.*, 2014 reported that the sulphur uptake by grain and straw of rice increased with sulphur applied through gypsum or phosphogypsum. Application of sulphur through gypsum @ 30 kg S ha⁻¹, gypsum @ 60 kg S ha⁻¹, phosphogypsum @ 30 kg S ha⁻¹ and phosphogypsum @ 60 kg S ha⁻¹ along with a common recommended dose of NPK, Zn (150, 26.2, 33.2, 5.0 kg ha⁻¹ respectively) increased the total S uptake of rice by 25.7, 34.1, 24.3 and 32.7 % respectively, over the control (no sulphur).

Yadav and Kumar, 2009, reported that in a study response to sulphur fertilization in rice-Indian mustard and rice-wheat cropping system, sulphur application to rice (S @ 40 kg ha⁻¹) + N₁₅₀ P₆₀ K₁₂₀ to rice increased sulphur use efficiency and S uptake appreciably.

Mohapatra (2003) reported highest uptake of N, P, K, S, Zn and B in grain & straw with combined application of S, Zn & B with RFD than single application of S, Zn, B or FYM with RFD and lowest in control plot (RFD).

Sahoo (2005) reported combined application of Zn @ 5 kg ha⁻¹ or FYM @ 5 t ha⁻¹ with RFD ensured higher uptake of all nutrients (N, K & Zn) than that of zinc alone.

2.6 Economics

Sahoo (2005) reported that in kharif season application of zinc @ 2.5 kg/ha recorded higher gross return (₹ 18,667/ha) than foliar application of Zn-EDTA (₹ 18,214/ha), GM and FYM applied alone. Highest net return (₹ 9,452/ha) was recorded from application of green manure + Zn @ 5 kg/ha followed by application of Zn @ 5 kg ha⁻¹ (₹ 8399 ha⁻¹). Similarly he reported return per rupee invested was highest (₹ 0.67) with application of green manure + zinc @ 5 kg ha⁻¹.

Mohapatra (2003) reported highest return (₹ 28879/ha) in 1997-98 and ₹ 28633/ha in 1998-99 and benefit: cost ratio (1.84 and 1.83) were obtained with application of S @ 30 kg ha⁻¹ + zinc 5 kg ha⁻¹ in rice hybrid NPH-4507 followed by Lalat variety treated with the same treatment in rice (Hybrid) – rice cropping sequence.

Tandon (2011) reported that S application is highly remunerative producing extra crop with ₹ 16.6 to 41.4 for each rupee spent on sulphur. This is understable as sulphur is the least expensive of all the major nutrients when delivered through common sulphate-containing fertilizers such SSP, APS and gypsum.

VCR (value: cost ratio) are indicators of the rate of gross returns. The rate of net return (BCR or benefit: cost ratio) is given by VCR-1 and a value of VCR-2 indicates 100 % profitability. The rate of returns from input use as represented by the VCR and the BCRs and generally higher at lower rate of S application as expected according to the law of diminishing returns (Tandon, 2011).



MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted at Instructional Farm, Department of Agronomy, College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar during *kharif* and *rabi* seasons of the year 2010-11 and 2011-12.

3.2 Soil characteristics

Soil samples collected randomly from the experimental site (0-15 cm depth) were mixed together and composite sample was drawn for mechanical and chemical analysis. The results of the analysis are presented in Table 3.1a and 3.1b

Table 3.1a Mechanical and physical composition of the soil (0-15 cm depth)

Constituents	Percentage composition (air dry basis)	Methods employed
Sand	74.2%	Hydrometer method (Bouyoucos, 1962)
Silt	12.0 %	
Clay	13.8%	
Textural class	Sandy loam	

Table 3.1b Chemical composition of the soil (0-15 cm depth)

Particulars	Value	Methods employed
pH	5.8	Glass electrode Beckman's pH meter with 1:2.5 (soil: water) ratio (Jackson, 1967)
Organic carbon (%)	0.54	Walkley and Black (Jackson, 1967).
Available N Kg ha ⁻¹	295	Alkaline Potassium permanganate method (Subbiah and Asija, 1956)
Available P Kg ha ⁻¹	15	Bray and Kurtz P method (Bray and Kurtz, 1945)
Available K Kg ha ⁻¹	162	Ammonium acetate extraction and Flame photometric method (Jackson, 1967)
Available S (ppm)	8.0	Monocalcium phosphate extractable method (Massoumi and Cornfield, 1963)
Available Zn (ppm)	0.33	DTPA extractable Zn estimation by AAS (Page <i>et al.</i> , 1982)
Available B (ppm)	0.43	Hot water extraction, Azomethine H (Page <i>et al.</i> , 1982)
Electrical conductivity (d Sm ⁻¹)	0.43	Solubridge (Piper, 1950)

The chemical composition of the soil indicated that the soil was medium in organic carbon, available N P K and acidic in reaction. It was deficient in Sulphur, Zinc and Boron (Table-3.2)

Table 3.2 Chemical composition of farm yard manure

Composition	Chemical composition (%) oven dry basis	Method employed
N	0.61	Micro-kjeldhal method (Jackson, 1967)
P ₂ O ₅	0.31	Vanadomolybdate yellow colour method (Jackson, 1967)
K ₂ O	0.53	Flame photometer method (Jackson, 1967)

Table 3.3 Methods employed for plant analysis

Nutrients	Methods employed
Nitrogen	Micro-kjeldahl method (Jackson, 1967)
Phosphorus	Vanadomolybdate yellow colour method (Jackson, 1967)
Potassium	Flame photometer method (Jackson, 1967)
Sulphur (ppm)	Turbidimetric Method (Massoumi and Cornfield,1963)
Zinc (ppm)	DTPA extractable Zn estimation by AAS (Page <i>et al.</i> ,1982)
Boron (ppm)	Hot water extraction , Azomethine H (Page <i>et al.</i> ,1982)

3.3 Cropping history of the experimental plot

Rice-rice cropping sequence was followed during kharif and rabi seasons in the experimental field for the last three years i.e., 2007-08, 2008-09 and 2009-10.

3.4 Climate and season

The Instructional Farm, Department of Agronomy, College of Agriculture OUAT, Bhubaneswar is situated at 20°15' North latitude and 85° 52' East longitude. It is located at about 65 km west of Bay of Bengal at an altitude of 25.9 m above mean sea level .The climate is warm and moist with hot and humid summer and a short mild winter. The meteorological parameters during the cropping season is presented in Table 3.4 a, b, c and d illustrated graphically in Fig. 3.1a, 3.1b and 3.2a, 3.2b

3.4.1 Rainfall

The mean annual rainfall of Bhubaneswar is 1451mm. Nearly 85% of the annual rainfall is received between June to September. In general April and May are the dry months. The monsoon usually sets on around mid June and recedes by mid-October, July and August are the wettest months, while January is the driest one.

The amount of rainfall received during the cropping seasons were 1133.3 mm in kharif 2010, 96.1mm in rabi 2010-11, 1308.5 mm in kharif 2011 and 135.7 mm in rabi 2011-12, with corresponding number of 74, 17, 86, and 11 rainy days. The rainfall was higher in 2011 than 2010 (Table 3.4 a, b, c & d and Fig. 3.1a, b & 3.2a, b).

3.4.2 Temperature

The mean maximum and minimum temperature in Kharif 2010 was 33.3⁰ C and 25.9⁰ C as against the normal of 32.9⁰ C and 25.2⁰ C. The maximum and minimum temperature was 31.9⁰ C and 18.4⁰ C as against the normal of 32.5⁰ C and 19.1⁰ C during rabi 2010-11.

The mean maximum and minimum temperature in kharif, 2011 was 33.2⁰ C and 25.0⁰ C as against the normal of 32.8⁰ C and 25.3⁰ C respectively. It was 33.3⁰ C and 19.3⁰ C as against the normal of 32.4⁰ C and 19.1⁰ C during rabi 2011-12.

3.4.3 Relative humidity

In kharif, 2010, the average relative humidity in the morning hours (92.2%) was slightly less than normal value of 92.6 %, however, it was same (72.6%) in afternoon hours as compared with the normal value of 72.6%. During rabi season, the average value in the morning was 89.2 % as against normal value of 91.2 % and it was 43.6% in afternoon hours as against the normal value of 44.6 %.

During Kharif 2011, the average relative humidity in the morning hours was 92.6% against the same normal value (92.6%). During the afternoon hours the average relative humidity was 73% which was slightly higher than the normal value of 72.6%.

3.4.4 Bright sunshine hours.

The bright sunshine hours per day was 5.3 on kharif 2010, 7.1 in rabi 2010-11, 4.3 in kharif 2011 and 6.5 in rabi 2011-12 against the normal values of 5.1, 8.3, 5.1 and 8.2 respectively (Table 3.4 a, b, c & d).

Table 3.4 a Meteorological data at Instructional Farm, OUAT, Bhubaneswar during kharif, 2010

Month		Mean Temperature °C			Rainfall (mm)	No. of rainy days	Mean relative humidity (%)			Bright sunshine hours day ⁻¹
		Max.	Min.	Mean			FN	AN	Mean	
June.	C	35.5	26.9	31.2	196.1	10	91	70	80.5	6.1
	N	35.4	26.3	30.8	234.2	13	90	66	78	5.3
	D	0.1	0.3	0.4	-38.1	-3	1.0	4.0	2.5	0.8
July	C	33.0	26.2	29.6	209.2	18	92	75	83.5	5.4
	N	32.3	25.7	29.0	369.5	21	93	77	85.0	3.6
	D	0.7	0.5	0.6	-160.3	-3	-1	-2	-1.5	1.8
Aug.	C	33.3	26.4	29.8	253.5	15	92	75	83.5	4.7
	N	31.8	25.5	28.7	363.4	21	93	78	85.5	4.1
	D	1.5	0.9	1.1	-109.9	-6	-1	-3	-2	0.6
Sept.	C	32.8	25.7	29.2	286.2	18	94	72	83	5.4
	N	32.8	25.2	28.7	306.1	17	94	77	85.5	5.6
	D	0	0.5	0.5	-19.9	1.0	0	-5.0	-2.5	-0.2
Oct.	C	31.8	24.5	28.5	188.3	13	92	71	81.5	4.8
	N	32.2	23.5	28.7	162.0	10	93	65	79.0	7.1
	D	-0.4	1	-0.2	26.3	3.0	-1	6	2.5	-2.3

C=Current N=Normal (10 years average),D=Deviation from normal

Table 3.4 b Meteorological data at Instructional Farm, OUAT, Bhubaneswar during rabi, 2010-11

Month		Mean Temperature °C			Rainfall (mm)	No. of rainy days	Mean relative humidity (%)			Bright sunshine hours day ⁻¹
		Max.	Min.	Mean			FN	AN	Mean	
Dec	C	27.0	14.9	21.00	41.5	6	90	51	70.5	6.2
	N	29.0	14.7	22.00	2.2	0.3	90	40	65.0	8.0
	D	-2	0.2	-0.9	39.3	5.7	0	11	5.5	-1.8
Jan.	C	28.7	13.9	21.3	0.0	1.0	87	37	62.0	7.2
	N	29.1	14.7	21.9	10.0	1.0	90	43	66.5	8.0
	D	-0.4	-0.8	-0.6	-10.0	0.0	-3	-6	-4.5	-1.2
Feb.	C	31.9	17.5	24.7	24.6	2.0	92	43	67.5	6.9
	N	32.3	18.3	25.3	11.7	1.0	93	41	67.0	8.6
	D	-0.4	-0.8	-0.6	12.9	1.0	-1	2	0.5	-1.7
Mar.	C	35.3	21.9	28.6	1.8	1.0	89	42	65.5	7.9
	N	35.2	22.4	28.8	19.3	3.0	93	47	70.0	8.3
	D	-0.1	-0.5	-0.2	-17.5	-2.0	-4.0	-5.0	-4.5	-0.4
April	C	36.4	23.9	30.1	28.2	7.0	87	45	66	7.1
	N	36.7	25.4	31.0	25.3	3.0	90	52	71	8.6
	D	-0.3	-1.5	-0.9	2.9	4.0	-3	-7	-5	-1.5

C=Current N=Normal (10 years average),D=Deviation from normal

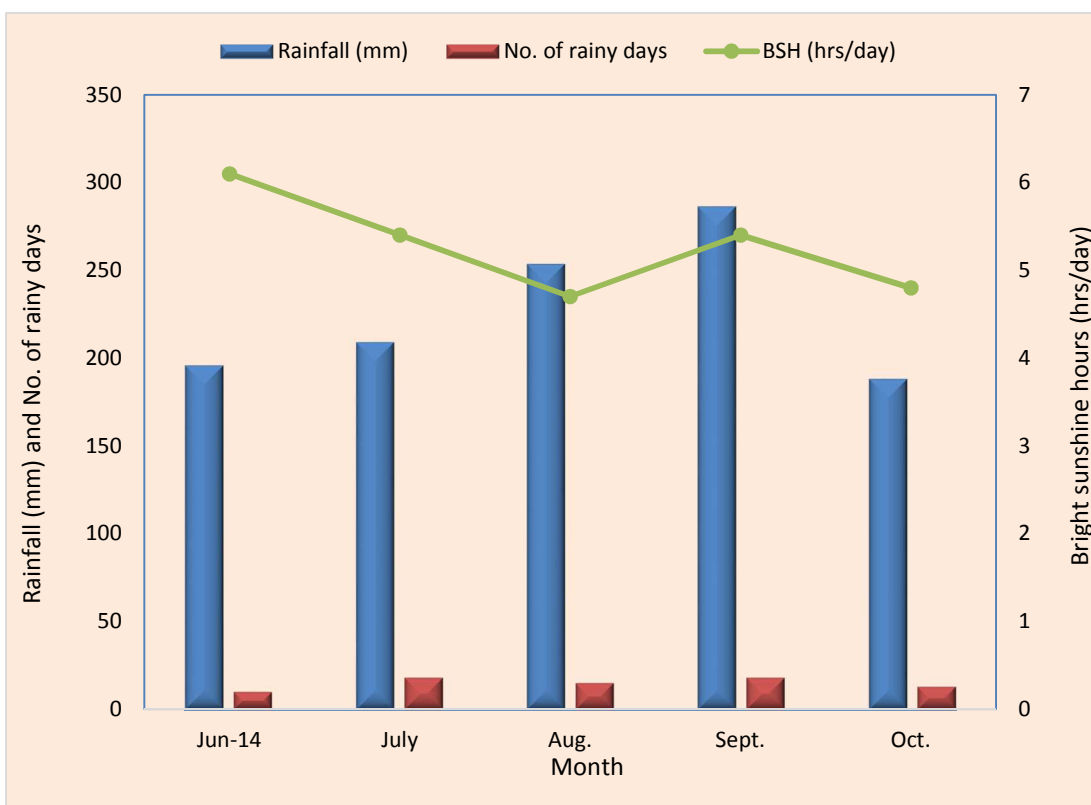
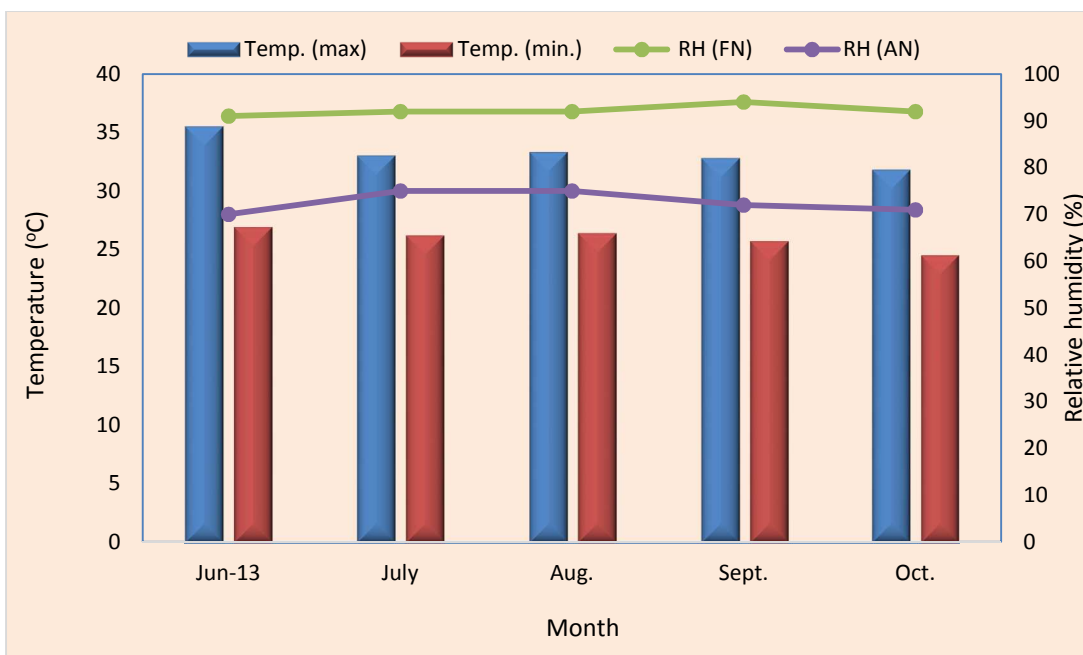


Fig. 3.1a Meteorological data at Instructional Farm, OUAT, Bhubaneswar during kharif, 2010

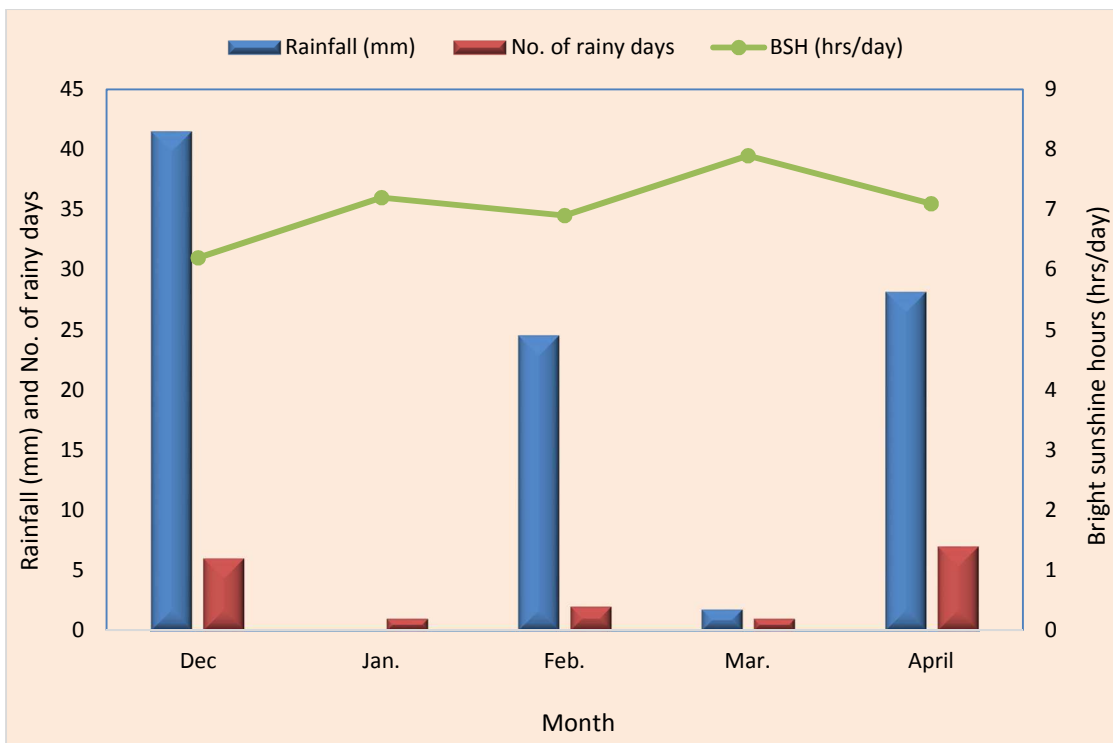
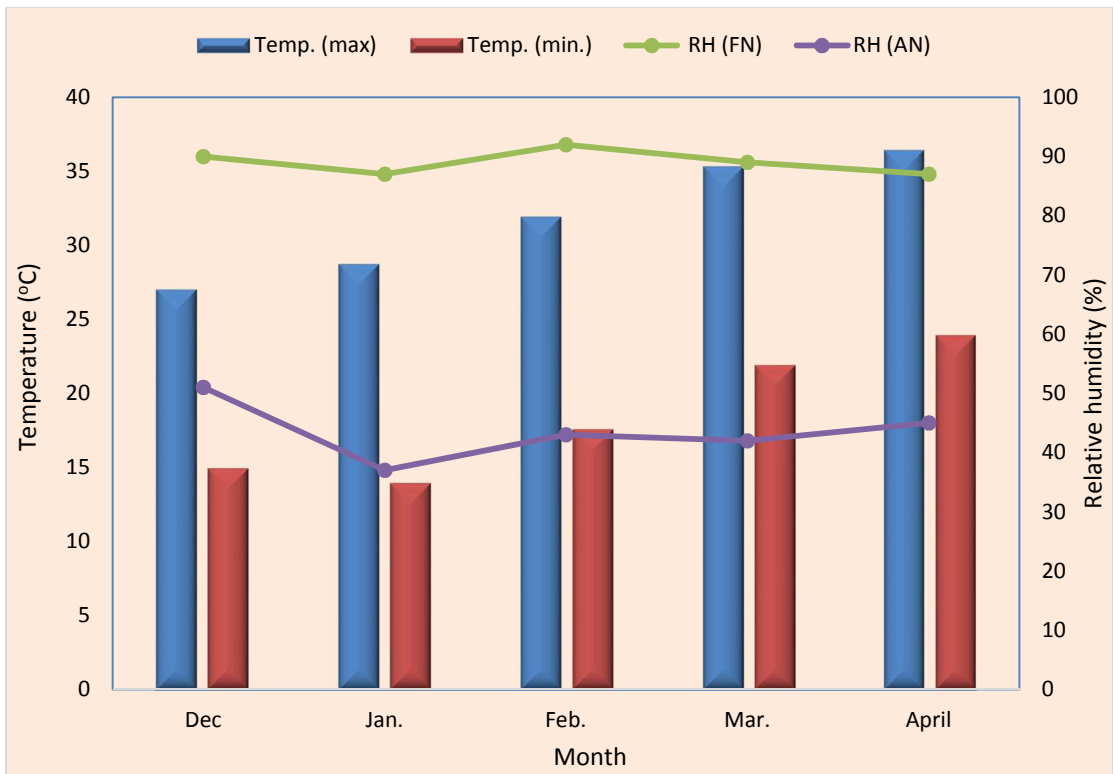


Fig. 3.1b Meteorological data at Instructional Farm, OUAT, Bhubaneswar during rabi, 2010-11

Table 3.4 c Meteorological data at Instructional Farm, OUAT, Bhubaneswar during kharif, 2011

Month		Mean Temperature °C			Rainfall (mm)	No. of rainy days	Mean relative humidity (%)			Bright sunshine hours day ⁻¹
		Max.	Min.	Mean			FN	AN	Mean	
June.	C	35.1	25.5	31.2	180.3	18	90	65	77.5	3.5
	N	35.6	26.5	30.8	224.0	13	90	66	78.0	5.4
	D	-0.5	-1.0	0.4	-43.7	5	0	-1	-0.5	-1.9
July	C	32.8	25.4	29.6	361.7	21	93	80	86.5	4.3
	N	32.4	25.8	29.1	348.0	21	93	77	85.0	3.6
	D	0.4	-0.4	0.5	13.7	0	0	3	1.5	0.7
Aug.	C	33.3	26.4	29.8	419.5	24	95	83	89	2.8
	N	31.8	25.6	28.7	366.6	20	93	77	85	4.0
	D	1.5	0.8	1.1	52.9	4	2	6	4	-1.2
Sept.	C	31.4	24.8	29.2	290.0	17	95	80	87.5	3.5
	N	32.2	25.4	28.9	324.9	17	94	77	85.5	5.6
	D	-0.8	-0.6	0.3	-34.9	0	1	3	2.0	-2.1
Oct.	C	33.4	23.1	28.1	57.0	6	90	57	73.5	7.3
	N	31.8	23.4	27.6	176.6	10	93	66	79.5	6.8
	D	1.6	-3.0	0.5	-119.6	-4	-3	-9	-6	0.5

C=Current N=Normal (10 years average),D=Deviation from normal

Table 3.4 d Meteorological data at Instructional Farm, OUAT, Bhubaneswar during rabi, 2011-12

Month		Mean Temperature °C			Rainfall (mm)	No. of rainy days	Mean relative humidity (%)			Bright sunshine hours day ⁻¹
		Max.	Min.	Mean			FN	AN	Mean	
Dec	C	29.0	15.5	22.2	0.0	0	81	38	59.5	5.1
	N	28.9	15.0	21.9	6.4	1	90	42	66.0	7.7
	D	0.1	0.5	0.3	-6.4	1	-9	-4	-6.5	-2.6
Jan.	C	28.7	16.3	22.5	44.4	3	91	51	71.0	6.1
	N	29.0	14.8	21.9	10.0	1	90	43	66.5	7.9
	D	-0.3	1.5	0.6	34.4	2	1	8	4.5	-1.8
Feb.	C	33.1	16.9	25.0	0	0	89	35	62.0	7.8
	N	32.1	18.2	25.1	14.1	1	93	42	67.5	8.4
	D	1.0	-1.3	-0.1	-14.1	-1	-4	-7	-5.5	-0.6
Mar.	C	37.4	22.8	30.8	5.4	2	94	35	64.5	6.6
	N	35.2	22.4	28.8	22.3	2	92	46	69.0	8.3
	D	2.2	0.4	2.0	-16.9	0	2	-11	-4.5	-1.7
April	C	38.2	25.1	31.6	85.9	5	88	52	70.0	7.0
	N	36.6	25.3	30.9	27.0	3	90	51	70.5	8.5
	D	1.6	-0.2	0.7	58.9	2	-2	1	-0.5	-1.5

C=Current N=Normal (10 years average),D=Deviation from normal

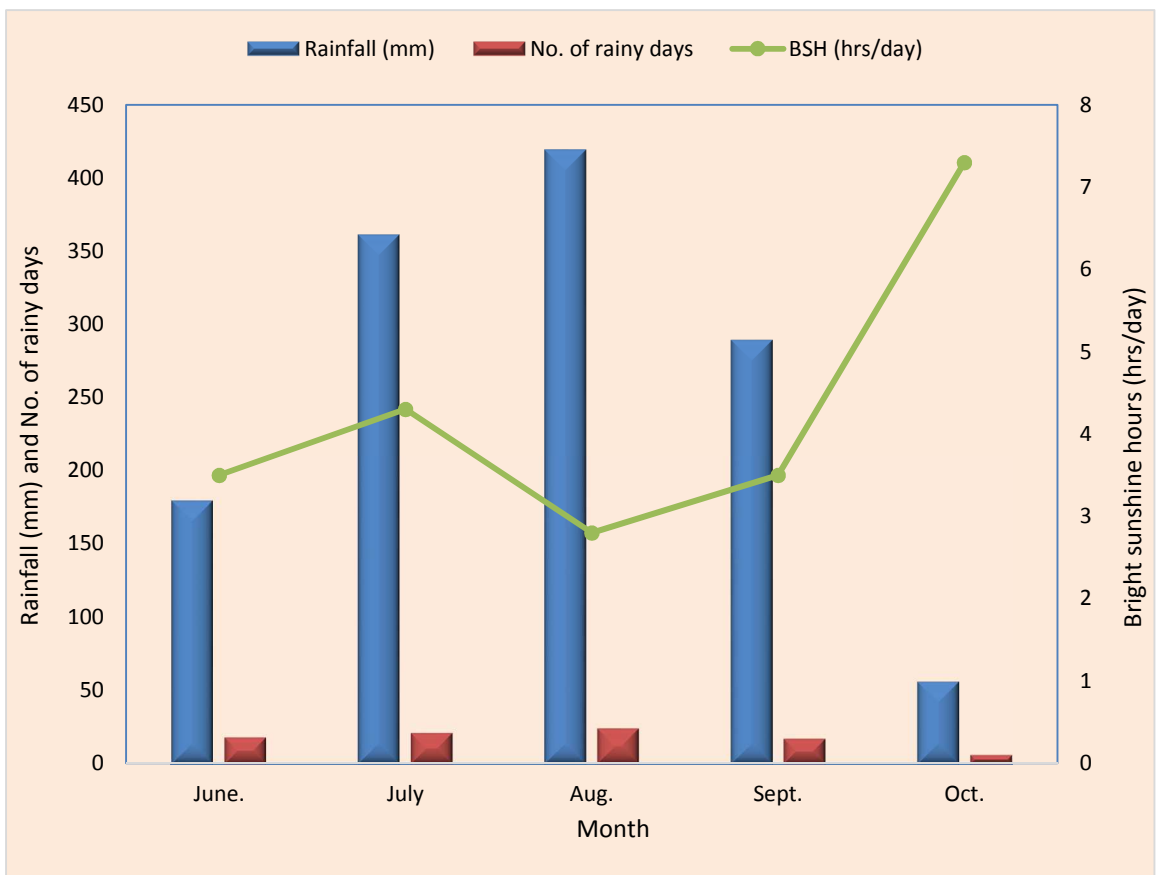
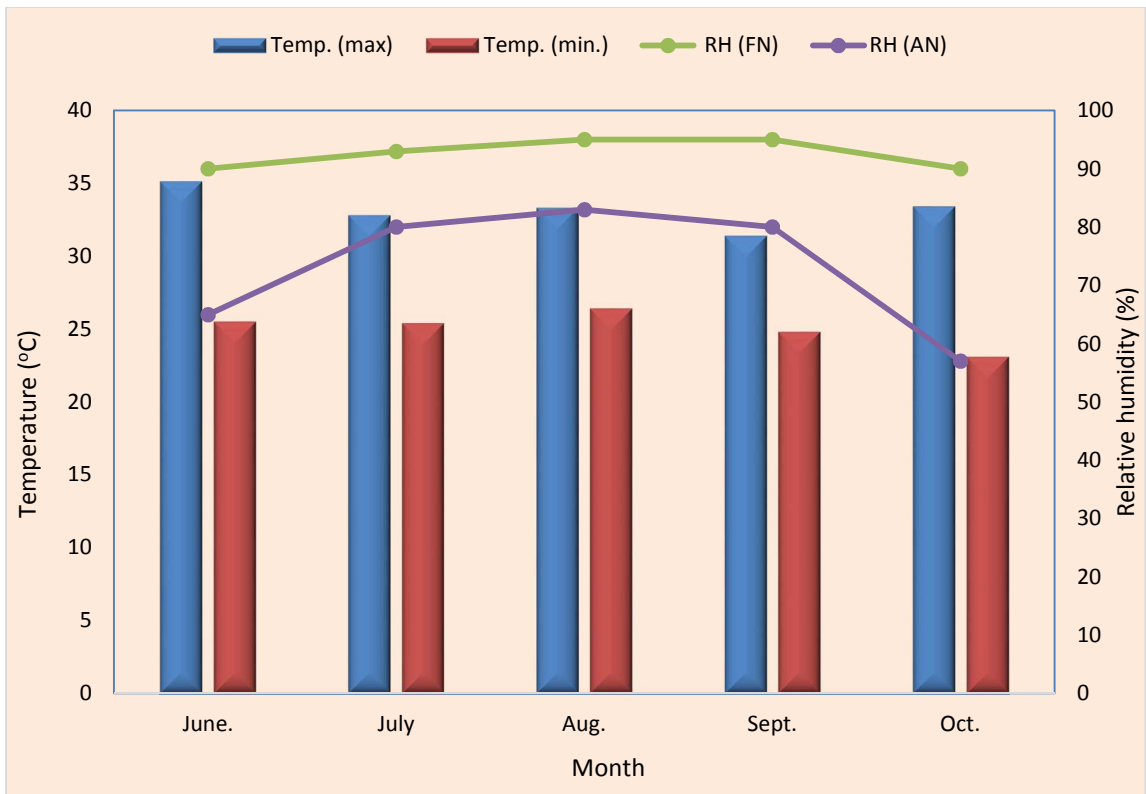


Fig. 3.2a Meteorological data at Instructional Farm, OUAT, Bhubaneswar during kharif, 2011

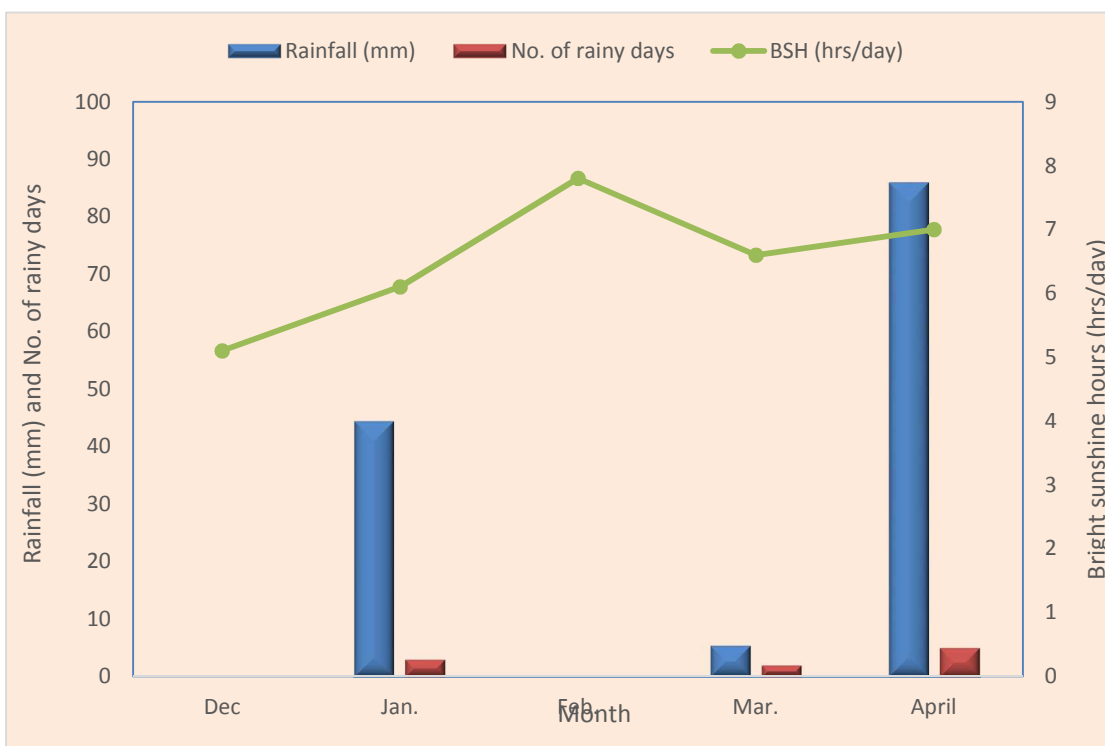
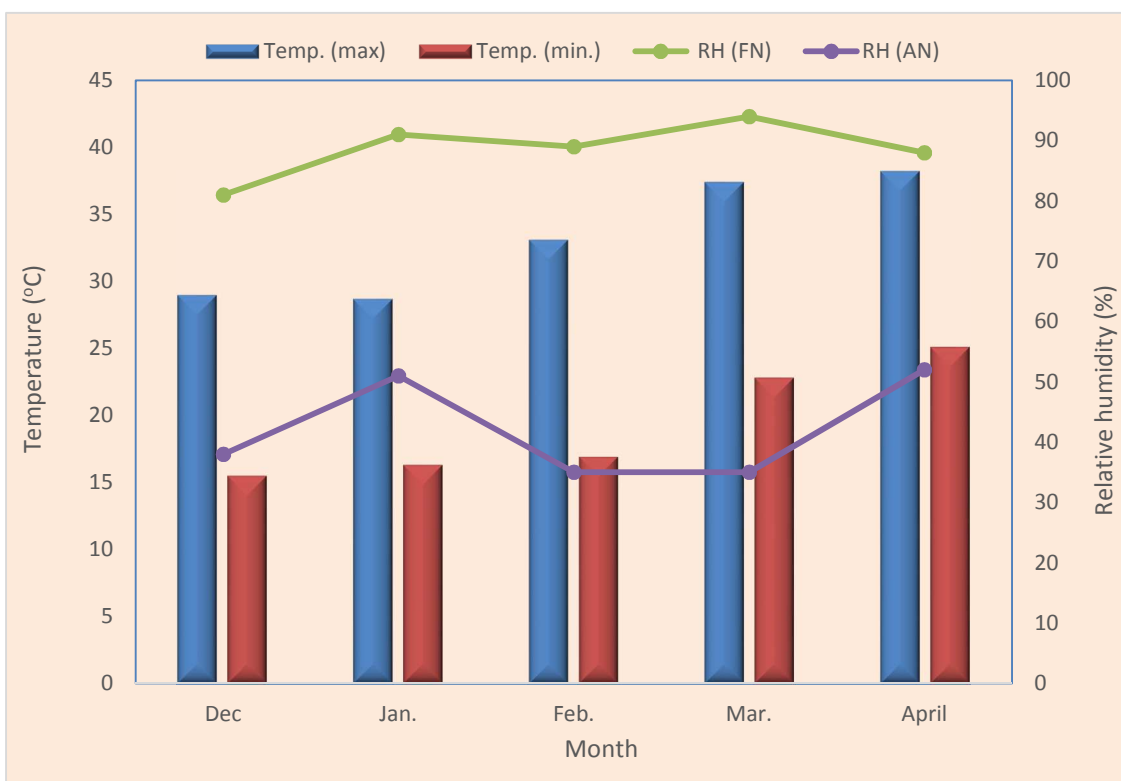


Fig. 3.2b Meteorological data at Instructional Farm, OUAT, Bhubaneswar during rabi, 2011-12

3.5 Experimental details

3.5.1 The field experiment

The field experiment was conducted in randomized block design with three replications, consisting of eleven treatments. The treatments were allocated to different plots following the random number table (Fisher and Yates ,1957). The experiment was conducted for two years i.e., kharif (wet) and rabi (dry) season of 2010-11 and 2011-12. The plan of lay out along with the treatments is given in Fig. 3.3.

Experimental design	:	Randomized block design (RBD)
Replication	:	Three
Plot size (gross)	:	5.0m x 4.0m
Plot size (net)	:	4.7 m x 3.8 m
Spacing (row to row x plant to plant)	:	15 cm x 10 cm
Crop	:	Paddy
Variety	:	Lalat

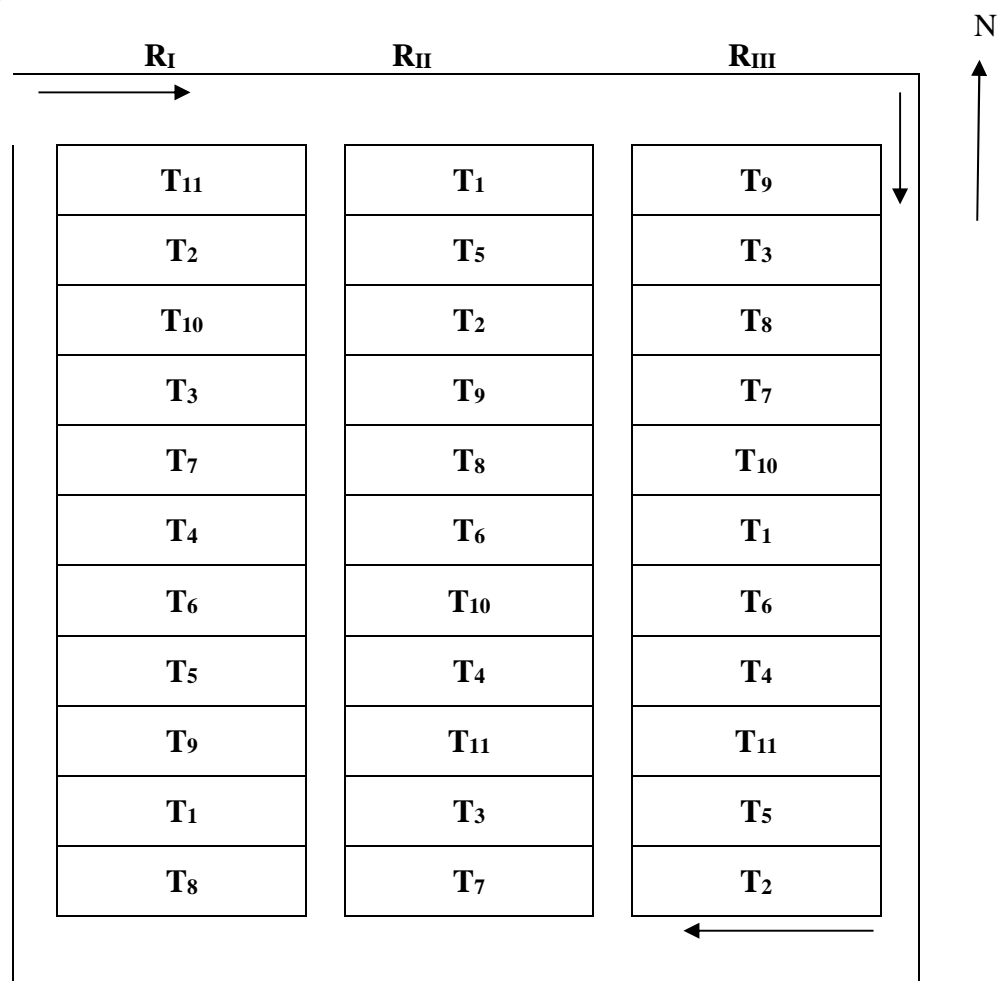


Fig. 3.3 Plan of lay-out

5.2 Details of treatment

Treatments	Details of the treatment
T ₁	- RFD (80-40-40 kg N-P ₂ O ₅ -K ₂ O ha ⁻¹)
T ₂	- RFD + FYM @ 5 t ha ⁻¹
T ₃	- RFD + Zn SO ₄ @ 25 kg ha ⁻¹ (5 kg Zn ha ⁻¹ + 2.8 kg S ha ⁻¹)
T ₄	- RFD + Zn EDTA @ 1 kg ha ⁻¹ (0.12 kg Zn ha ⁻¹)
T ₅	- RFD + S @ 30 kg ha ⁻¹
T ₆	- RFD + B @ 1 kg ha ⁻¹
T ₇	- RFD + Zn EDTA @ 1 kg ha ⁻¹ + S @ 30 kg ha ⁻¹ (0.12 kg Zn ha ⁻¹ + S @ 30 kg ha ⁻¹)
T ₈	- RFD + Zn-EDTA @ 1 kg ha ⁻¹ + B @ 1 kg ha ⁻¹
T ₉	- RFD + S @ 30 kg ha ⁻¹ + B @ 1 kg ha ⁻¹
T ₁₀	- RFD + ZnSO ₄ @ 25 kg ha ⁻¹ + B @ 1 kg ha ⁻¹ (5 kg Zn ha ⁻¹ + B @ 1 kg ha ⁻¹)
T ₁₁	- RFD + Zn-EDTA @ 1 kg ha ⁻¹ + S @ 30 kg ha ⁻¹ + B @ 1 kg ha ⁻¹ (0.12 kg Zn ha ⁻¹ + S @ 30 kg ha ⁻¹ + B @ 1 kg ha ⁻¹)

S = Sulphur (Fertisulph-G (90% elemental S), B = Boron (Borax-10.5 % B), Zn = Zinc (Zinc sulphate- 21 % Zn, Zn-EDTA - 12 % Zn), FYM = Farm yard manure

Source: S, Zn and B-Products of Karnataka Agrochemicals Limited, Bangalore (Multiplex).

3.6 Varietal characteristics

Rice variety 'Lalat' is semi-dwarf in height and matures in 125 days .The grain is long and slender. It is resistant to gall midge, brown plant hopper and bacterial diseases. It is grown in wet and dry seasons under medium land situations.

Table 3.5 Calendar of operations for kharif (wet season)

Sl.No.	Particulars	Date of operation	
		2010	2011
1.	Initial soil sample collection	22.6.10	24.6.11
2	Nursery sowing of sprouted seeds	25.6.10	27.6.11
3	Ploughing,land preparation and bond trimming.	16.7.10 and 17.7.10	18.7.11 and 19.7.11
4	Puddling, leveling and lay out of main field.	18.7.10 and 19.7.10	20.7.11 and 21.7.11
5	Leveling of plots,basal application of N,P,K,FYM,S,Zn,B as per treatment and transplanting.	20.7.10	22.7.11
6	Application of granular insecticides (Phorate 10 G @ 15 kg ha ⁻¹) to control insect pest.	9.8.10	11.8.11
7	Interculture:- a) First manual weeding b) Second manual weeding	11.8.10 26.8.10	13.8.11 3.9.11
8	Top dressing a) First top dressing of N b)Second top dressing of N and first top dressing of K	12.8.10 2.9.10	14.8.11 4.9.11
9	Plant protection a)Spraying of Quinalphos @ 1lit ha ⁻¹ b)Spraying of Mancozeb (0.3%) to the crop	3.9.10 4.9.10	5.9.11, 6.9.11
10	Draining of excess water	18.10.10	20.10.11
11	Harvesting	28.10.10	30.10.11
12	Sun drying, threshing, cleaning of grain	29.10.10 to 31.10.10	31.10.11 to 2.11.11
13	Weighing and bagging	1.11.10	3.11.11
14	Soil sample collection	7.11.10	9.11.11

Table 3.6 Calendar of operations for rabi (dry season)

Sl.No.	Particulars	Date of operation	
		2010-11	2011-12
1.	Initial soil sample collection	22.12.10	21.12.11
2	Nursery sowing of sprouted seeds	27.12.10	26.12.11
3	Ploughing, land preparation and bond trimming.	17.1.11 and 18.1.11	16.1.12 and 17.1.12
4	Puddling, leveling and lay out of main field.	19.1.11 and 20.1.11	18.1.12 and 19.1.12
5	Leveling of plots, basal application of N,P,K, as per treatment and transplanting.	21.1.11	20.1.12
6	Application of granular insecticides (Phorate 10 G @ 15kg ha ⁻¹) to control insect pest.	10.2.11	9.2.12
7	Interculture:- a) First manual weeding b) Second manual weeding	10.2.11 4.3.11	9.2.12 2.3.12
8	Top dressing a) First top dressing of N b) Second top dressing of N and first top dressing of K	11.2.11 5.3.11	10.2.12 3.3.12
9	Plant protection a) Spraying of Quinalphos @ 1lit ha ⁻¹ b) Spraying of Mancozeb (0.3%) to the crop	7.3.11 8.3.11	5.3.12 6.3.12
10	Draining of excess water	20.4.11	29.4.12
11	Harvesting	4.5.11	29.4.12
12	Sun drying, threshing, cleaning of grain	5.5.11 to 7.5.11	4.5.12 to 6.5.12
13	Weighing and bagging	8.5.11	7.5.12
14	Soil sample collection	12.5.11	11.5.12

3.7 Details of field operation**3.7.1 Nursery management**

Seedlings were raised in nursery beds of 10m length, 1m width and 15 cm height with drainage channels of 30 cm width between beds. Sprouted seeds were sown in the nursery bed. The bed was fertilized with well-decomposed FYM (Farm

Yard Manure) at the rate of one basket (20 kg) along with 175 g DAP + 100 g urea for a bed. A seed rate of 50 kg per hectare for HYV Lalat was used. After sowing of sprouted seeds, soil moisture was maintained at saturation level up to 10 day of sowing and 1-2 cm standing water was maintained thereafter. Drainage of excess water was ensured during heavy rains in kharif seasons for both the year of experimentation. In order to protect tender seedlings from insect pest infestation, granular insecticide was applied to the nursery bed. The seedlings uprooted for transplanting after 25 days of sowing in nursery.

3.7.2 Field preparation

Ploughing was done twice by tractor to bring the field into a fine tilth .It was laid out according to the plan of lay out. Before transplanting, puddling and leveling were undertaken both in the kharif and rabi season. Well decomposed FYM @ 5 t ha⁻¹ was applied to the designated treatments in kharif season only and incorporated in to the soil.

3.7.3 Fertilizer application

Full P @ 40 kg P₂O₅ ha⁻¹ at the time of transplanting .Full K @ 40 kg K₂O ha⁻¹ was applied in two splits i.e half at transplanting and half at panicle initiation stage of rice. Nitrogen @ 80Kg ha⁻¹ was applied as 50 % at transplanting, 25 % at tillering and rest 25 % at panicle initiation stage. Sulphur, Zinc and Boron fertilizers were applied to soil before planting as per treatment in kharif season only. Urea, DAP, and Muriate of potash were used as source of N, P₂O₅ and K₂O during both the kharif and rabi seasons. Sulphur @ 30 kg ha⁻¹ as Fertisulph-G(90 %S), zinc as ZnSO₄ @ 25 kg ha⁻¹ and ZnEDTA @ 1 kg ha⁻¹ and boron @ 1 kg ha⁻¹ as borax were applied as per treatment in kharif season only.

The succeeding rabi rice (Lalat) was transplanted with a uniform fertilizer dose of 80:40:40 kg N:P₂O₅:K₂O ha⁻¹ only in the said layout and the residual effect of FYM,S,Zn,and B (applied to kharif rice)were studied .The sources of N, P₂O₅ and K₂O were similar to that of kharif rice.

3.7.4 Transplanting

Transplanting was carried out as per calendar of operations (Table 3.5 & 3.6) with a spacing of 15 cm x 10 cm About 1 to 2 seedlings per hill were planted in north-south direction.

3.7.5 Water management

After transplanting, a saturation level of soil water was maintained up to 25 days to induce more tillering and thereafter submergence of 5 ± 2 cm standing water was maintained throughout the crop growing season. The field was drained out one day before fertilizer application followed by irrigation in the next day after fertilization to maintain submergence at desired level. Drainage of excess water from all experimental plots were done ten days before harvest of crops.

3.7.6 Intercultural operation

Two manual weedings were done at 20 and 40 days after transplanting for both kharif and rabi season.

3.7.7 Plant protection

Prophylactic measures were taken to protect the crop from insect, pest and disease attack. Seed treatment with bavistin (Carbendazim) @ 2g kg^{-1} of seed was done to prevent seed borne diseases. To control the insect pest attack insecticide i.e Phorate 10 G @ 15kg ha^{-1} and Quinalphos @ 1 litre ha^{-1} was applied. To control diseases, Mancozeb(0.3%) was applied to the crop.

3.7.8 Harvesting and threshing

Harvesting operations were done manually by eliminating two border rows. The crop was harvested when 85 per cent grains turned to straw yellow colour. The harvested crop was left two days in the field for sun drying before it was bundled and carried to the threshing floor. Threshing was done for each plot separately with the help of pedal thresher. Grain and straw yields were recorded after drying in the sun for 3 to 5 days to reduce the moisture to 14 % in the grain during both the seasons.

3.8 Calendar of operation

The details of calendar of field operations during kharif and rabi seasons of experimentation are presented in Table 3.5 and 3.6.

3.9 Pre-harvest observations

3.9.1 Sampling technique

The sampling unit of one square meter was ear marked in each plot to take biometric observations. Four corner hills and the central one of each quadrant were marked by pegs and periodic growth observations were recorded from the five hills.

The observations were recorded at an interval of 30 days commencing from 30th day after transplanting (30DAT) and at harvest.

3.9.2 Plant height

The plant height was recorded from the ground level up to the auricle of the top most leaf of the main shoot of the sample plants till flowering and from ground level up to the neck of the top most panicle after flowering, at regular interval of 30 days commencing from 30 DAT from each plot.

3.9.3 Tiller number

Number of tillers per plant of the sample plants was recorded at 30 days interval commencing from 30 DAT. Thereafter the observations were totaled and averaged at different stages of growth.

3.9.4 Leaf area

Five leaves (third from the top) were randomly chosen from the field and actual leaf area was taken by the help of a leaf area metre. The apparent leaf area was determined by multiplying the length and the middle width of the third leaf. The leaf area coefficient and the LAI were determined by using the following formula (Watson,1947).

$$\text{Leaf area coefficient (LAC)} = \frac{\text{Actual leaf area}}{\text{Apparent leaf area}}$$

$$\text{Leaf area index (LAI)} = \frac{\text{Total actual leaf area}}{\text{Total land area}}$$

$$= \frac{\text{Apparent leaf area (m}^2\text{)} \times \text{LAC} \times \text{tillers/m}^2 \times \text{average no. of leaves/tiller}}{\text{Land area (m}^2\text{)}}$$

3.9.5 Dry matter accumulation

Two hills from the destructive sampling rows of each plot were uprooted at 30 days interval, starting from 30 DAT and the roots were separated. They were initially sun dried and then oven dried at 65°C for 24 hours till a constant weight was achieved. The dry matter accumulation per plant was expressed in g plant⁻¹ on oven dry basis.

3.10 Post-harvest studies

The post harvest observations were recorded at the time of harvesting from the five peg marked plants.

3.10.1 Number of panicles per m²

Total number of panicles per square meter of the sampling units were counted at the time of harvest of each plot and averaged to obtain panicles per square meter.

3.10.2 Length of panicles

The length of five panicles from five sample hills were measured from neck node to tip of the panicle, averaged and recorded as panicle length in cm.

3.10.3 Number of fertile grains per panicle

The number of fertile grains of five panicles selected randomly from sample hills were recorded and counted and averaged as fertile grains per panicle.

3.10.4 1000-grain weight (Test weight)

Five random samples of one thousand grains were taken from each plot after threshing. Their weights were recorded separately to find out the average 1000-grain weight in gram.

3.10.5 Grain yield

The sun dried bundles of each plot were threshed using power operated thresher. The grains were cleaned and dry weight was recorded. The weight of the grains of the five sample hills was added to respective net plot grain yield and the final grain yield was reported in tonnes per hectare.

3.10.6 Straw yield

Weight of the straw in each plot was recorded after threshing. Straw weight of the five sample hills were added and final straw yield was reported as tonnes per hectare.

3.10.7 Harvest index (HI)

The harvest index was calculated by the following formula.

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

where economic yield refers to grain yield and biological yield is the sum of grain, chaff & straw yields.

3.11 Chemical analysis of plant

3.11.1 Plant nutrient content

Composite plant samples from each treatment for three replications were collected at the time of the crop harvest for kharif and rabi season. The samples were oven dried, properly grinded by a Willey mill grinder and passed through a 2 mm sieve for the purpose of chemical analysis for N, P, K, S, Zn, and B content in plant samples. Analysis was done as per methods mentioned in Table 3.2d.

3.11.2 Nutrient uptake

The uptake of the particular nutrient by grain and straw was sorted out by multiplying their nutrient content with corresponding per hectare treatment yield. Total nutrient uptake was determined by summing up the amount removed by the grain and straw and was expressed in kg ha⁻¹ in case of N, P, K, S and g ha⁻¹ for Zn and B.

3.12 Statistical analysis

The data were analysed as per the procedure described for Randomized Block Design (Panse and Sukhatme, 1978). Standard error of means, SE(m) and critical differences (CD) were calculated at 5 per cent level for comparing the treatment means, wherever 'F' test was found significant. The following formulae were used for estimation of SE(m) and CD.

$$SE(m) \pm = \sqrt{\frac{EMS}{r}}$$

Where EMS = error mean sum of square

r = number of replications

CD (0.05) = SE(m) \pm X $\sqrt{2}$ x t (0.05) at error degrees of freedom.

3.12.1 Correlation Studies

Correlation between yield and other ancillary characters were studied. Correlation coefficient (r) was calculated by using the following formulae (Panse and Sukhatme, 1978).

$$r = \frac{\sum xy - \frac{\sum x \cdot \sum y}{N}}{\sqrt{\left[\sum x^2 - \frac{(\sum x)^2}{N} \right] \left[\sum y^2 - \frac{(\sum y)^2}{N} \right]}}$$

Where ,r= Correlation coefficient

x and y represent the mean values of different agronomic traits of which

x = independent variable

y = dependent variable

N = Number of treatments

3.13 Economics

The cost of cultivation and gross return of the rice-rice cropping system under different nutrient management practices for the years of experimentation in 2010-11 and 2011-12 were calculated on hectare basis taking in to account the prevailing price of inputs and total grain and straw produced of the system. Net return was calculated by deducting the cost of cultivation from the gross return for the system. Benefit-cost ratio (B:C) was calculated by dividing net return with cost of cultivation (Singh *et al.*, 2015).



RESULTS

The present investigation was made to assess the effect of integrated nutrient management in rice-rice cropping system. Data collected from the experiments were analysed and presented in this chapter with interpretation.

4.1 Pre-harvest studies

4.1.1 Plant height

Data relating to height are presented in Table 4.1a, b and illustrated in Fig. 4.1. The height increased with time and reached its maximum at harvest. The rate of increase in height was maximum between 30 to 60 days after transplanting (DAT), coinciding with the elongation stage of the crop.

The height was influenced significantly by different treatments from 30 DAT till harvest. It was highest at harvest during kharif 2010 (106.00 cm) and 2011 (105.00 cm) by application of RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ (T₁₀) with an average height of 106.00 cm. It was superior to other treatments as there was an increase of 1 to 27 per cent in height. The highest increase was 27 per cent over application of RFD alone (T₁) while it was lowest (1 %) over application of RFD + Zn-EDTA + S + B (T₁₁). The increase was 3, 5, 19, 22 and 23 per cent over application of ZnSO₄, FYM, S, Zn-EDTA and B respectively along with RFD. Application of ZnSO₄ + B along with RFD (T₁₀) was significantly superior over other treatments except T₁₁ in increasing the plant height.

During rabi season taller plants (104 cm) were produced due to the residual effect of ZnSO₄ + B which was applied along with RFD to kharif rice (T₁₀). It was significantly superior over other treatments except T₁₁ (RFD + Zn-EDTA + S + B) and T₃ (RFD + ZnSO₄). The plants became taller during the kharif (83 to 106) than that of rabi season (80 to 104) (Table 4.1a and 4.1b).

Table 4.1a Effect of integrated nutrient management on plant height (cm) during kharif season

Treatments		30 DAT*			60 DAT			90 DAT			At Harvest		
		2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T ₁	RFD	41	37	39	62	60	61	84	79	81	85	81	83
T ₂	RFD+FYM	58	56	57	80	78	79	99	98	99	102	99	101
T ₃	RFD+ZnSO ₄	59	57	58	84	81	82	102	100	101	103	102	103
T ₄	RFD+Zn-EDTA	44	42	43	68	63	65	86	82	84	88	86	87
T ₅	RFD+S	47	45	46	70	67	67	88	83	86	91	87	89
T ₆	RFD+B	42	40	41	63	61	62	85	79	82	87	84	86
T ₇	RFD+Zn-EDTA+S	58	51	53	79	76	77	96	95	95	99	97	98
T ₈	RFD+Zn-EDTA+B	52	48	49	73	69	71	91	89	89	92	93	93
T ₉	RFD+S+B	51	50	50	74	71	73	95	94	94	97	95	96
T ₁₀	RFD+ ZnSO ₄ +B	62	60	61	87	83	85	106	103	105	106	105	106
T ₁₁	RFD+Zn-EDTA+S+B	61	59	60	86	84	84	103	102	102	104	105	105
SEm (±)		1.05	1.16	1.26	1.56	1.57	1.78	0.87	1.26	1.41	1.02	1.330	1.40
CD (P = 0.05)		3.09	3.43	3.72	4.62	4.64	5.26	2.56	3.72	4.18	3.02	3.922	4.15

*DAT – Days after transplanting

Table 4.1b Residual effect of integrated nutrient management on plant height (cm) during rabi season

Treatments		30 DAT			60 DAT			90 DAT			At Harvest		
		2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T ₁	RFD	37	34	35	58	58	58	80	74	77	81	78	80
T ₂	RFD+FYM	53	52	53	76	75	76	95	95	95	100	96	88
T ₃	RFD+ZnSO ₄	56	54	55	81	77	79	98	97	98	102	100	100
T ₄	RFD+Zn-EDTA	41	40	41	65	61	63	83	78	80	84	83	84
T ₅	RFD+S	42	42	43	66	64	65	87	81	84	87	84	86
T ₆	RFD+B	39	38	39	60	60	60	81	74	74	84	82	83
T ₇	RFD+Zn-EDTA+S	52	49	51	75	74	74	92	92	92	96	95	96
T ₈	RFD+Zn-EDTA+B	46	44	45	68	68	68	89	86	88	91	91	91
T ₉	RFD+S+B	48	46	47	70	69	70	92	90	91	94	94	94
T ₁₀	RFD+ ZnSO ₄ +B	58	57	58	83	84	83	101	100	101	105	103	104
T ₁₁	RFD+Zn-EDTA+S+B	57	55	56	82	80	81	100	100	100	103	101	102
SEm (±)		1.45	1.26	1.48	2.03	0.96	1.93	1.28	0.84	1.39	1.21	0.83	1.42
CD (P = 0.05)		4.28	3.74	4.38	5.98	2.84	5.69	3.79	2.48	4.11	3.58	2.47	4.18

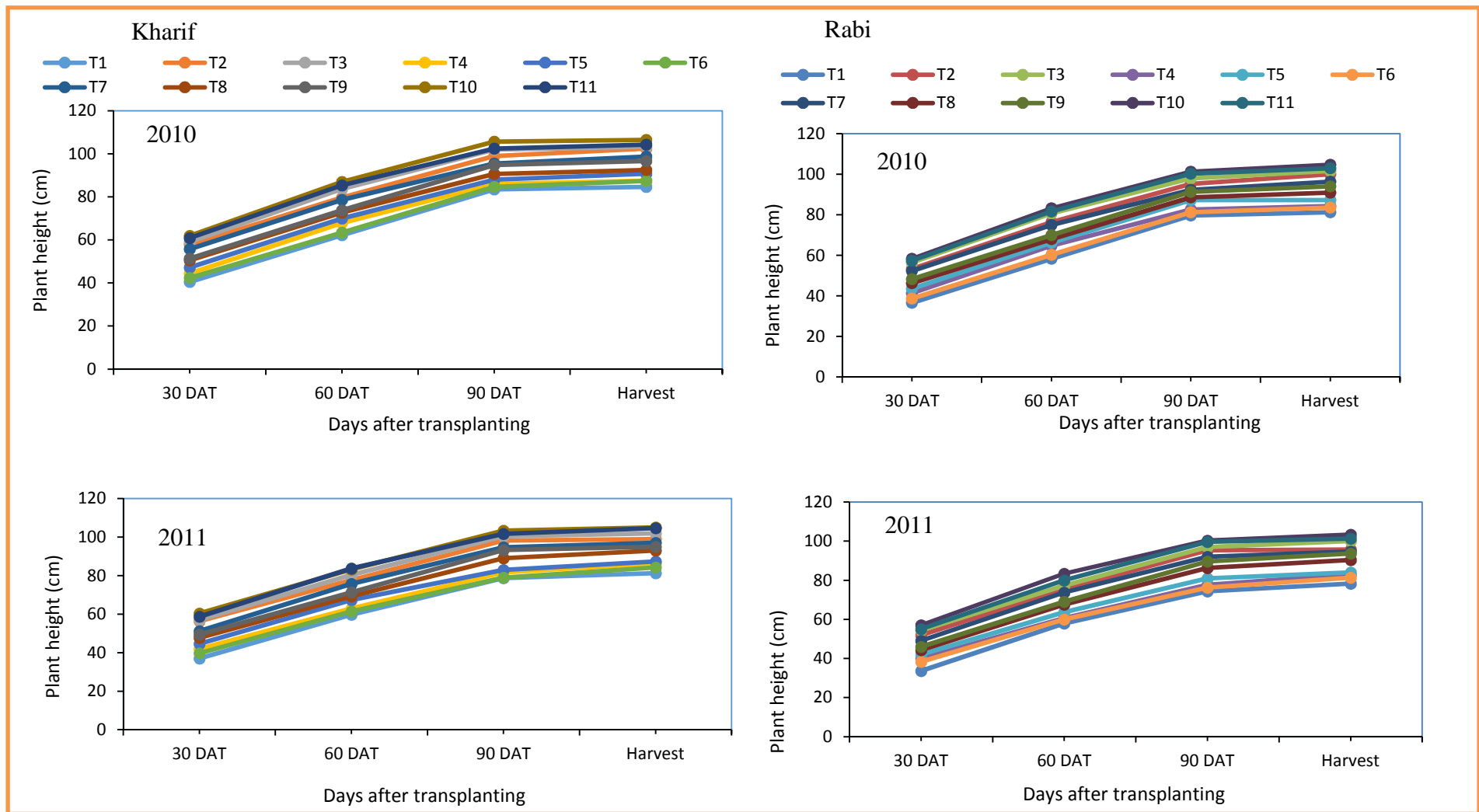


Fig. 4.1 Effect of integrated nutrient management on plant height (cm)

4.1.2 Number of tillers plant⁻¹

Data on number of tillers per plant are presented in Table 4.2a, b and illustrated in Fig. 4.2. Rapid increase in number of tillers was observed between 30 to 60 DAT. Maximum number of tillers per plant (15) was recorded in treatment T₁₀ (RFD + ZnSO₄ + B) which was at par with T₁₁ (RFD + Zn-EDTA + S + B) (14.7) and T₃ (RFD + ZnSO₄) (14.7). Application of RFD + ZnSO₄ + B increased 30 per cent more tillers over application of RFD (T₁) only. Application of RFD + ZnSO₄ + B increased 9.4, 5.6, 22.0, 17.1 and 27.1 per cent over single application of FYM, ZnSO₄, Zn-EDTA, S and B along with RFD. Application of RFD + FYM increased 11.4, 7 and 16.1 per cent over single application of Zn-EDTA, S and B along with RFD.

During rabi season there was rapid increase in number of tillers per plant between 30 to 60 DAT. Residual effect of ZnSO₄ + B applied along with RFD to kharif rice (T₁₀) increased 45 per cent more tillers per plant over T₁ (RFD). T₁₀ was significantly superior over other treatments, but was at par with T₁₁ and T₃. Residual effect of ZnSO₄ + B along with RFD increased 45, 11.5, 6.8, 32.4, 29.1 and 37.1 per cent more number of tillers per plant over single application of RFD (T₁), FYM (T₂), ZnSO₄ (T₃), Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD. Residual effect of FYM along with RFD increased 18.8, 15.8 and 23 per cent more number of tillers over single application of Zn-EDTA, (T₄), S (T₅) and B (T₆) along with RFD.

4.1.3 Leaf area index (LAI)

Data pertaining to leaf area index are presented in Table 4.3a, b and illustrated in Fig. 4.3. LAI increased from 30 to 60 DAT rapidly and there after decreased. It was affected significantly by different treatments. During kharif, highest LAI (3.51 to 3.57) was obtained at 60 DAT with application of RFD + ZnSO₄ + B (T₁₀) which was significantly superior over all other treatments.

Table 4.2a Effect of integrated nutrient management on number of tillers during Kharif season

Treatments		30 DAT			60 DAT			90 DAT		
		2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	4.7	4.5	4.6	10.6	8.9	9.80	12.2	10.8	11.5
T ₂	RFD+FYM	7.1	6.7	6.9	13.0	11.0	12.0	14.7	12.6	13.7
T ₃	RFD+ZnSO ₄	7.4	6.8	7.1	13.9	11.6	12.8	15.3	13.2	14.2
T ₄	RFD+Zn-EDTA	5.1	5.1	5.1	11.3	9.5	10.4	13.2	11.4	12.3
T ₅	RFD+S	5.5	5.3	5.4	11.7	9.8	10.8	13.5	12.1	12.8
T ₆	RFD+B	4.9	4.7	4.8	11.1	9.3	10.2	12.6	11.1	11.8
T ₇	RFD+Zn-EDTA+S	6.7	6.3	6.5	12.7	10.6	11.7	14.4	12.4	13.4
T ₈	RFD+Zn-EDTA+B	6.1	5.9	5.9	12.2	10.1	11.2	13.8	12.2	12.9
T ₉	RFD+S+B	6.4	6.1	6.3	12.4	10.3	11.4	14.0	12.4	13.2
T ₁₀	RFD+ ZnSO ₄ +B	8.1	7.2	7.6	15.2	12.9	14.0	16.3	13.8	15.0
T ₁₁	RFD+Zn-EDTA+S+B	7.5	7.6	7.5	14.7	12.1	13.4	16.0	13.5	14.7
SEm (±)		0.16	0.13	0.09	0.22	0.26	0.17	0.178	0.51	0.27
CD (P = 0.05)		0.48	0.40	0.26	0.67	0.76	0.51	0.525	1.50	0.80

Table 4.2b Residual effect of integrated nutrient management on number of tillers during rabi season

Treatments		30 DAT			60DAT			90DAT		
		2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	6.2	6.4	6.3	11.5	11.4	11.5	10.6	10.9	10.7
T ₂	RFD+FYM	8.6	8.6	8.6	15.2	13.9	14.6	14.6	13.2	13.9
T ₃	RFD+ZnSO ₄	9.3	9.2	9.2	15.9	14.1	15.0	15.2	13.8	14.5
T ₄	RFD+Zn-EDTA	6.5	7.0	6.7	12.9	12.1	12.5	12.1	11.3	11.7
T ₅	RFD+S	6.9	7.2	7.0	13.4	12.9	13.2	12.2	11.7	12.0
T ₆	RFD+B	6.4	6.9	6.7	12.0	11.5	11.7	11.5	11.1	11.3
T ₇	RFD+Zn-EDTA+S	8.0	8.2	8.1	14.6	13.4	14.0	13.3	12.9	13.1
T ₈	RFD+Zn-EDTA+B	7.0	7.6	7.3	13.6	13.1	13.9	12.7	12.0	12.4
T ₉	RFD+S+B	7.0	7.8	7.4	14.3	13.2	13.7	13.1	12.5	12.8
T ₁₀	RFD+ ZnSO ₄ +B	9.8	9.5	9.7	15.8	16.2	16.0	16.1	14.8	15.5
T ₁₁	RFD+Zn-EDTA+S+B	9.4	9.4	9.4	16.2	15.1	15.7	15.7	14.1	14.9
SEm (±)		0.13	0.13	0.10	0.31	0.11	0.19	0.17	0.12	0.10
CD (P = 0.05)		0.40	0.39	0.30	0.93	0.33	0.56	0.52	0.36	0.30

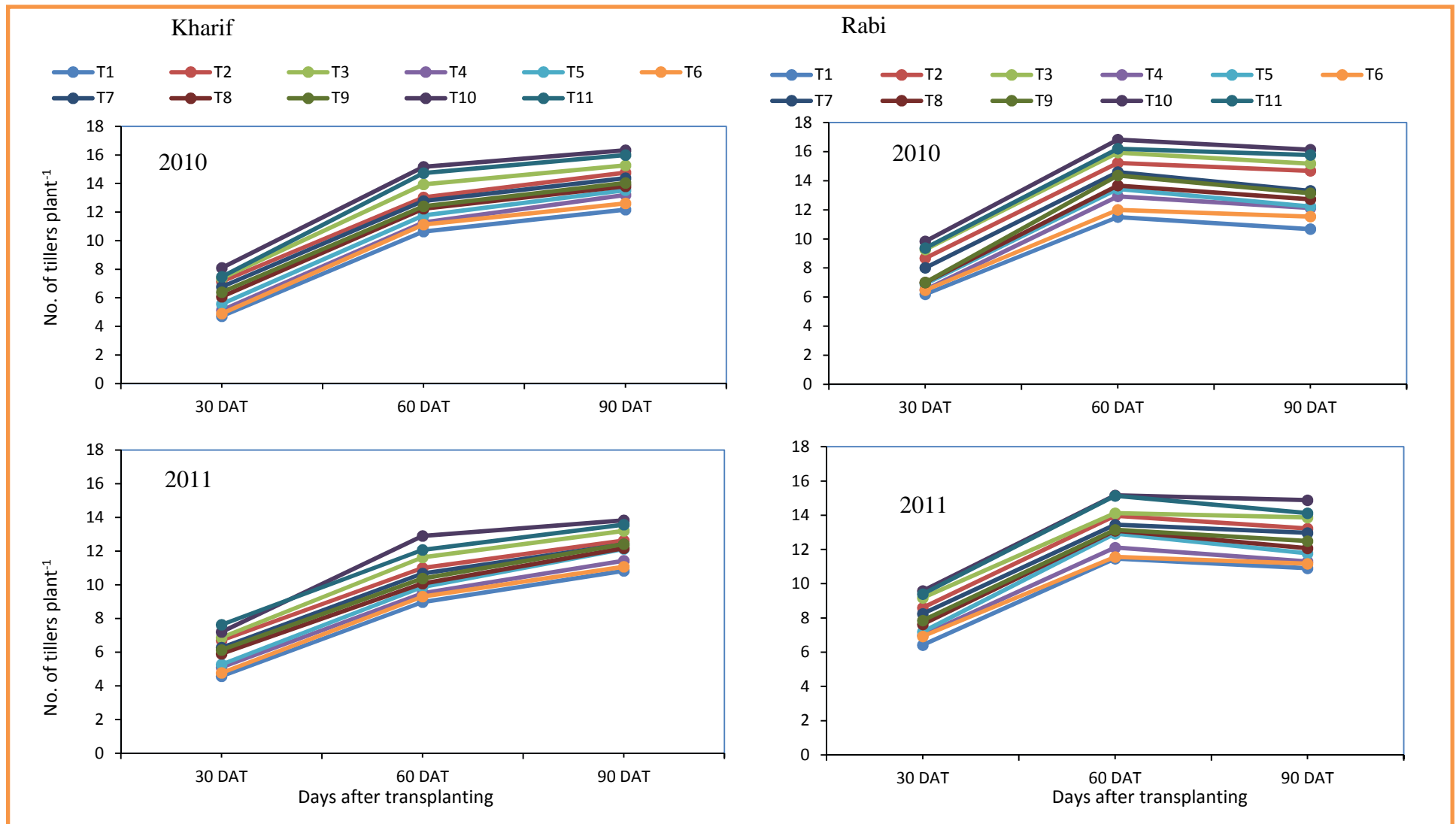


Fig. 4.2 Effect of integrated nutrient management on number of tillers per plant

Table 4.3a Effect of integrated nutrient management on leaf area index in kharif season-2010 & 2011

Treatments		30 DAT			60DAT			90DAT		
		2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	1.13	1.20	1.17	2.13	2.17	2.15	1.23	1.27	1.25
T ₂	RFD+FYM	1.90	1.93	1.92	2.63	2.67	2.65	2.27	2.20	2.24
T ₃	RFD+ZnSO ₄	1.90	2.00	1.95	2.73	2.80	2.77	2.33	2.40	2.37
T ₄	RFD+Zn-EDTA	1.40	1.43	1.42	2.23	2.30	2.27	1.73	1.47	1.60
T ₅	RFD+S	1.43	1.50	1.47	2.33	2.37	2.35	1.88	1.60	1.57
T ₆	RFD+B	1.17	1.23	1.20	2.17	2.23	2.20	1.43	1.40	1.42
T ₇	RFD+Zn-EDTA+S	1.73	1.80	1.77	2.53	2.57	2.55	2.13	1.97	2.05
T ₈	RFD+Zn-EDTA+B	1.53	1.60	1.57	2.37	2.40	2.38	1.93	1.67	1.80
T ₉	RFD+S+B	1.60	1.67	1.63	2.47	2.43	2.45	2.03	1.77	1.90
T ₁₀	RFD+ ZnSO ₄ +B	2.53	2.60	2.57	3.51	3.57	3.55	3.23	3.33	3.28
T ₁₁	RFD+Zn-EDTA+S+B	1.97	2.10	2.04	2.87	2.93	2.90	2.53	2.60	2.57
SEm (±)		0.05	0.05	0.04	0.03	0.05	0.03	0.21	0.04	0.02
CD (P = 0.05)		0.15	0.14	0.13	0.10	0.14	0.11	0.62	0.13	0.06

Table 4.3b Residual effect of integrated nutrient management on leaf area index in rabi season-2010 & 2011

Treatments		30 DAT			60DAT			90DAT		
		2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	1.40	1.53	1.47	3.20	2.60	2.90	1.70	1.80	1.75
T ₂	RFD+FYM	2.20	2.63	2.42	5.10	4.37	4.73	4.07	3.33	3.70
T ₃	RFD+ZnSO ₄	2.40	2.93	2.67	5.60	4.53	5.07	4.47	3.63	4.05
T ₄	RFD+Zn-EDTA	1.60	1.80	1.70	3.40	3.07	3.24	2.23	2.30	2.27
T ₅	RFD+S	1.73	1.97	1.85	3.47	3.23	3.35	2.43	2.53	2.48
T ₆	RFD+B	1.50	1.80	1.65	3.23	2.77	3.00	2.07	1.90	1.98
T ₇	RFD+Zn-EDTA+S	2.00	2.40	2.20	4.50	4.03	4.27	3.50	3.03	3.27
T ₈	RFD+Zn-EDTA+B	1.87	2.03	1.95	3.63	3.53	3.58	2.80	2.70	2.75
T ₉	RFD+S+B	1.93	2.23	2.08	4.13	3.80	3.97	3.17	2.87	3.02
T ₁₀	RFD+ ZnSO ₄ +B	2.60	3.30	2.95	6.30	5.96	6.13	5.47	4.73	5.10
T ₁₁	RFD+Zn-EDTA+S+B	2.50	3.13	2.82	6.00	4.90	5.45	5.03	3.83	4.43
SEm (±)		0.04	0.04	0.05	0.09	0.10	0.21	0.11	0.07	0.23
CD (P = 0.05)		0.11	0.11	0.13	0.26	0.30	0.63	0.32	0.22	0.69

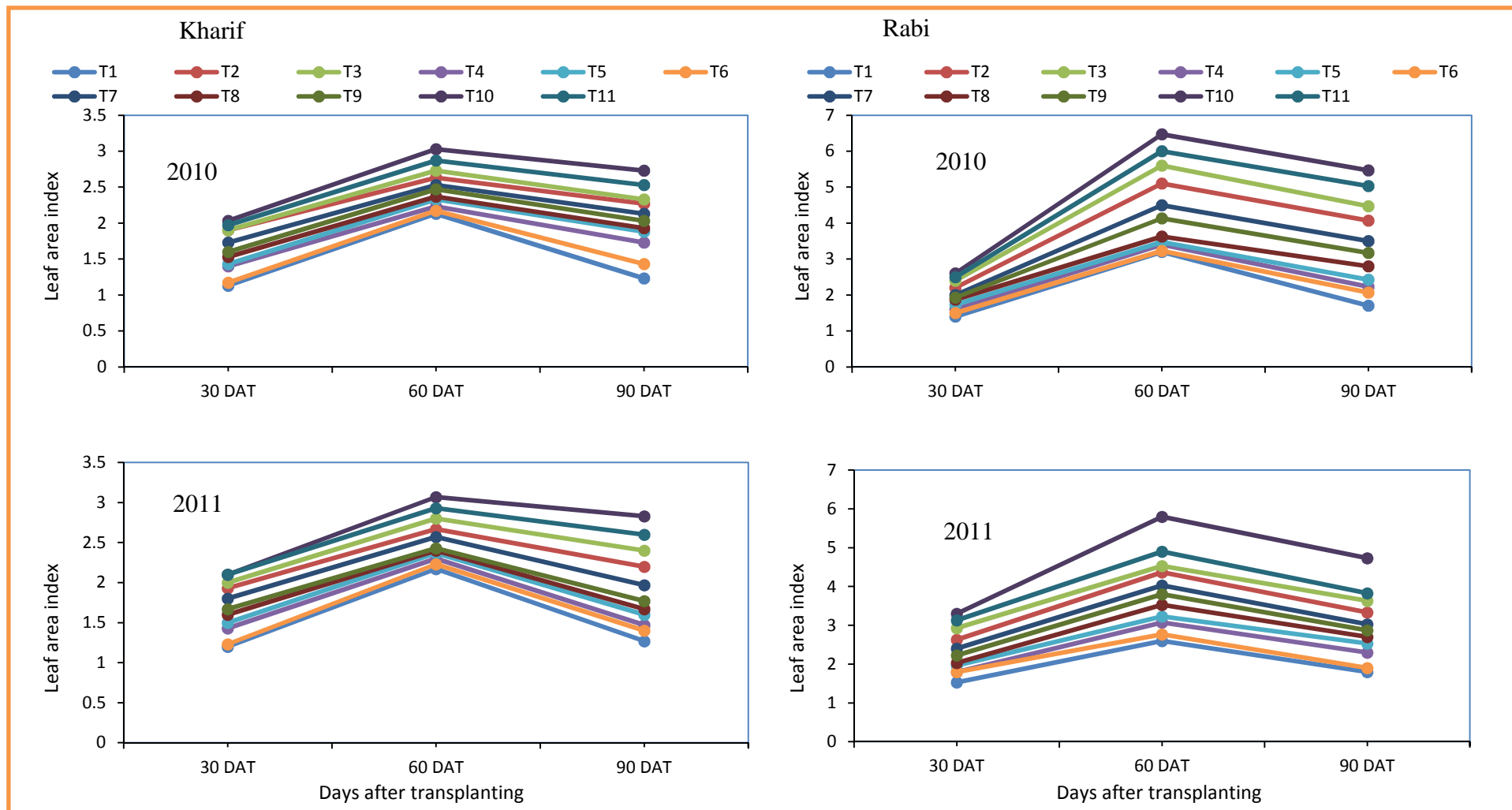


Fig. 4.3 Effect of integrated nutrient management on leaf area index

Application of RFD+ZnSO₄+B (T₁₀) increased 6.0, 4.6, 3.8, 10.5, 11.0 and 13.0 per cent more LAI at 60 DAT over RFD(T₁), FYM (T₂), ZnSO₄ (T₃), Zn-EDTA(T₄), S(T₅) and B(T₆) respectively.

LAI increased rapidly from 30 to 60 DAT during rabi and decreased thereafter (Table 4.3b and Fig. 4.3). Residual effect of ZnSO₄ + B applied along with RFD to kharif rice (T₁₀) recorded highest LAI (5.96-6.30) which was significantly superior over other treatments. Residual effect of ZnSO₄ + B applied with RFD to kharif rice (T₁₀) recorded higher LAI as compared to residual effect of either ZnSO₄ (T₃), B (T₆), Zn-EDTA (T₄) applied along with RFD to kharif rice.

Application of RFD+ZnSO₄+B (T₁₀) increased 97.0, 21.0, 12.6, 76.0, 70.0 and 90.0 per cent more LAI at 60 DAT over RFD (T₁), FYM (T₂), ZnSO₄ (T₃), Zn-EDTA (T₄), S (T₅) and B (T₆), respectively.

4.1.4 Dry matter production

Data on dry matter production, presented in Table 4.4a, 4.4b and Fig. 4.4. It was observed that dry matter production increased with time and reached its maximum at harvest. The rate of increase was slow up to 30 DAT, but got momentum after 60 DAT. The rate of increase was maximum between 60 to 90 DAT both for kharif and rabi season during 2010 and 2011.

Dry matter production was influenced significantly by different treatments. During kharif season maximum dry matter was produced with application of RFD + ZnSO₄ + B (28.03 - 29.40 g hill⁻¹) (T₁₀) followed by application of RFD + Zn-EDTA + S + B (27.20 to 28.13 g hill⁻¹) (T₁₁) and RFD + ZnSO₄ (25.20 to 25.40 g hill⁻¹) (T₃).

Application of RFD + ZnSO₄ + B increased 39.4, 15.8, 13.4, 30.6, 27.7 and 31.2 per cent more dry matter over single application of RFD (T₁), FYM (T₂), ZnSO₄ (T₃), Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD. Application of RFD + FYM increased 12.7, 10.2, 13.3 per cent more dry matter over single application of Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD.

Table 4.4a Effect of integrated nutrient management on dry matter production (g/hill) on kharif season-2010 and 2011

Treatments		30 DAT			60DAT			90DAT		
		2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	3.70	3.50	3.60	10.17	11.10	10.63	20.70	20.50	20.60
T ₂	RFD+FYM	5.10	5.00	5.05	13.47	13.43	13.45	24.77	24.80	24.78
T ₃	RFD+ZnSO ₄	5.40	5.30	5.35	13.90	13.60	13.75	25.40	25.20	25.30
T ₄	RFD+Zn-EDTA	4.13	4.03	4.08	11.20	10.97	11.08	21.83	22.13	21.98
T ₅	RFD+S	4.40	4.33	4.37	11.37	11.17	11.27	22.20	22.77	22.48
T ₆	RFD+B	3.83	3.60	3.72	11.23	11.10	11.17	21.93	21.80	21.87
T ₇	RFD+Zn-EDTA+S	5.07	5.00	5.03	13.47	13.17	13.32	24.60	24.40	24.50
T ₈	RFD+Zn-EDTA+B	4.30	4.20	4.25	11.33	11.30	11.31	23.33	23.20	23.27
T ₉	RFD+S+B	4.70	4.60	4.65	11.53	11.50	11.51	24.53	24.44	24.48
T ₁₀	RFD+ ZnSO ₄ +B	5.90	5.73	5.82	15.17	16.27	15.72	29.40	28.03	28.71
T ₁₁	RFD+Zn-EDTA+S+B	5.65	5.69	5.67	15.27	15.13	15.20	28.13	27.20	27.66
SEm (±)		0.03	0.04	0.03	0.02	0.33	0.16	0.12	0.30	0.16
CD (P = 0.05)		0.11	0.12	0.09	0.08	0.98	0.48	0.36	0.90	0.49

Table 4.4b Residual effect of integrated nutrient management on dry matter (g/hill) production on rabi season-2010 & 2011

Treatments		30 DAT			60DAT			90DAT		
		2010	2011	Pooled	2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	3.90	3.80	3.85	10.40	10.30	10.35	20.90	20.57	20.73
T ₂	RFD+FYM	5.30	5.40	5.35	13.70	13.60	13.65	25.20	25.00	25.10
T ₃	RFD+ZnSO ₄	5.50	5.60	5.55	14.13	14.00	14.07	25.60	25.20	25.40
T ₄	RFD+Zn-EDTA	4.30	4.20	4.25	11.30	11.27	11.28	22.40	21.67	22.03
T ₅	RFD+S	4.60	4.50	4.55	11.50	11.33	11.42	22.40	22.50	22.45
T ₆	RFD+B	4.10	4.20	4.15	11.40	11.30	11.35	22.13	21.23	21.68
T ₇	RFD+Zn-EDTA+S	5.30	5.27	5.28	13.60	12.50	13.05	24.80	24.73	24.77
T ₈	RFD+Zn-EDTA+B	4.50	4.60	4.55	11.30	11.80	11.55	24.60	24.20	24.40
T ₉	RFD+S+B	5.00	5.13	5.07	11.60	12.20	11.90	24.80	24.50	24.65
T ₁₀	RFD+ ZnSO ₄ +B	5.90	6.00	5.95	14.80	16.60	15.70	28.60	27.80	28.20
T ₁₁	RFD+Zn-EDTA+S+B	5.50	5.70	5.60	14.13	15.13	14.63	25.60	27.20	26.40
SEm (±)		0.01	0.02	0.01	0.01	0.08	0.04	0.01	0.34	0.17
CD (P = 0.05)		0.05	0.06	0.04	0.04	0.25	0.12	0.03	1.02	0.51

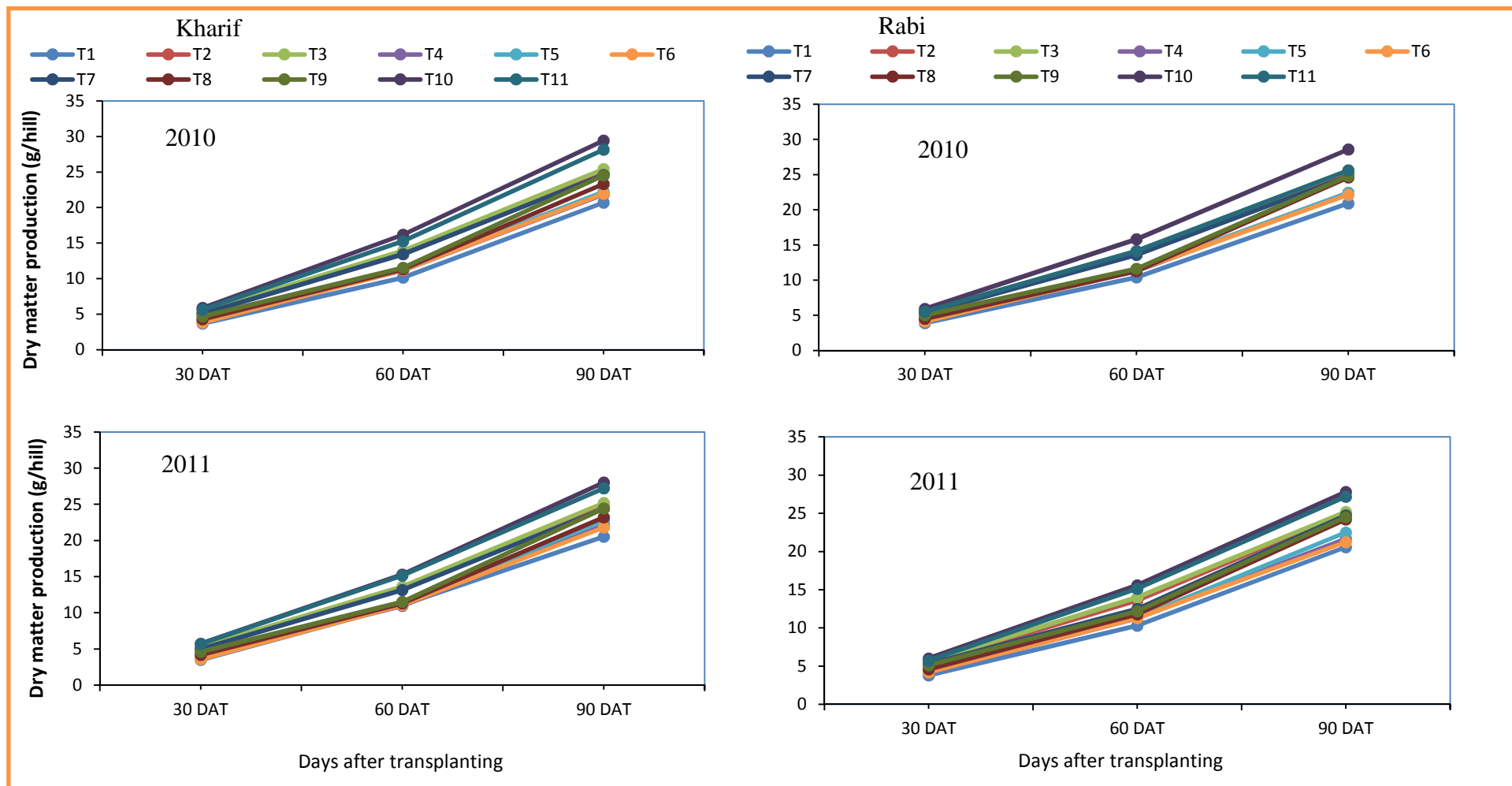


Fig. 4.4 Effect of integrated nutrient management on dry matter

During rabi season maximum dry matter was produced (27.80 to 28.60 g hill⁻¹) due to residual effect of ZnSO₄ + B applied along with RFD to kharif rice (T₁₀) followed by the residual effect of Zn-EDTA + S + B applied along with RFD to kharif rice (25.60 to 27.20 g hill⁻¹) (T₁₁). These two treatments (T₁₀ and T₁₁) were significantly superior to other treatments.

Residual effect of RFD + ZnSO₄ + B (T₁₀) increased 36.0,12.4,11.0,28.1,25.6, and 30.0 per cent more dry matter over single application of RFD (T₁), FYM (T₂), ZnSO₄ (T₃), Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD. Residual effect of RFD + FYM increased 13.9,11.8 and 15.8 per cent more dry matter over single application of Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD.

4.2 Observations at maturity

4.2.1 Yield attributing characters

4.2.1.1 Length of panicle

Data on length of panicle during kharif and rabi seasons are presented in Table 4.5a, 4.5b and illustrated in Fig. 4.5 to 4.10.

The length of panicle was influenced significantly by different treatments. When RFD was applied along with ZnSO₄ + B (T₁₀). It produced the longest panicles (27 cm), which remained at par with application of RFD + Zn-EDTA + S + B (T₁₁) or RFD + FYM (T₂), RFD + ZnSO₄ (T₃), RFD + Zn-EDTA + S (T₇) and RFD + S + B (T₉). Application of RFD + Zn-EDTA + S + B during kharif season produced longer panicles (26.3 cm) than RFD + ZnSO₄ (26.2 cm) and RFD + FYM (26.1 cm) and RFD alone (18.1 cm).

Application of RFD + ZnSO₄ + B increased 35, 32, 46 and 21 per cent more panicle length over single application of Zn-EDTA (T₄), S (T₅), B (T₆) and Zn-EDTA+B (T₈) along with RFD. Application of RFD + FYM increased 30, 27.3 and 41 per cent more panicle length over single application of Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD.

During rabi season longest panicle (28.1 cm) was produced due to residual effect of ZnSO₄ + B applied along with RFD to kharif rice (T₁₀). This was significantly superior over other treatments but at par with T₁₁ (RFD + Zn-EDTA + S + B) producing panicle length of 28.0 cm.

Residual effect of ZnSO₄ + B along with RFD (T₁₀) increased 29.0, 11.9, 6.0, 25.4, 25 and 26.0 per cent more panicle length over residual effect of RFD, FYM, ZnSO₄, Zn-EDTA, S and B along with RFD. Residual effect of FYM along with RFD increased 12, 11.6 and 12.6 per cent more panicle length over single application of Zn-EDTA (T₄), S (T₅) and B (T₆).

4.2.1.2 Weight of panicle

Data on weight of the panicle of kharif and rabi are given in Table 4.5a and 4.5b and illustrated in Fig. 4.6 and 4.11. Application of RFD + ZnSO₄ + B (T₁₀) produced heavier panicles (2.74 g) during kharif which was significantly superior to T₁, T₅ and T₆ but at par with other treatments.

Application of RFD + Zn-EDTA + S + B (T₁₁) produced heavier panicle (2.60 g) than application of RFD (T₁) and RFD + B (T₆) (2.30 g). T₁ and T₆ produced lighter panicles.

During rabi season the residual effect of ZnSO₄ + B which was applied along with RFD during kharif season (T₁₀) recorded heavier panicles (2.65 g) which was significantly superior to all other treatments but at par with T₁₁ (RFD + Zn-EDTA + S + B) producing a panicle weight of (2.60 g). Application of RFD (T₁), RFD + Zn-EDTA (T₄) and RFD + B (T₆) produced lighter panicles i.e., 2.01 g, 2.27 g and 2.18 g respectively.

4.2.1.3 Number of panicles m⁻²

Data on number of panicles m⁻² are given in Table 4.5a, b and illustrated in Fig 4.7 and 4.12.

The number of panicles were significantly influenced by different treatments during kharif. Application of RFD + ZnSO₄ + B (T₁₀) produced maximum panicle

(307) which was significantly superior to other treatments. Applications of only RFD (T₁) produced the lowest number of panicles⁻² (234). Application of RFD + FYM (T₂) produced panicles (278) which was at par with RFD + ZnSO₄ (T₃) but superior over RFD + Zn-EDTA (T₄), RFD + S (T₅), RFD + B (T₆) RFD + Zn-EDTA + S (T₇), RFD + Zn-EDTA + B (T₈) and RFD (T₁).

Application of RFD + ZnSO₄ + B (T₁₀) increased 10, 8.5, 24, 21 and 24 per cent more number of panicles over single application of FYM (T₂), ZnSO₄ (T₃), Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD. T₁₀ increased 31.1 per cent more number of panicles over T₁. Application of RFD + FYM increased 13, 9.4 and 12.6 per cent more number of panicles over single application of Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD.

During rabi season highest panicles (331) was produced due to residual effect of ZnSO₄ + B applied along with RFD to kharif rice (T₁₀) which was significantly superior over other treatments but at par with T₁₁ (RFD + Zn-EDTA + S + B) (T₁₁) producing 325 number of panicles. T₁ recorded lowest number of panicles (258).

Residual effect of ZnSO₄ + B along with RFD (T₁₀) increased 28.6, 7.5, 4.0, 19.0, 17.0 and 22.0 per cent more number of panicles over residual effect of RFD (T₁), FYM(T₂), ZnSO₄(T₃), Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD. Residual effect of FYM along with RFD increased 11.0, 8.8 and 13.2 per cent more number of panicles over single application of Zn-EDTA (T₄) S (T₅) and B (T₆) applied along with RFD. T₂ (FYM) produced more panicles (308) which remained at par with ZnSO₄(T₃) producing 319 number of panicles applied along with RFD but was superior over RFD +Zn-EDTA (277), RFD+S (283) and RFD+B (272).

4.2.1.4 Fertile grains panicle⁻¹

Data on number of fertile grains panicle⁻¹ are given in Table 4.5a and 4.5b and illustrate in Fig. 4.8 and 4.13.

The fertile grains per panicle were significantly influenced by various treatments during kharif. Application of RFD + ZnSO₄ + B (T₁₀) produced maximum fertile grains panicle⁻¹ (157) which was significantly superior over other treatments, however, it remained at par with application of RFD + Zn-EDTA + S + B (T₁₁) (154). Application of RFD (T₁), recorded lowest number of fertile grains (97). Application of RFD + ZnSO₄ + B increased 18.9, 8.3, 40.1, 36.5 and 45.3 per cent over single application of FYM, ZnSO₄, Zn-EDTA, S and B applied along with RFD kharif season.

During rabi, the residual effect of ZnSO₄ and B which was applied along with RFD in kharif rice (T₁₀) recorded highest number of fertile grains per panicle (166) which was significantly superior over all treatments. This was closely followed by T₃, T₂, T₇ and T₉ recording 152, 141, 137 and 132 number of fertile grains per panicle respectively. T₁ (RFD) recorded lowest number of fertile grains per panicle (107). T₁₀ (RFD + ZnSO₄ + B) recorded 18.0, 9.2, 42.0, 36.0 and 45.6 % increase in number of fertile grains per panicle over single application of FYM (T₂), ZnSO₄(T₃), Zn-EDTA (T₄), S(T₅) and B(T₆) applied along with RFD.

4.2.1.5 Thousand grain weight

Data on thousand grain weight for kharif and rabi season are presented in Table 4.5a, b and illustrated in Fig. 4.9 and 4.14. Application of RFD + ZnSO₄ + B (T₁₀) recorded highest test weight (24.14 g) which was significantly superior over other treatments, but at par with T₁₁ (RFD + Zn-EDTA + S + B) recording a test weight of 23.25 g, T₂ (RFD + FYM) recording a test weight of 23.10 g and T₃ (RFD + ZnSO₄) recording a test weight of 23.38 g. Lowest test weight (19.38 g) was recorded by application of RFD only (T₁).

Table 4.5a Effect of integrated nutrient management on yield attributing characters during kharif season

Treatments		Panicle length (cm)			Panicle weight (g)			Panicles m ⁻²			Fertile grains panicles ⁻¹			1000 grain weight (g)		
		2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T ₁	RFD	18.4	17.8	18.1	2.10	1.93	2.01	232	245	234	96	97	97	19.10	19.67	19.38
T ₂	RFD+FYM	26.1	26.1	26.10	2.40	2.40	2.40	270	286	278	127	136	132	22.57	23.63	23.10
T ₃	RFD+ZnSO ₄	26.3	26.2	26.2	2.60	2.50	2.55	278	287	283	143	147	145	22.87	23.90	23.38
T ₄	RFD+Zn-EDTA	19.7	20.4	20.0	2.20	2.10	2.16	241	253	247	107	116	112	20.47	20.43	20.45
T ₅	RFD+S	20.4	20.7	20.5	2.20	2.13	2.11	249	258	254	113	117	115	20.47	20.63	20.55
T ₆	RFD+B	17.2	19.9	18.5	2.10	1.93	2.01	241	252	247	105	111	108	20.13	20.13	20.13
T ₇	RFD+Zn-EDTA+S	26.1	26.1	26.7	2.33	2.37	2.35	261	272	267	123	132	128	21.87	22.30	22.08
T ₈	RFD+Zn-EDTA+B	22.4	22.5	22.4	2.30	2.21	2.25	244	264	254	118	122	120	21.10	21.37	21.23
T ₉	RFD+S+B	24.60	24.5	24.5	2.33	2.23	2.28	255	268	262	120	130	125	21.70	22.20	21.95
T ₁₀	RFD+ ZnSO ₄ +B	27.13	26.8	27.0	2.78	2.70	2.74	302	312	307	155	158	157	24.10	24.17	24.14
T ₁₁	RFD+Zn-EDTA+S+B	26.30	26.3	26.3	2.70	2.50	2.60	289	295	292	152	155	154	23.33	23.17	23.25
SEm (±)		0.98	0.67	0.90	0.23	0.07	0.18	1.84	3.54	3.54	3.16	2.59	2.97	0.57	0.68	0.59
CD (P = 0.05)		2.94	2.01	2.67	0.69	0.20	0.56	5.45	10.58	10.45	9.48	7.78	8.92	1.70	2.04	1.78

Table 4.5b Residual effect of integrated nutrient management on yield attributing characters during rabi season

Treatments		Panicle length (cm)			Panicle weight (gm)			Panicles m ⁻²			Fertile grains panicles ⁻¹			1000 grain weight(g)		
		2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T ₁	RFD	21.6	22.1	21.8	2.00	2.03	2.01	260	255	258	109	105	107	21.90	21.60	21.75
T ₂	RFD+FYM	25.2	25.0	25.1	2.55	2.52	2.50	306	310	308	137	145	141	23.50	24.60	24.05
T ₃	RFD+ZnSO ₄	26.5	26.4	26.5	2.55	2.50	2.52	320	317	319	153	151	152	23.60	24.90	24.25
T ₄	RFD+Zn-EDTA	22.4	22.5	22.4	2.30	2.25	2.27	280	275	278	118	116	117	22.60	23.17	22.88
T ₅	RFD+S	22.5	22.6	22.5	2.33	2.30	2.32	284	282	283	121	122	122	22.90	23.50	23.20
T ₆	RFD+B	22.3	22.4	22.3	2.23	2.13	2.18	275	269	272	116	112	114	22.50	22.80	22.65
T ₇	RFD+Zn-EDTA+S	23.8	23.5	23.7	2.50	2.50	2.50	302	299	301	131	142	137	23.40	24.60	24.00
T ₈	RFD+Zn-EDTA+B	22.7	22.8	22.7	2.30	2.43	2.36	292	288	290	122	129	126	23.30	24.13	23.72
T ₉	RFD+S+B	23.2	22.9	23.1	2.37	2.47	2.42	294	291	293	128	136	132	23.40	24.40	23.90
T ₁₀	RFD+ ZnSO ₄ +B	28.1	28.1	28.1	2.70	2.60	2.65	328	334	331	168	163	166	24.13	25.03	24.58
T ₁₁	RFD+Zn-EDTA + S+B	28.0	28.0	28.0	2.60	2.60	2.60	325	325	325	161	154	158	23.83	24.93	24.38
SEm (±)		0.08	0.10	0.07	0.04	0.05	0.03	0.62	0.96	3.80	1.44	1.74	1.25	0.04	0.04	0.03
CD (P = 0.05)		0.25	0.30	0.21	0.14	0.15	0.09	1.83	2.85	11.40	4.32	5.22	4.16	0.11	0.12	0.09

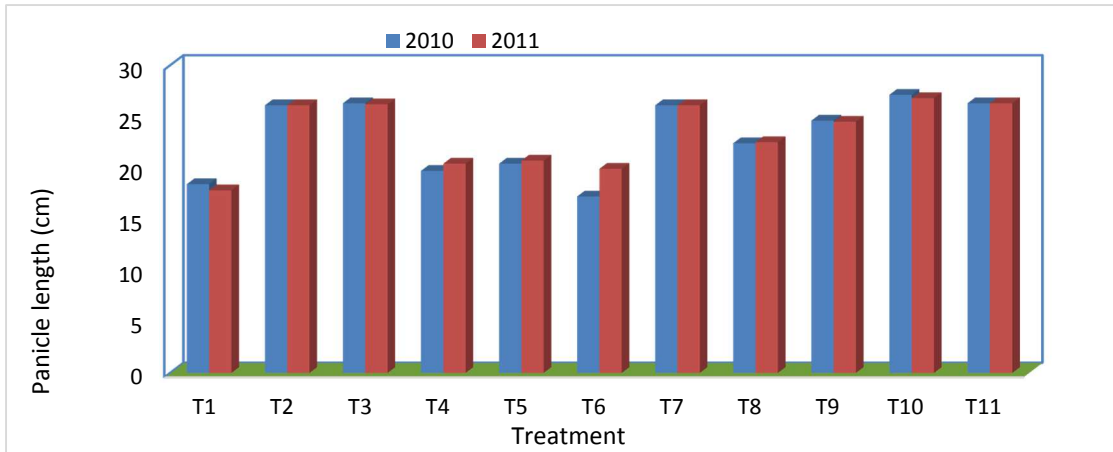


Fig.4.5 Effect of integrated nutrient management on panicle length of rice during kharif season

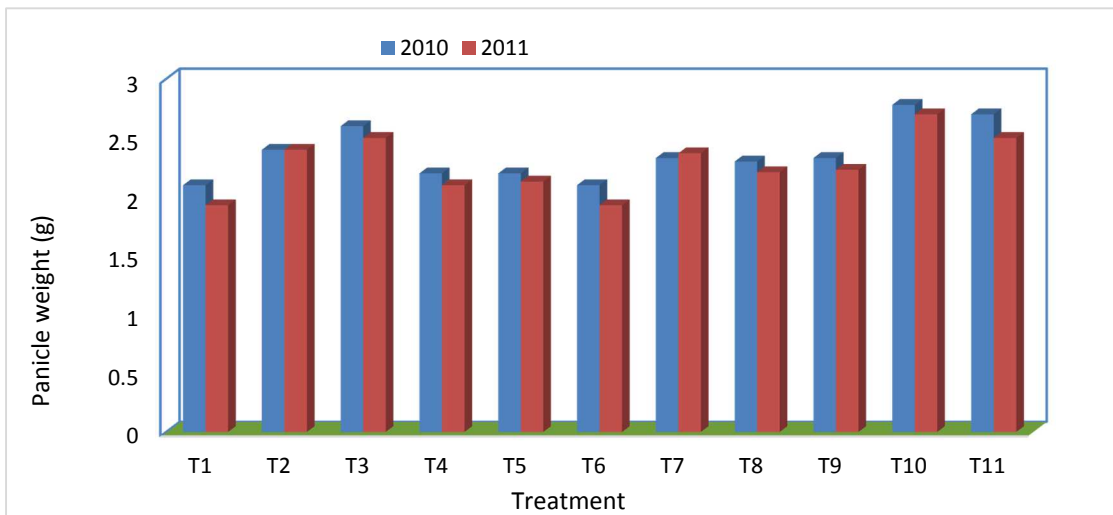


Fig.4.6 Effect of integrated nutrient management on panicle weight of rice during kharif season

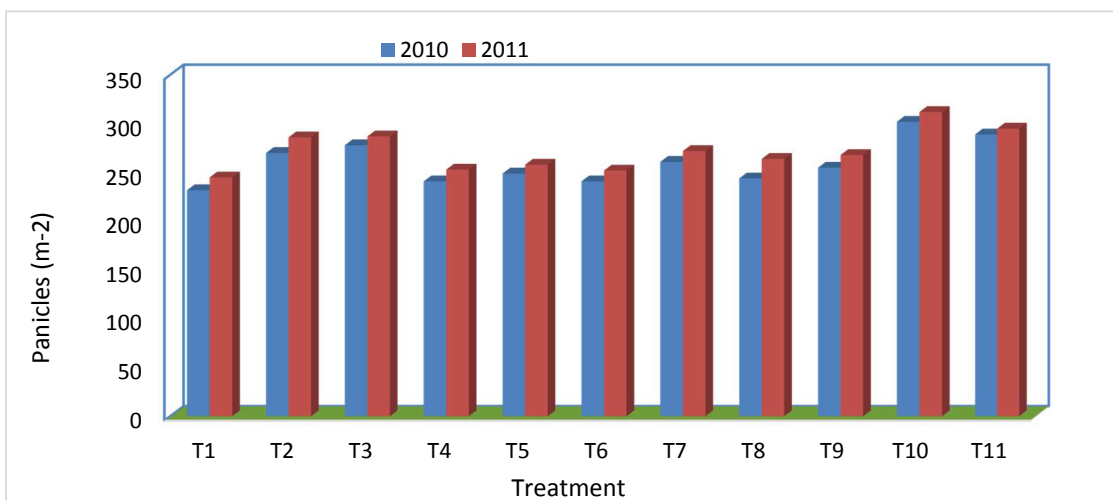


Fig.4.7 Effect of integrated nutrient management on panicle m⁻² of rice during kharif season

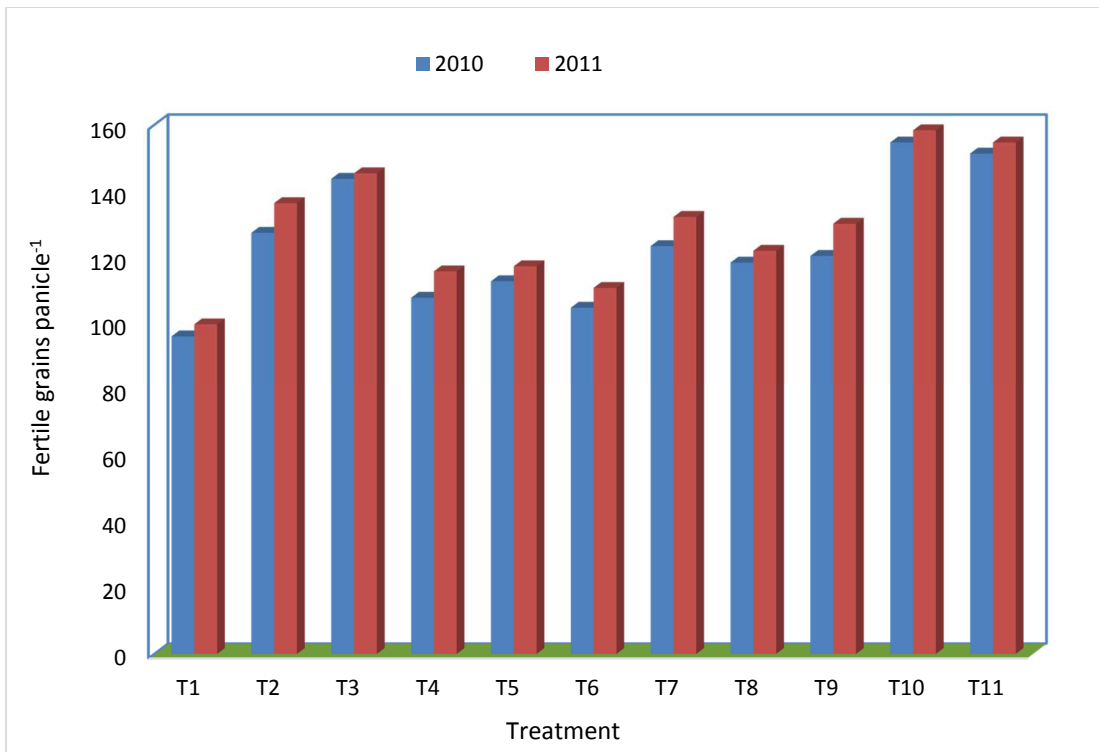


Fig.4.8 Effect of integrated nutrient management on fertile grains panicle⁻¹ of rice during kharif season

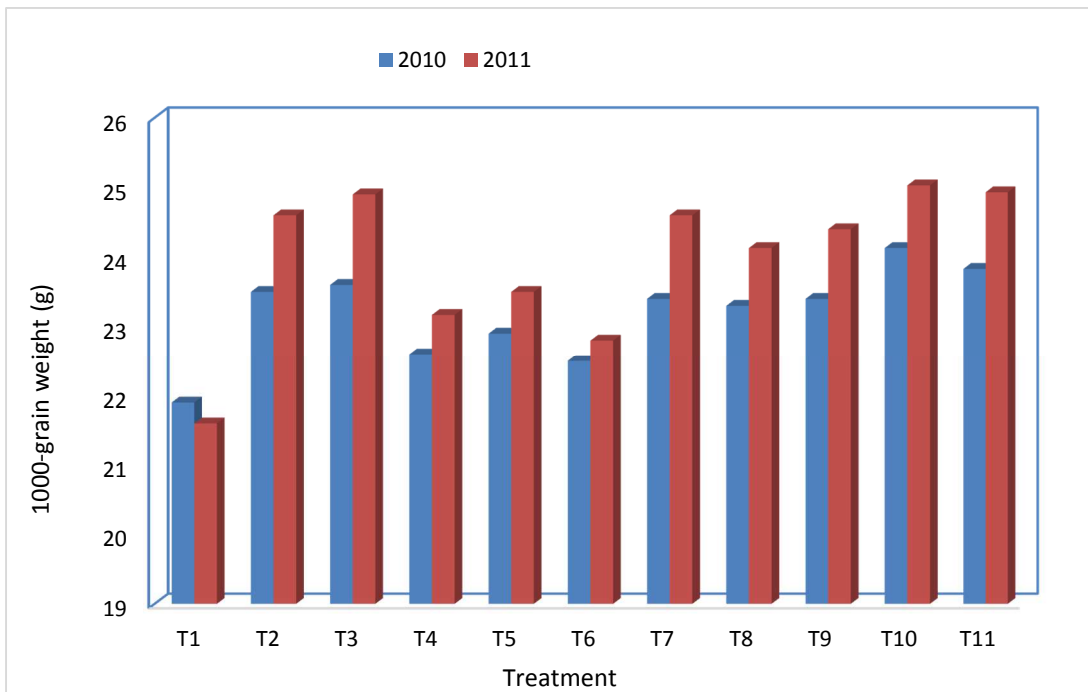


Fig. 4.9 Effect of integrated nutrient management on 1000-grain weight (g) of rice during kharif season

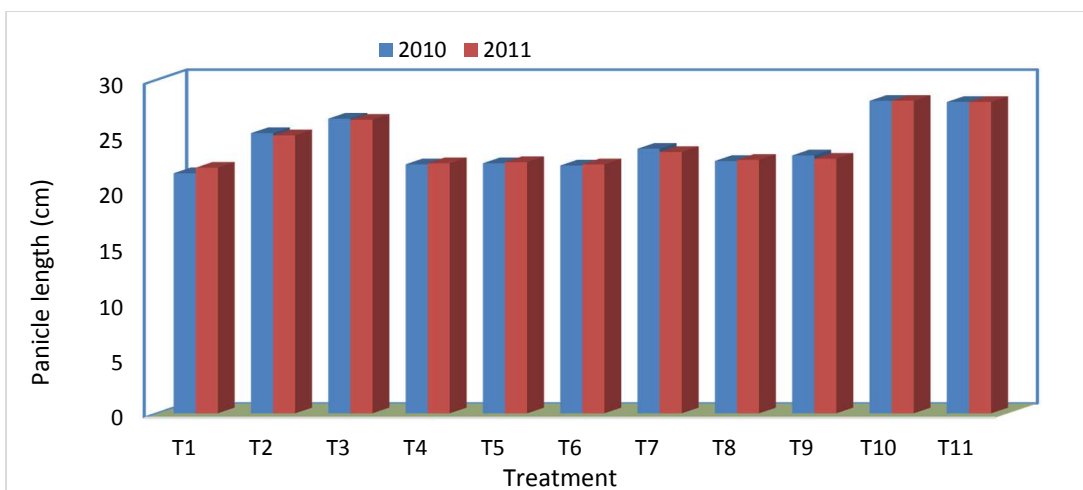


Fig.4.10 Effect of integrated nutrient management on panicle length of rice during rabi season

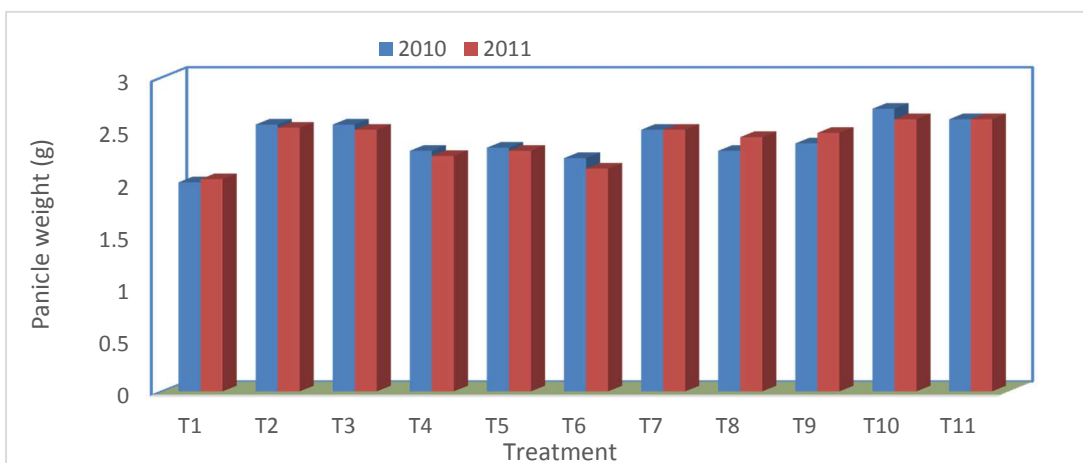


Fig.4.11 Effect of integrated nutrient management on panicle weight of rice during rabi season

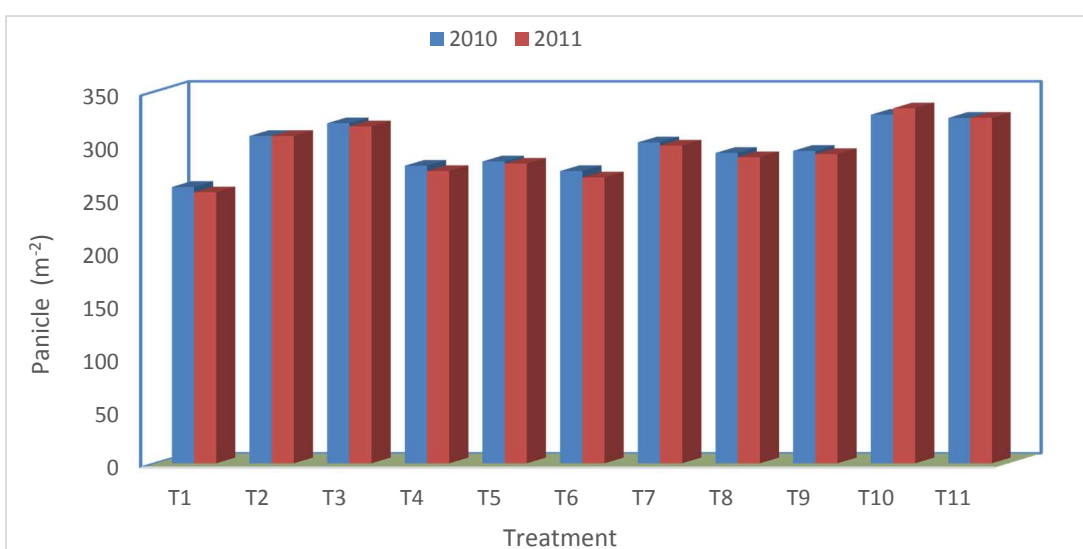


Fig.4.12 Effect of integrated nutrient management on panicle m² of rice during rabi season

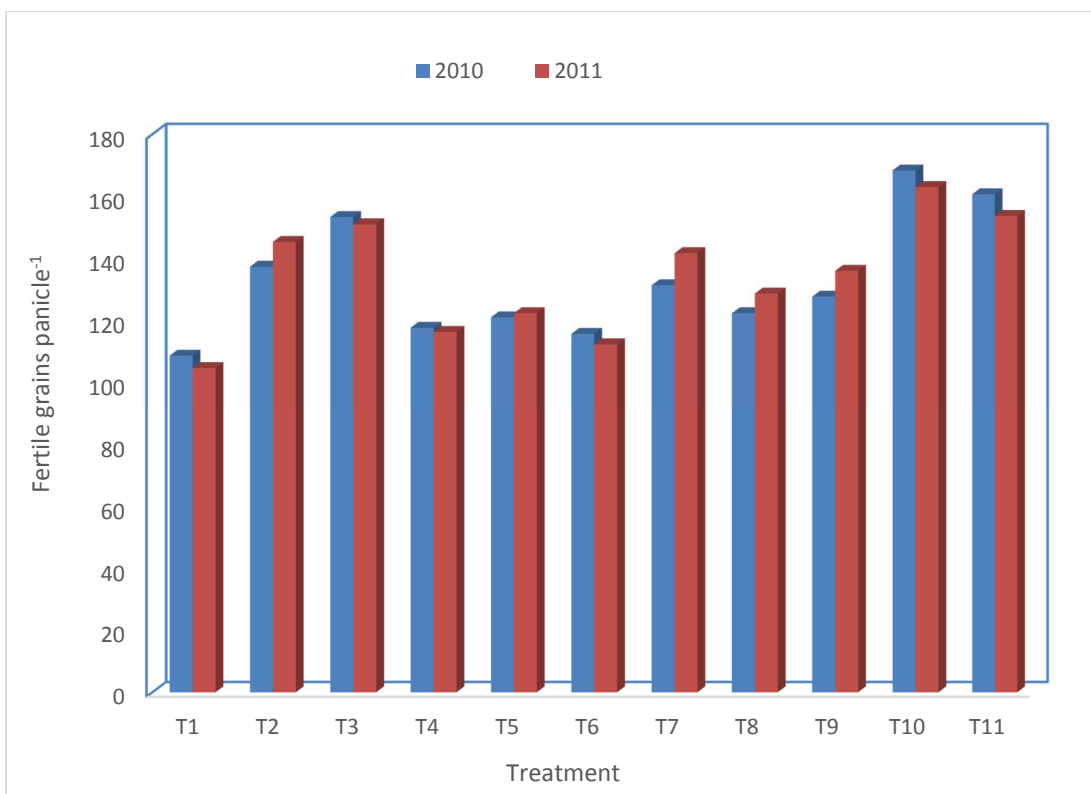


Fig. 4.13 Effect of integrated nutrient management on fertile grains panicle⁻¹ of rice during rabi season

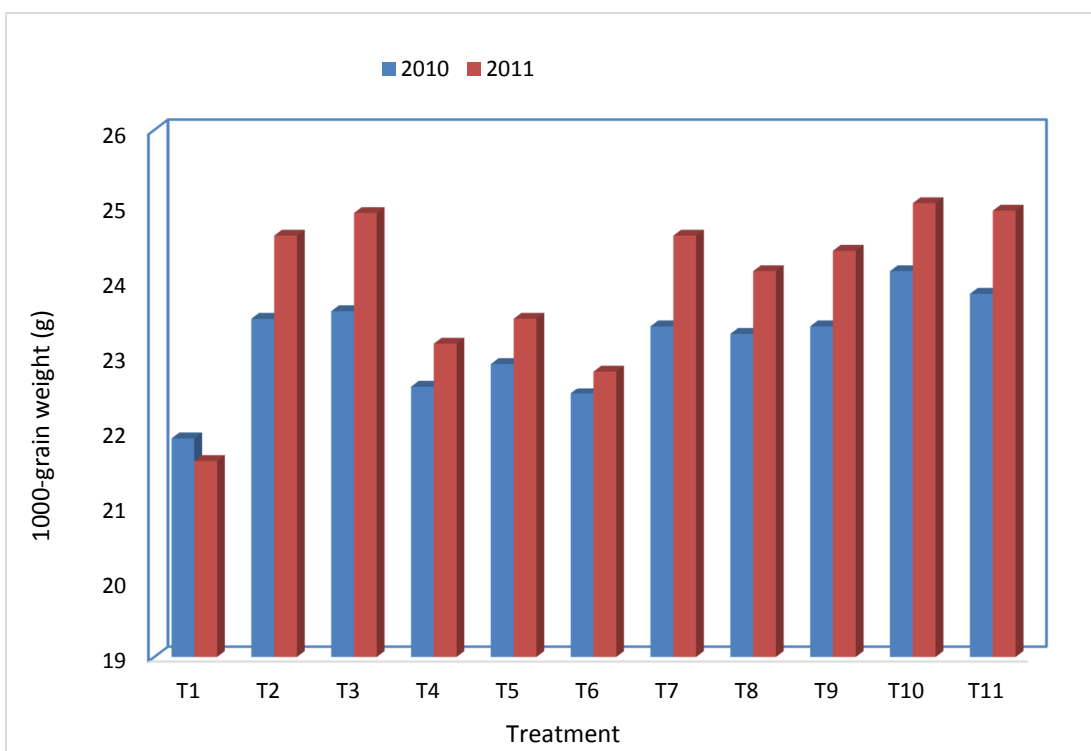


Fig. 4.14 Effect of integrated nutrient management on 1000-grain weight of rice during rabi season

Application of RFD + ZnSO₄ + B (T₁₀) recorded 24.5 per cent increase in test weight over application of RFD (T₁) it also recorded 4.5, 3.3, 18.0, 17.4 and 19.9 per cent increase in test weight over single application of FYM(T₂), ZnSO₄(T₃), Zn-EDTA (T₄), S (T₅) and B (T₆) along with RFD Treatment T₁₀ also recorded 3.8 per cent increase in test weight over T₁₁.

During rabi, residual effect of ZnSO₄ + B which was applied with RFD to kharif rice (T₁₀) recorded highest test weight (24.58 g) which was significantly superior over other treatments. This was closely followed by T₁₁ (RFD + Zn-EDTA - S + B), T₃, (RFD + ZnSO₄), T₂ (RFD + FYM) and T₇ (RFD + Zn-EDTA + S), recording a test weight of 24.38 g, 24.25 g, 24.05 g and 24.0 g, respectively. Lowest test weight was recorded by T₁ (RFD) recording a test weight of 21.75 g. T₁₀ (RFD + ZnSO₄ + B) recorded 13 per cent increase in test weight over RFD (T₁).

4.2.2 Yield

4.2.1 Grain yield

Data on grains yield are presented in Table 4.6 and illustrated in Fig. 4.15. The kharif grain yield ranged from 3.57 to 5.28 t ha⁻¹ due to imposition of different treatment . Highest grain yield (5.28 t ha⁻¹) was recorded in T₁₀ (RFD + ZnSO₄ + B) which was significantly superior over other treatments. Application of RFD + ZnSO₄ + B (T₁₀) recorded an increase of 14.7 and 42.3 per cent more in grain yield over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). The same treatment i.e., T₁₀ (RFD + ZnSo₄ + B) increased 10.7 per cent in grain yield over T₁₁ (RFD + Zn-EDTA + S + B).

Application of RFD +Zn-EDTA + S + B (T₁₁) recorded 23.5, 19.5, 28.5, 10.4, 17.2 and 15.2 per cent increase in grain yield over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). Application of T₁₀ (RFD + ZnSo₄ + B) recorded on increase 18.9, 32.4, 22, 29.7 and 27.5 per cent more grain yield over T₂ (RFD + FYM), T₅ (RFD + S), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA+B) and T₉(RFD + S + B) respectively. Application of RFD + FYM recorded 15, 11.2 and 19.7 per cent increase in grain yield over treatments T₄, T₅ and T₆ respectively. T₁ (RFD) recorded

lowest grain yield (3.57 t ha⁻¹). T₁₀ recorded an increase of 48 per cent in grain yield over sole application of T₁.

The residual rice crop grain yield ranged from 4.28 to 6.21 t ha⁻¹ due to imposition of various treatments. During rabi, residual effect of ZnSO₄ + B which was applied along with RFD to kharif rice (T₁₀) recorded highest grain yield (6.21 t ha⁻¹) which was significantly superior over all other treatments. This was closely followed by T₁₁, T₃, T₂, T₇, T₉ and T₈ recording a grain yield of 5.66, 5.48, 5.38, 5.21, 5.08 and 4.92 t ha⁻¹. T₁₀ recorded 13.3 and 38.6 per cent increase in yield over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). The same treatment i.e., T₁₀ was significantly superior over T₁₁ (RFD + Zn-EDTA + S + B) and recorded an 9.7 per cent increase in grain yield over the same treatment.

Table 4.6 Effect of integrated nutrient management on grain yield (t ha⁻¹) over seasons 2010 & 2011

Treatments		Kharif			Rabi			Total grain yield
		2010	2011	Pooled	2010	2011	Pooled	
T ₁	RFD	3.59	3.55	3.57	4.34	4.22	4.28	15.69
T ₂	RFD+FYM	4.35	4.53	4.44	5.36	5.39	5.38	19.63
T ₃	RFD+ZnSO ₄	4.52	4.68	4.60	5.46	5.51	5.48	20.16
T ₄	RFD+Zn-EDTA	3.87	3.85	3.86	4.59	4.58	4.59	16.89
T ₅	RFD+S	3.92	4.07	3.99	4.76	4.70	4.73	17.44
T ₆	RFD+B	3.71	3.70	3.71	4.52	4.44	4.48	16.37
T ₇	RFD+Zn-EDTA+S	4.24	4.40	4.32	5.22	5.20	5.21	19.06
T ₈	RFD+Zn-EDTA+B	3.99	4.15	4.07	4.89	4.94	4.92	17.98
T ₉	RFD+S+B	4.06	4.23	4.14	5.07	5.09	5.08	18.45
T ₁₀	RFD+ ZnSO ₄ +B	5.19	5.36	5.28	6.14	6.28	6.21	22.96
T ₁₁	RFD+Zn-EDTA+S+B	4.69	4.86	4.77	5.69	5.63	5.66	20.86
SEm (±)		0.06	0.06	0.06	0.05	0.06	0.05	2.11
CD (P = 0.05)		0.18	0.18	0.17	0.16	0.16	0.16	6.27

T₁₁ (RFD + Zn-EDTA + S + B) recorded an increase of 23.3, 19.6, 26.3, 8.6, 15.0, and 11.4 per cent more grain yield over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). Similarly T₁₀ recorded 15.4, 35.3, 31 and 39 per cent more grain yield over T₂ (RFD + FYM), T₄ (RFD+Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B) respectively. T₁₀ recorded 13.3 and 38.6 per cent increase in grain yield over T₃ (RFD + ZnSO₄) and T₆ (RFD+B) respectively.

Residual effect of FYM which was applied in kharif along with RFD recorded an increase of 25.7, 17.2, 14 and 20 per cent in grain yield over T₁ (RFD), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD + B) respectively. Lowest grain yield (4.28 t ha⁻¹) was recorded by treatment T₁ (RFD). T₁₀ recorded 45 per cent increase in grain yield over T₁ (RFD).

It was revealed that application of RFD + ZnSO₄ + B (T₁₀) recorded highest total grain yield (22.96 t ha⁻¹) of the system followed by T₁₁ (RFD + Zn-EDTA + S + B) recording a system grain yield of 20.86 t ha⁻¹.

4.2.3 Straw yield

Data on straw yield are present in Table 4.7. and illustrated in Fig.4.16. The straw yield ranged from 4.78 to 6.33 t ha⁻¹ due to imposition of various treatments. Highest straw yield was recorded (6.33 t ha⁻¹) by T₁₀ (RFD + ZnSO₄ + B) which was significantly superior over other treatments. Application of RFD + ZnSO₄ + B (T₁₀) recorded an increase of 11 and 30 per cent in straw yield over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). Application of T₁₁ (RFD + Zn-EDTA + S + B) recorded 16, 14, 20, 6.6, 10.8 and 9.4 per cent increase in yield over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) respectively. Application of T₁₀ (RFD + ZnSO₄ + B) recorded 13, 26, 24 and 30 per cent increase in yield over T₂ (RFD + FYM), T₄ (RFD+Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B) respectively. Application of RFD + FYM (T₂) recorded 17, 11, 9 and 14.5 per cent more yield over treatments T₁, T₄, T₅ and T₆ respectively.

Lowest straw yield (4.78 t ha⁻¹) was recorded by T₁ (RFD). T₁₀ (RFD + ZnSO₄ + B) recorded 32.4 per cent increase in straw yield over T₁ (RFD).

The rabi straw yield ranged between 6.11 to 7.45 t ha⁻¹ due to imposition of various treatments applied in kharif. Residual effect of ZnSO₄ + B (T₁₀) applied along with RFD in kharif season recorded highest straw yield of 7.45 t ha⁻¹ followed by T₁₁, T₃, T₂, T₇, T₉ and T₈ recording a straw yield of 6.95, 6.81, 6.72, 6.64, 6.50 and 6.41 t ha⁻¹ respectively. T₁₀ recorded on 9 and 22.3 per cent increase in yield over T₃ (RFD + ZnSO₄) and T₆ (RFD + B) respectively.

Table 4.7 Effect of integrated nutrient management on straw yield (t ha⁻¹) over seasons 2010 and 2011

Treatments		Kharif			Rabi			Total straw yield
		2010	2011	Pooled	2010	2011	Pooled	
T ₁	RFD	4.70	4.85	4.78	5.96	6.26	6.11	19.73
T ₂	RFD+FYM	5.45	5.73	5.59	6.54	6.91	6.72	24.62
T ₃	RFD+ZnSO ₄	5.55	5.88	5.71	6.66	6.97	6.81	25.04
T ₄	RFD+Zn-EDTA	4.95	5.11	5.03	6.04	6.24	6.14	22.33
T ₅	RFD+S	4.99	5.24	5.11	6.19	6.32	6.25	22.73
T ₆	RFD+B	4.81	4.96	4.88	6.03	6.14	6.09	21.94
T ₇	RFD+Zn-EDTA+S	5.32	5.62	5.47	6.50	6.78	6.64	24.23
T ₈	RFD+Zn-EDTA+B	5.10	5.41	5.26	6.23	6.60	6.41	23.34
T ₉	RFD+S+B	5.15	5.51	5.33	6.37	6.63	6.50	23.65
T ₁₀	RFD+ ZnSO ₄ +B	6.21	6.46	6.33	7.34	7.56	7.45	27.56
T ₁₁	RFD+Zn-EDTA+S+B	5.72	5.94	5.83	6.82	7.08	6.95	25.56
SEm (±)		0.07	0.05	0.04	0.05	0.06	0.05	1.63
CD (P = 0.05)		0.20	0.16	0.13	0.16	0.16	0.16	4.89

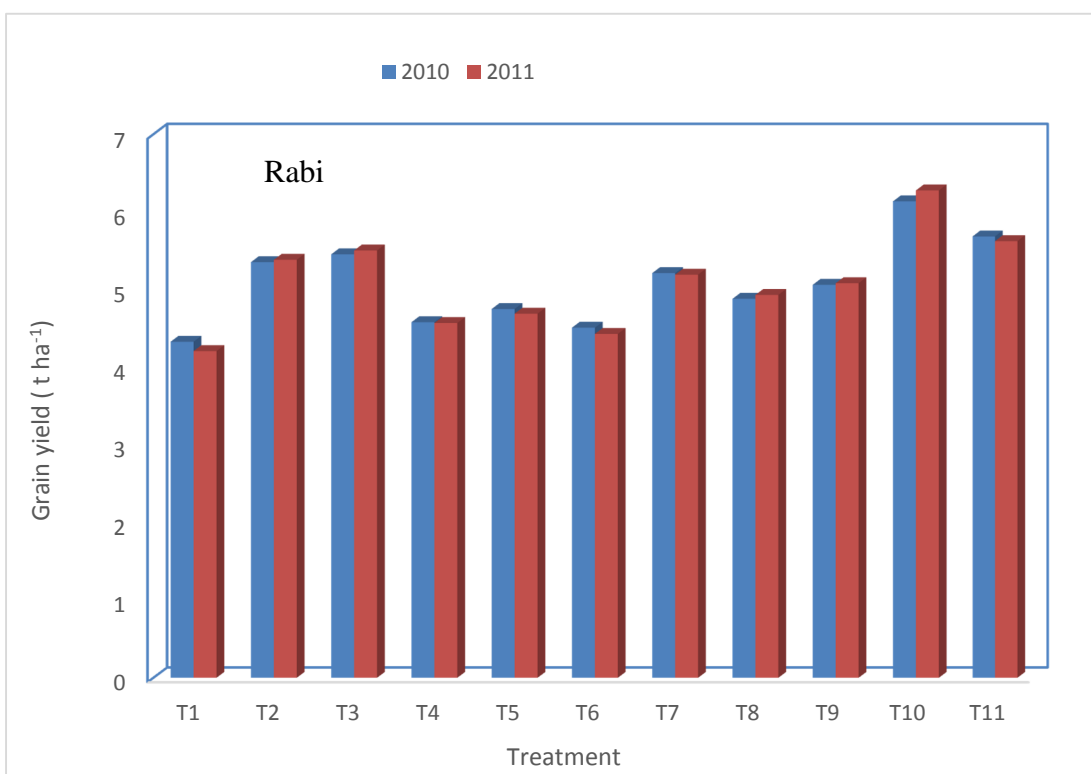
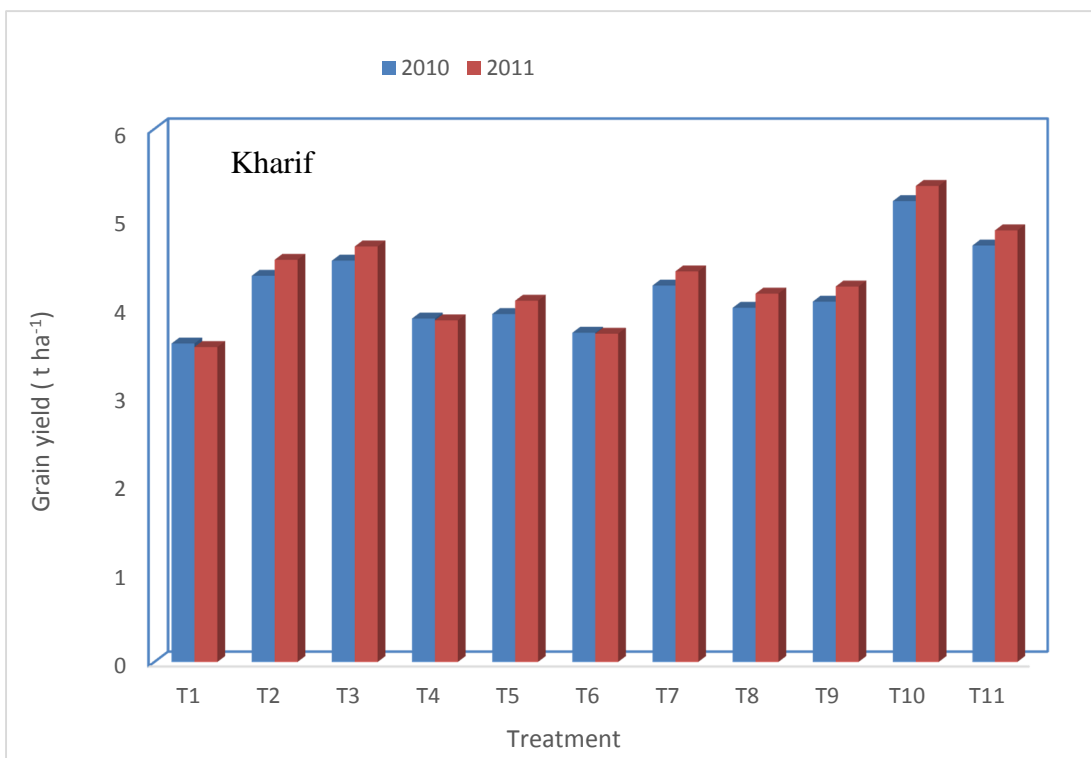


Fig. 4.15 Effect of integrated nutrient management on grain yield (t ha⁻¹) over seasons 2010 & 2011

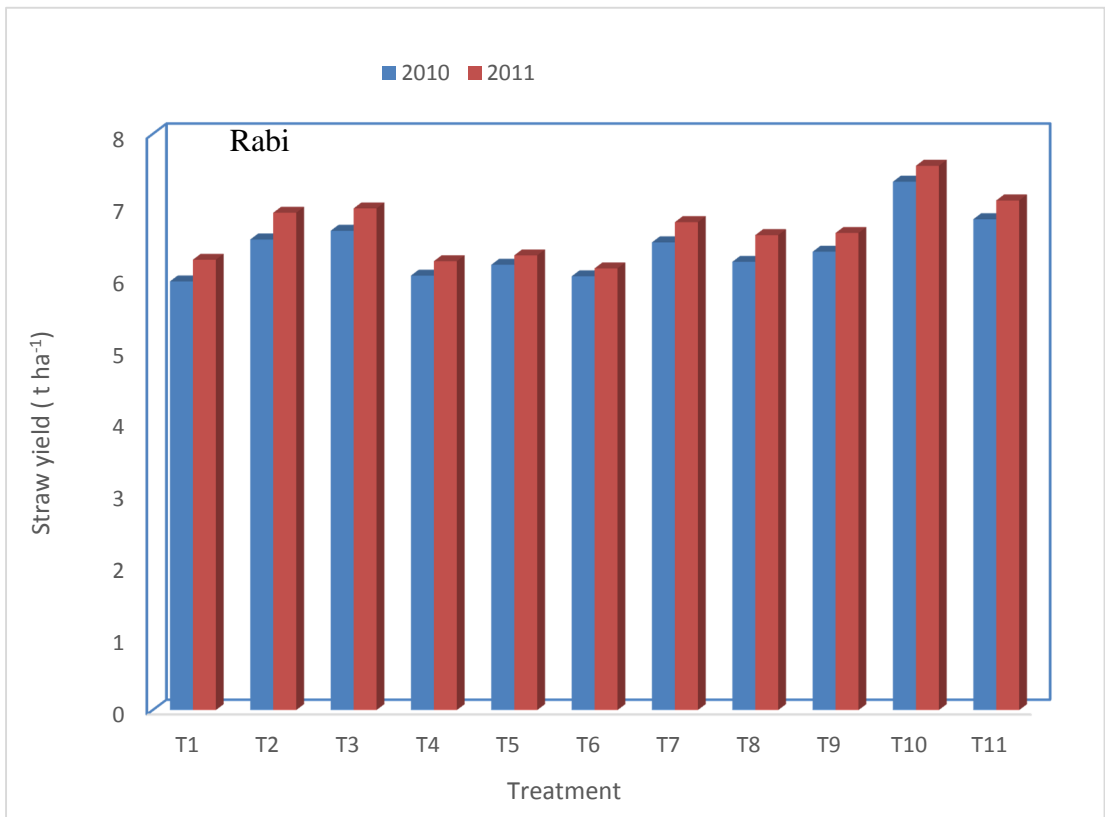
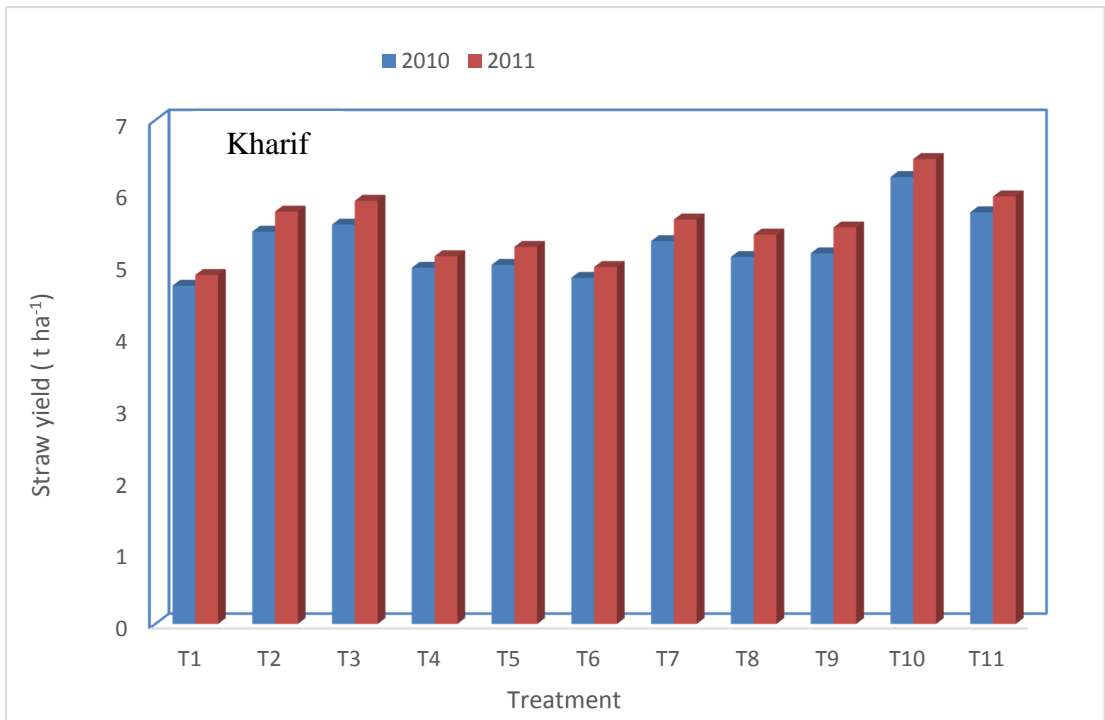


Fig. 4.16 Effect of integrated nutrient management on straw yield (t ha⁻¹) over seasons 2010&2011

T₁₁ (RFD + Zn-EDTA + S + B) recorded an increase of 13, 11, 14, 5, 8. 4 and 7 per cent more straw yield over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B) T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) respectively.

T₁₀ (RFD + ZnSO₄ + B) applied in kharif recorded an increase 11, 21 and 19 per cent more straw yield over treatments T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA) and T₅ (RFD +S) respectively.

Residual effect of FYM which was applied in kharif along with RFD recorded an increase of 10.9, 5, 7.5 and 10 per cent more yield over T₁ (RFD), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD + B) respectively. Lowest straw yield (6.11 t ha⁻¹) was recorded by treatment T₁ (RFD).

It was revealed that T₁₀ (RFD + ZnSO₄ + B) applied in kharif recorded highest system total straw yield of 27.56 t ha⁻¹ followed by T₁₁ (RFD + Zn-EDTA + S + B) recording a total straw yield of 25.56 t ha⁻¹.

4.3.3 Harvest index (%)

Data on harvest index are presented in Table 4.8. Both the years (2010 and 2011) recorded more or less similar harvest index. Highest harvest index (45.44) was recorded by T₁₀ (RFD + ZnSO₄ +B) which remained at par with T₁₁ (RFD + Zn-EDTA + S + B) recording a harvest index of 45.01.

Application of T₁₀ (RFD + ZnSO₄ + B) recorded an increase of 2 and 5 per cent more harvest index over T₃ (RFD + ZnSO₄) and T₆ (RFD + B) . Similarly. Application of T₁₁ (RFD + Zn-EDTA + S + B) recorded 3.6, 2.7, 4.3, 2, 3 and 3 per cent more harvest index over T₄ (RFD + Zn-EDTA), T₅ (RFD +S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA +S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) respectively. Application of T₁₀ (RFD + ZnSO₄ + B) recorded an increase of 2.6, 4.6, 3.7 and 5.3 per cent more harvest index over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B) respectively. Lowest harvest index (42.75) was recorded by T₁ (RFD).

Table 4.8 Effect of integrated nutrient management on harvest index over seasons 2010&2011

Treatments		Kharif			Rabi		
		2010	2011	Pooled	2010	2011	Pooled
T ₁	RFD	43.26	42.24	42.75	42.26	40.23	41.24
T ₂	RFD+FYM	44.36	44.14	44.25	45.04	43.82	44.43
T ₃	RFD+ZnSO ₄	44.86	44.28	44.57	45.05	44.14	44.59
T ₄	RFD+Zn-EDTA	43.84	42.98	43.41	43.19	42.34	42.76
T ₅	RFD+S	43.91	43.70	43.81	43.50	42.65	43.07
T ₆	RFD+B	43.53	42.70	43.13	42.86	42.21	42.53
T ₇	RFD+Zn-EDTA+S	44.33	43.89	44.11	44.52	43.39	43.95
T ₈	RFD+Zn-EDTA+B	43.89	43.40	43.64	43.99	42.84	43.41
T ₉	RFD+S+B	44.08	43.42	43.75	44.37	43.43	43.90
T ₁₀	RFD+ ZnSO ₄ +B	45.54	45.34	45.44	45.51	45.39	45.46
T ₁₁	RFD+Zn-EDTA+S+B	45.05	44.98	45.01	45.49	44.29	44.89
SEm (±)		0.44	0.26	0.29	0.39	0.38	0.38
CD (P = 0.05)		1.29	0.77	0.86	1.15	1.11	1.12

During rabi residual effect of ZnSO₄ + B (T₁₀) applied along with RFD in kharif season recorded highest harvest index (45.46) which was significantly superior over other treatment. Residual effect of RFD + Zn-EDTA + S + B applied in kharif recorded 5, 4.2, 5.5, 2.1 and 3.4 per cent more harvest index over treatment T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA +S) and T₈ (RD + Zn-EDTA + B), respectively.

Residual effect of ZnSO₄ + B applied along with RFD (T₁₀) in kharif recorded an increase of 2.3, 6.3, 5.5 and 6.8 per cent more harvest index over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD + B), respectively. Lowest harvest index (41.24) was recorded by T₁ (RFD).

4.2.4 Correlation studies

Correlation studies were taken up to determine the nature and degree of relationship between the yields and attributed. The data are presented in Table 4.9.

It was evident from the data that the ancillary characters such as plant height, (at harvest), LAI (60 DAT), dry matter production (90 DAT), length of panicle, height of panicle, number of fertile grains⁻¹, panicle m⁻², test weight and harvest index had a positive and significant correlation with grain yield both at 5 per cent and 1 per cent levels during kharif and rabi seasons of 2010 and 2011.

Table 4.9 Correlation of growth characters and yield attributes with grain yield (kharif 2010, 2011) and (rabi, 2010, 2011)

Sl. No	Characters	Correlation coefficient (Kharif)		Correlation coefficient (Rabi)	
		2010	2011	2010	2011
1	Plant height at harvest	0.514**	0.590**	0.527**	0.629**
2	LAI at 60 DAT	0.478**	0.561**	0.641**	0.571**
3	Dry matter production (90 DAT)	0.513**	0.629**	0.617**	0.622**
4	Length of panicle	0.563**	0.647**	0.574**	0.568**
5	Weight of panicle	0.615**	0.498**	0.494*	0.434*
6	Fertile grain/panicle	0.642**	0.595**	0.644**	0.633**
7	Test weight	0.379**	0.618**	0.621**	0.608**
8	Harvest index	0.831**	0.946**	0.897**	0.415*

* Significant at 5 per cent level

** Significant at 5 per cent and 1 per cent level

4.3 Nutrient uptake

4.3.1 Nitrogen uptake

Kharif grain

The uptake of nitrogen (N) by grain was significantly affected by various treatments (Table 4.10a and Fig.4.17a, b). The N uptake varied from 51.4 to 86.5 kg ha⁻¹ in 2010 and 51.5 kg to 85.6 kg ha⁻¹ in 2011. Application of recommended

fertilizer dose (RFD) absorbed 51.4 to 51.5 kg N ha⁻¹ by grain with a mean absorption of 51.5 kg ha⁻¹. Highest uptake of N (86 kg ha⁻¹) was recorded by T₁₀ (RFD + ZnSO₄ + B). It also recorded 18 and 59 % increase in uptakes over application of T₃ (RFD + ZnSO₄) and T₆ (RFD + B), respectively. T₁₀ was found to be significantly superiority over other treatments.

T₁₁ (RFD + Zn-EDTA + S + B) recorded 15.3 to 41.3 % increase in uptake over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S). T₁₀ recorded 23.0 to 59.0 % increase in uptakes over treatments T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). Application of T₁ (RFD) recorded lowest N uptake (51.5 kg ha⁻¹)

Kharif straw

Nitrogen uptake by straw was significantly affected by different treatments (Table 4.10a and Fig.4.17a, b).

Application of recommend dose of fertilizer (RFD) absorbed less N than its combinations with ZnSO₄, Zn-EDTA, S, B and FYM in both the years.

Maximum N uptake (49.5 kg ha⁻¹) was recorded by T₁₀ (RFD + ZnSO₄ + B) which recorded 13 and 43 % more uptake over T₅ (RFD + ZnSO₄) and T₆ (RFD + B) respectively.

Residual effect of T₁₁ (RFD + Zn-EDTA + S + B) recorded 11.3 to 31.3 % more uptake by straw over treatments of T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) respectively. Similarly T₁₀ recorded 17.3 to 37.5 % more uptake by straw over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) respectively. T₁₀ recorded 13 and 43 per cent more uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁ (RFD) recorded lowest (33.4 kg ha⁻¹) uptake by grain.

Total N uptake

Application of T₁₀ (RFD + ZnSO₄ + B) recorded maximum N uptake (135.5 kg ha⁻¹) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 121.5 kg N ha⁻¹.

Addition of ZnSO₄/FYM also resulted the crop to absorb more N (26.9 -31.8 kg ha⁻¹) which were significantly different from each other than RFD. The uptake increased from 3.7 to 32 kg ha⁻¹, when FYM/ZnSO₄/Zn-EDTA / S and B applied with RFD. Lowest uptake of N (84.8 kg ha⁻¹) was recorded by T₁ (RFD).

Rabi grain

During rabi higher N uptake in grain was recorded than in Kharif (Table 4.10b and illustrated in Fig.4.18a,b). Highest grain uptake (121.6 kg ha⁻¹) was recorded by residual effect of T₁₀ (RFD + ZnSO₄ + B) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 108.6 kg ha⁻¹. T₁₁ (RFD + Zn-EDTA + S + B) recorded an increase 12.6 to 41.8 % more uptake over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). Similarly residual effect of T₁₀ recorded 21.6 to 59 % more uptake of N over T₂, T₄, T₅ and T₆ respectively. Residual effect of T₁₀ recorded 17.8 and 59 % increase in uptake over single application of ZnSO₄ and B with RFD. Lowest grain (70.8 kg ha⁻¹) uptake was recorded from T₁ (RFD). T₁₀ recorded 17.9 to 58.6 % increase in N uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B) and T₁ (RFD).

Rabi Straw

Highest uptake of N (73.8 kg ha⁻¹) was recorded by T₁₀ (RFD + ZnSO₄ + B) followed by T₁₁(RFD + Zn-EDTA + S + B) recording an uptake of 67.10 kg ha⁻¹. T₁₁ (RFD + Zn-EDTA + S + N) recorded 8.9 to 26.8 % increase in N uptake over T₄ (Zn-EDTA), T₅(S), T₆(B), T₇(Zn-EDTA+S), T₈ (Zn-EDTA+B) and T₉ (S + B). Similarly T₁₀ (RFD + ZnSO₄ + B) recorded 17.0 to 39.6 % increase in N uptake over T₂, T₃, T₄, T₅ and T₆. T₁₀ recorded 14.2 and 39.6 % increase in N uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B) T₁ (RFD) recorded lowest N uptake (51.7 kg ha⁻¹) (Table 4.10b and illustrated in Fig.4.18 a, b).

Table 4.10a Effect of integrated nutrient management on nitrogen uptake (kg ha^{-1}) during kharif

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	51.37	51.54	51.46	33.3	33.4	33.35	84.81
T ₂	RFD+FYM	69.08	70.08	69.58	41.3	43.1	42.20	111.80
T ₃	RFD+ZnSO ₄	72.51	72.88	72.70	42.6	45.1	43.85	116.55
T ₄	RFD+Zn-EDTA	56.54	57.35	56.95	36.1	35.8	35.95	92.90
T ₅	RFD+S	57.47	61.06	59.27	36.5	37.3	36.90	96.20
T ₆	RFD+B	53.91	54.11	54.01	34.4	34.6	34.50	88.50
T ₇	RFD+Zn-EDTA+S	65.52	66.94	66.23	39.6	41.7	40.65	106.88
T ₈	RFD+Zn-EDTA+B	59.41	62.74	61.08	37.6	39.0	38.30	99.38
T ₉	RFD+S+B	61.25	64.15	62.70	38.1	40.3	39.20	101.90
T ₁₀	RFD+ ZnSO ₄ +B	86.54	85.57	86.06	48.5	50.4	49.45	135.50
T ₁₁	RFD+Zn-EDTA+S+B	76.13	76.38	76.26	44.5	46.1	45.30	121.55
	SEm (\pm)	0.92	0.89	0.56	0.52	3.9	0.89	0.84
	CD (P = 0.05)	2.72	2.62	1.68	1.53	1.15	2.67	2.52

Table 4.10b Effect of integrated nutrient management on nitrogen uptake (kg ha⁻¹) during rabi

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	71.6	70.1	70.85	50.0	53.3	51.65	122.50
T ₂	RFD+FYM	99.6	100.4	100.00	61.0	65.0	63.00	163.00
T ₃	RFD+ZnSO ₄	102.2	104.1	103.15	63.0	66.1	64.55	167.70
T ₄	RFD+Zn-EDTA	79.7	79.4	79.55	52.8	55.5	54.15	133.70
T ₅	RFD+S	84.9	85.5	85.20	55.5	56.9	56.20	141.40
T ₆	RFD+B	77.1	76.2	76.65	51.9	53.9	52.90	129.55
T ₇	RFD+Zn-EDTA+S	96.3	96.5	96.40	60.9	62.3	61.60	158.00
T ₈	RFD+Zn-EDTA+B	88.1	90.3	89.20	57.2	60.3	58.75	147.95
T ₉	RFD+S+B	92.4	93.9	93.15	59.3	60.0	59.65	152.80
T ₁₀	RFD+ ZnSO ₄ +B	118.5	124.7	121.60	72.6	75.1	73.85	195.50
T ₁₁	RFD+Zn-EDTA+S+B	107.7	109.6	108.65	65.7	68.5	67.10	175.75
	SEm (±)	0.97	1.49	0.98	0.53	0.53	0.54	1.36
	CD (P = 0.05)	2.88	4.47	2.94	1.57	1.58	1.62	4.08

Total N uptake

Residual effect of ZnSO₄ + B applied along with RFD (T₁₀) recorded highest N uptake in rabi rice (195.4 kg ha⁻¹) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 175.7 kg ha⁻¹. The uptake increased 5.7 and 36.9 % when applied singly with FYM, ZnSO₄, Zn-EDTA, S and B along with RFD.

4.3.2 Phosphorus

Kharif grain

Phosphorus of (P) uptake by grains were significantly affected by various treatments (Table 4.11a and Fig 4.17a,b).

P uptake ranged from 11.9 to 20.1 kg ha⁻¹ in 2010 and 11.9 to 21.3 kg ha⁻¹ in 2011. Maximum uptake was recorded (20.1-21.3 kg ha⁻¹) with application of RFD + ZnSO₄ + B which remained superior over other treatments with a mean uptake of 20.7 kg ha⁻¹.

T₁₁ (RFD + Zn-EDTA + S + B) recorded 17.4 to 44.5 % increase in uptake by grain over treatments T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) respectively.

Similarly T₁₀ (RFD + ZnSO₄ + B) recorded 26.0 to 64.2 % increase in uptake over treatment T₂, T₃, T₄, T₅ and T₆. T₁₀ recorded 20.3 to 64.2 % increase in P uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁ (RFD) recorded lowest grain uptake (11.9 kg ha⁻¹).

Kharif straw

Phosphorus uptake by straw was significantly affected by treatments (Table 4.11a and Fig. 4.17a,b) It ranged from 7.7 to 11.9 kg ha⁻¹ in 2010 and 7.8 to 12.8 kg ha⁻¹ in 2011. Highest P uptake (12.4 kg ha⁻¹) was recorded from treatment T₁₀ (RFD + ZnSO₄ + B) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording up uptake of 11 kg ha⁻¹.

T₁₁ recorded 13.4 to 35.8 % increase in P uptake over treatments T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B), and T₉ (RFD + S + B).

T₁₀ recorded 24 to 38 % increase in uptake over treatments T₂ (RFD +FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B). T₁ (RFD) recorded lowest (7.8 kg ha⁻¹) uptake.

Total P uptake

The total P uptake was differed significantly between the treatments (Table 4.11a,). Maximum uptake (33.1 kg ha⁻¹) was recorded with RFD + ZnSO₄ + B which recorded 68 % increase in uptake over T₁ (RFD). This was closely followed by T₁₁ (RFD + Zn-EDTA + S + B) recording a total uptake of 29.2 kg ha⁻¹. Sole application of FYM, ZnSO₄, Zn-EDTA, S and B increased 34.0 to 51.0 % more total P uptake over T₁ (RFD).

Rabi Grain

During rabi higher grain uptake was recorded than kharif (Table 4.11b and Fig. 4.18a,b). Uptake of phosphorus (P) was significantly influenced by residual use of various nutrients applied in kharif

Highest P uptake (29.7 kg ha⁻¹) was recorded by T₁₀ (RFD+ZnSO₄+B) applied in kharif followed by T₁₁ (RFD + Zn-EDTA + S + N) recording an uptake of 26.7 kg ha⁻¹.

T₁₁ recorded 11.7 to 33.5 % more grain uptake over treatments T₄ (RFD + Zn-EDTA), T₅(RFD +S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B).

T₁₀ recorded 19 to 48.5 % more uptake of P over treatments T₂ (RFD +FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B). T₁₀ recorded 15.5 and 48.5 % more uptake by grain over treatments T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁ (RFD) recorded lowest P uptake (18.6 kg ha⁻¹).

Table 4.11a Effect of integrated nutrient management on phosphorus uptake (kg ha⁻¹) during kharif

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	11.9	11.9	11.90	7.7	7.8	7.75	19.65
T ₂	RFD+FYM	16.1	16.7	16.40	9.8	10.2	10.00	26.40
T ₃	RFD+ZnSO ₄	16.8	17.6	17.20	10.2	10.8	10.50	27.70
T ₄	RFD+Zn-EDTA	13.4	13.1	13.25	8.4	8.5	8.45	21.70
T ₅	RFD+S	13.7	14.1	13.90	8.5	8.9	8.70	22.60
T ₆	RFD+B	12.7	12.5	12.60	8.0	8.1	8.05	20.65
T ₇	RFD+Zn-EDTA+S	15.3	15.7	15.50	9.4	10.0	9.70	25.20
T ₈	RFD+Zn-EDTA+B	14.3	14.6	14.45	8.8	9.3	9.05	23.50
T ₉	RFD+S+B	14.6	15.1	14.85	9.0	9.7	9.35	24.20
T ₁₀	RFD+ ZnSO ₄ +B	20.1	21.3	20.70	11.9	12.8	12.35	33.10
T ₁₁	RFD+Zn-EDTA+S+B	17.8	18.5	18.15	10.7	11.3	11.00	29.15
	SEm (±)	0.22	0.54	0.73	0.12	0.09	0.64	0.99
	CD (P = 0.05)	0.64	1.62	2.19	0.37	0.27	1.92	2.97

Table 4.11b Effect of integrated nutrient management on phosphorus uptake (kg ha⁻¹) during rabi

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	16.8	20.3	18.55	14.1	14.6	14.35	32.90
T ₂	RFD+FYM	22.3	27.8	25.05	16.9	16.9	16.90	41.95
T ₃	RFD+ZnSO ₄	22.9	28.6	25.75	17.4	17.5	17.45	43.20
T ₄	RFD+Zn-EDTA	18.3	22.9	20.60	14.6	14.8	14.70	35.30
T ₅	RFD+S	19.1	23.7	21.40	15.0	15.0	15.00	36.40
T ₆	RFD+B	17.9	22.1	20.00	14.3	14.4	14.35	34.35
T ₇	RFD+Zn-EDTA+S	21.3	26.5	23.90	16.4	16.5	16.45	40.35
T ₈	RFD+Zn-EDTA+B	19.8	25.0	22.40	15.4	15.8	15.60	38.00
T ₉	RFD+S+B	20.7	25.8	23.25	15.8	16.0	15.90	39.15
T ₁₀	RFD+ ZnSO ₄ +B	26.2	33.2	29.70	19.8	20.2	20.00	49.70
T ₁₁	RFD+Zn-EDTA+S+B	23.9	29.5	26.70	17.4	18.5	17.95	44.65
	SEm (±)	0.42	0.56	0.87	0.14	0.15	0.66	1.14
	CD (P = 0.05)	1.27	1.68	2.61	0.42	0.43	1.98	3.42

Rabi straw

Phosphorus uptake during rabi was affected by residual effect of various treatments imposed during kharif. It ranged from 14.1 to 19.8 kg ha⁻¹ in 2010 to 14.6 to 20.2 kg ha⁻¹ in 2011 (Table 4.11b and Fig.18a,b).

Maximum uptake (20 kg ha⁻¹) was recorded with residual effect of (ZnSO₄ + B) applied along with RFD during kharif season followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 17.9 kg ha⁻¹.

T₁₁ recorded 9.1 to 25 % more P uptake by straw over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + S).

T₁₀ recorded 18.3 to 39 % more uptake over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B).

T₁ (RFD) recorded lowest P uptake (14.3 kg ha⁻¹) by straw, which was 39 % less than T₁₀.

Total P uptake

The total P uptake during rabi was significantly influenced by residual effect of various nutrients applied only with RFD in kharif. Maximum uptake was recorded with RFD + ZnSO₄ + B (49.7 kg ha⁻¹) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 44.6 kg ha⁻¹.

Residual effect of FYM, ZnSO₄, Zn-EDTA, S and B applied along with RFD in kharif recorded an increase 4.8 to 31.4% increase in total uptake over application of recommended fertilizer dose T₁ (RFD).

4.3.3 Potassium uptake

Kharif grain

Uptake of potassium during kharif was influenced significantly among various treatments (Table 12a and Fig 4.17a,b). It ranged from 19.1 to 31.1 kg ha⁻¹ in 2010 and 19.1 to 31.9 kg ha⁻¹ in 2011.

Highest uptake (31.5 kg ha^{-1}) was recorded on grain by T₁₀ (RFD + ZnSO₄ + B) followed by (28.3 kg ha^{-1}) uptake by T₁₁ (RFD + Zn-EDTA + S + B). T₁₁ recorded 14.1 to 41.5 % more uptake over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B).

Similarly T₁₀ recorded an increase of 21.1 to 57.5 % increase in K uptake over treatments T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ ((RFD + S) and T₆ (RFD+B). T₁₀ recorded 21.1 to 57.5 per cent increase in K uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). Lowest uptake (19.1 kg ha^{-1}) was recorded by T₁ (RFD).

Kharif straw

Potassium uptake by straw was significantly affected by various treatments (Table 4.12a and Fig. 4.17a, b). It ranged from 103.5 to 143.5 kg ha^{-1} in 2010 and 107.6 to 149.7 kg ha^{-1} in 2011. The uptake in straw was more in straw than grain.

Application of ZnSO₄ + B along with RFD (T₁₀) recorded maximum K uptake (146.6 kg ha^{-1}) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 133.6 kg ha^{-1} . T₁₁ recorded 7.9 to 23.3 % more uptake over treatment T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). T₁₀ recorded 15.5 to 35.2 % more K uptake in straw over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B). T₁ (RFD) recorded lowest K uptake in straw (105.5 kg ha^{-1}).

Total K uptake

Maximum uptake (178.1 kg ha^{-1}) was recorded from T₁₀ followed by T₁₁ (162 kg ha^{-1}). T₁ recorded 43 % less K uptake over T₁₀.

Rabi grain

Potassium uptake by grain was affected by treatments (Table 4.12b and Fig.4.18a,b). It ranged from 19.6 to 30 kg ha^{-1} 2010 and 25.3 to 41.0 kg ha^{-1} in 2011.

Residual effect of ZnSO₄ + B applied along with RFD (T₁₀) recorded highest K uptake by grain (35.5 kg ha^{-1}) followed by T₁₁ (RFD + Zn-EDTA + S + B)

recording an uptake of 31.7 kg ha⁻¹. T₁₁ recorded 11.2 to 33.2 % more K uptake over T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA) + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S). T₁₀ recorded 19.9 to 48.8 % increase in K uptake over treatments T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B). T₁₀ recorded 16.7 to 48.8 % increase in K uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). Lowest K uptake (22.4 kg ha⁻¹) was recorded by T₁ (RFD) which produced 58.5 % less K uptake over T₁₀ (RFD + ZnSO₄ + B).

Rabi straw

Potassium uptake by straw was influenced by imposition of various treatments during rabi. The straw absorbed more K than grain.

Residual effect of ZnSO₄ + B applied along with RFD in rabi recorded highest K uptake (169.4 kg ha⁻¹) than T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 157.8 kg ha⁻¹ (Table 4.12b and Fig.4.18a,b)..

T₁₁ recorded 5 to 16 % more K uptake over treatment T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B) . T₁₀ recorded 11.3 to 24.3 % more K uptake by straw over treatment T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA) , T₅ (RFD + S) and T₆ (RFD+B). S + B). T₁ (RFD) recorded lowest (135.1 kg ha⁻¹) K uptake which was 25 % less than treatment T₁₀ (RFD + ZnSO₄ + B).

Total K uptake

The total K uptake during rabi was found to be more than kharif due to residual effect various treatments applied in kharif. It different significantly between treatments. Maximum total uptake (204.9 kg ha⁻¹) was recorded by T₁₀ (RFD + ZnSO₄ + B) than T₁₁ (RFD + Zn-EDTA + S + B) recording a total uptake of 189.5 kg ha⁻¹. Single application of FYM, ZnSO₄, Zn-EDTA, S and B increased 1.6 to 17.8 % more total uptake over treatment of recommended fertilizer dose (RFD).

Table 4.12a Effect of integrated nutrient management on potassium uptake (kg ha⁻¹) during kharif

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	19.1	19.1	19.10	103.5	107.6	105.5	124.6
T ₂	RFD+FYM	25.6	26.3	25.95	123.6	130.3	126.9	152.9
T ₃	RFD+ZnSO ₄	24.5	27.5	26.00	126.5	134.5	130.5	156.5
T ₄	RFD+Zn-EDTA	21.1	21.0	21.05	109.6	113.9	111.7	132.8
T ₅	RFD+S	21.6	22.4	22.00	110.7	117.4	114.0	136.0
T ₆	RFD+B	20.1	20.0	20.05	106.3	110.4	108.3	128.4
T ₇	RFD+Zn-EDTA+S	24.2	25.3	24.75	120.2	127.5	123.8	148.6
T ₈	RFD+Zn-EDTA+B	22.5	23.3	22.90	114.2	121.6	117.9	140.8
T ₉	RFD+S+B	23.1	24.1	23.60	115.7	124.3	120.0	143.6
T ₁₀	RFD+ ZnSO ₄ +B	31.1	31.9	31.50	143.5	149.7	146.6	178.1
T ₁₁	RFD+Zn-EDTA+S+B	27.8	28.7	28.25	130.9	136.4	133.6	161.9
	SEm (±)	0.33	0.33	0.55	1.57	1.22	1.26	0.35
	CD (P = 0.05)	0.99	0.98	1.65	4.62	3.61	3.78	1.05

Table 4.12b Effect of integrated nutrient management on potassium uptake (kg ha⁻¹) during rabi

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	19.6	25.3	22.45	134.9	135.2	135.05	157.50
T ₂	RFD+FYM	25.4	33.8	29.60	148.7	155.8	152.25	181.85
T ₃	RFD+ZnSO ₄	26.1	34.7	30.40	151.4	158.8	155.10	185.50
T ₄	RFD+Zn-EDTA	21.2	28.1	24.65	136.9	138.3	137.60	162.25
T ₅	RFD+S	22.1	29.1	25.60	140.3	140.4	140.35	165.95
T ₆	RFD+B	20.7	27.0	23.85	136.5	135.8	136.15	160.00
T ₇	RFD+Zn-EDTA+S	24.5	32.5	28.50	147.1	152.4	149.75	178.25
T ₈	RFD+Zn-EDTA+B	22.8	30.8	26.80	140.7	146.9	143.80	170.60
T ₉	RFD+S+B	23.7	31.7	27.70	144.0	148.5	146.25	173.95
T ₁₀	RFD+ ZnSO ₄ +B	30.0	41.0	35.50	167.5	171.3	169.40	204.90
T ₁₁	RFD+Zn-EDTA+S+B	27.7	35.7	31.70	155.5	160.1	157.80	189.50
	SEm (±)	0.25	0.34	0.62	1.22	1.24	1.33	0.25
	CD (P = 0.05)	0.75	0.99	1.86	3.61	3.66	3.99	0.75

4.3.4 Sulphur uptake

Kharif grain

Uptake of sulphur (S) by grain was significantly differed by various treatments (Table 4.13a and illustrated in Fig.4.17a,b). It ranged from 2.7 to 6.2 kg ha⁻¹ in 2010 and 2.7 to 6.3 kg ha⁻¹ in 2011. Highest S uptake (6.3 kg ha⁻¹) was recorded by T₁₀ (RFD + ZnSO₄ + B) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 5.4 kg ha⁻¹. T₁₁ increased 30 to 80 % more S uptake over treatments T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B), respectively. T₁₀ recorded an increase 38 to 108 % more S uptake over treatments T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B), respectively. T₁₀ recorded an increase and 25 and 108 % uptake by grain over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁ (RFD) recorded lowest S uptake (2.7 kg ha⁻¹).

Kharif straw

Significant difference was observed between treatments with respect to S uptake (Table 4.13a and Fig.4.17a, b). It ranged from 3 to 6.8 kg ha⁻¹ in 2010 and 3.0 to 7.2 kg ha⁻¹ in 2011.

Application of RFD (T₁) recorded minimum amount of S uptake (3 kg ha⁻¹) and similar for both the years and treatment of residual effect of RFD + ZnSO₄ + B recorded maximum uptake of 7-7.2 kg ha⁻¹ during the both the years.

Highest uptake (7 kg ha⁻¹) was recorded with residual effect of ZnSO₄ + B along with RFD (T₁₀) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 6.10 kg ha⁻¹. T₁₁ recorded 30 to 80 % increase in S uptake over T₄ (RFD + Zn-EDTA, T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). T₁₀ increased 22.8 to 112 % S uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁₀ recorded an increase of 28 to 112 % more S uptake over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD+B). T₁ (RFD) recorded lowest uptake (3 kg ha⁻¹) and produced 133 % less than T₁₀.

Total S uptake

The total uptake was maximum (13.3 kg ha⁻¹) by applying RFD + ZnSO₄ + B (T₁₀) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 11.5 kg ha⁻¹. The former increased the S uptake by 133 % more than RFD and the later increased 101.7 % more S uptake over RFD(T₁). Addition of FYM/ZnSO₄, Zn-EDTA/S and B increased S uptake 0.6 to 5 kg ha⁻¹ over RFD. Addition of FYM increased 75.4 % S uptake over RFD whereas single application of B along with RFD decreased 132 % S uptake compared to ZnSO₄ + B applied along with RFD during Kharif.

Rabi grain

There exist significant difference between treatments with respect to S uptake due to residual effect of applied nutrients in kharif. It ranged from 5.6 to 9.8 kg ha⁻¹ in 2010 and 4.9 to 9.9 kg ha⁻¹ in 2011 (Table 4.13b and illustrated in Fig.4.18a,b).

Application of FYM/ZnSO₄/Zn-EDTA/S/B increased 7.6 to 53.3 % more S uptake over recommended fertilizer dose (RFD). Highest S uptake was recorded with residual effect of ZnSO₄+B (9.85 kg ha⁻¹) followed by T₁₁ (RFD + Zn-EDTA + S + B) (8.1 kg ha⁻¹).

T₁₁ recorded an increase of 9.4 to 44.6 % more S uptake by grain over treatments T₄ (Zn-EDTA), T₅ (S), T₆ (B), T₇ (Zn-EDTA+S), T₈ (Zn-EDTA+B) and T₉ (S+B) applied along with RFD. T₁₀ recorded an increase of 23 to 74 % more S uptake over T₃ (RFD+ZnSO₄) and T₆ (RFD+B).

Similarly, T₁₀ also recorded an increase of 26 to 74 % more S uptake over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD+S) and T₆ (RFD+B). Lowest S uptake was recorded by T₁ (5.25 kg ha⁻¹) which was 88.4 % less than T₁₀.

Rabi straw

Significant difference was observed between different treatments with respect to S uptake (Table 4.13b and Fig.4.18a, b). It ranged from 6 to 10.2 kg ha⁻¹ in 2010 and 7 to 10.1 kg ha⁻¹ in 2011.

Table 4.13a Effect of integrated nutrient management on sulphur uptake (kg ha⁻¹) during kharif

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	2.7	2.7	2.70	3.0	3.0	3.00	5.70
T ₂	RFD+FYM	4.3	4.8	4.55	5.0	5.9	5.45	10.00
T ₃	RFD+ZnSO ₄	5.0	5.1	5.05	5.2	6.2	5.70	10.75
T ₄	RFD+Zn-EDTA	3.3	3.3	3.30	3.8	3.5	3.65	6.95
T ₅	RFD+S	3.4	3.6	3.50	3.8	3.8	3.80	7.30
T ₆	RFD+B	3.0	3.0	3.00	3.3	3.3	3.30	6.30
T ₇	RFD+Zn-EDTA+S	3.9	4.4	4.15	4.8	5.4	5.10	9.25
T ₈	RFD+Zn-EDTA+B	3.5	3.8	3.65	4.0	4.1	4.05	7.70
T ₉	RFD+S+B	3.7	4.0	3.85	4.1	4.8	4.45	8.30
T ₁₀	RFD+ ZnSO ₄ +B	6.2	6.3	6.25	6.8	7.2	7.00	13.30
T ₁₁	RFD+Zn-EDTA+S+B	5.3	5.5	5.40	5.8	6.4	6.10	11.50
	SE (m) ±	0.06	0.06	1.12	0.06	0.05	1.32	0.56
	CD (P= 0.05)	0.17	0.17	3.36	0.19	0.15	3.96	1.68

Table 4.13b Effect of integrated nutrient management on sulphur uptake (kg ha⁻¹) during rabi

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	5.6	4.9	5.25	6.0	7.0	6.50	11.75
T ₂	RFD+FYM	7.9	7.7	7.80	8.2	8.8	8.50	16.30
T ₃	RFD+ZnSO ₄	8.1	8.0	8.05	8.6	9.0	8.80	16.85
T ₄	RFD+Zn-EDTA	6.1	5.7	5.90	6.9	7.2	7.05	12.95
T ₅	RFD+S	6.6	6.0	6.30	7.4	7.5	7.45	13.75
T ₆	RFD+B	5.9	5.4	5.65	6.6	7.0	6.80	12.45
T ₇	RFD+Zn-EDTA+S	7.6	7.2	7.40	8.2	8.5	8.35	15.75
T ₈	RFD+Zn-EDTA+B	6.8	6.5	6.65	7.5	7.9	7.70	14.35
T ₉	RFD+S+B	7.2	6.8	7.00	7.6	8.2	7.90	14.90
T ₁₀	RFD+ ZnSO ₄ +B	9.8	9.9	9.85	10.2	10.1	10.15	20.00
T ₁₁	RFD+Zn-EDTA+S+B	8.0	8.2	8.10	8.5	9.3	8.90	17.00
	SE (m) ±	0.08	0.08	1.17	0.07	0.07	1.59	0.49
	CD (P= 0.05)	0.23	0.26	3.51	0.21	0.22	4.77	1.47

Application of RFD (T₁) recorded minimum amount of S uptake (6.5 kg ha⁻¹). The residual effect of RFD + ZnSO₄ + B recorded maximum uptake of 10.1 to 10.2 kg ha⁻¹ during the both the years.

Highest uptake (10.1 kg ha⁻¹) was recorded with residual effect of ZnSO₄ + B along with RFD (T₁₀) followed by T₁₁ (RFD + Zn-EDTA + S + B) recording an uptake of 8.9 kg ha⁻¹. T₁₁ recorded 6.6 to 30.9 % increase in S uptake over T₄ (RFD + Zn-EDTA, T₅ (RFD + S), T₆ (RFD + B), T₇ (RFD + Zn-EDTA + S), T₈ (RFD + Zn-EDTA + B) and T₉ (RFD + S + B). T₁₀ increased 15 to 49 % S uptake over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁₁ recorded an increase of 6.6 to 27 % more S uptake over T₂ (RFD + FYM), T₄ (RFD + Zn-EDTA), T₅ (RFD + S), T₇ (RFD + Zn-EDTA + S) and T₈ (RFD + Zn-EDTA + S) and T₉ (RFD + S + B). T₁ (RFD) recorded lowest uptake (6.5 kg ha⁻¹) and recorded 55 % less uptake than T₁₀.

Total S uptake

Total S uptake was maximum (20 kg ha⁻¹) by residual effect of T₁₀ (RFD+ZnSO₄+B) followed by T₁₁ (RFD + Zn-EDTA + S + B) (17 kg ha⁻¹). The former increased the uptake by 70.9 % more than RFD and was found superior over other treatments. Addition of FYM/ZnSO₄/Zn-EDTA/S/B increased the S uptake by 0.7 kg ha⁻¹ to 5.2 kg ha⁻¹ over RFD. Addition of FYM increased 39 % S uptake over RFD where as single application B along with RFD (T₆) decreased 61 % S uptake in comparison to RFD+ZnSO₄+B (T₁₀) applied along with RFD during kharif.

4.3.5 Zinc uptake

Kharif grain

Data on zinc uptake is presented in Table 4.14a and illustrated in Fig.4.17a, b) There exist significant difference between treatment with respect to zinc uptake due to imposition of various treatments. It was slightly more in 2010 than 2011. It ranged from 61 to 123 g ha⁻¹ in 2010 and 47 to 123 g ha⁻¹ in 2011. Application of FYM/ZnSO₄/Zn-EDTA/S and B increased zinc uptake by 7 g ha⁻¹ to 46 g ha⁻¹ compared with RFD. Application of RFD decreased 69 g ha⁻¹ uptake as compared to RFD + ZnSO₄ + B (T₁₀). It recorded highest grain uptake of 123 g ha⁻¹ and was found

to be significantly superior over other treatments. However, addition of ZnSO₄ and FYM to RFD increased 41 to 46 g ha⁻¹ respectively compared to RFD. T₁₁ (RFD + Zn-EDTA + S + B) recorded a higher grain uptake of 106 g ha⁻¹ and was found to be superior over other treatments.

Addition of Zn-EDTA+ S/Zn-EDTA + B/S + B and Zn-EDTA + S + B with RFD increased zinc uptake by 18 to 38 g ha⁻¹ in 2010 and 16 to 49 g ha⁻¹ in 2011 in comparison to T₁₀ (RFD + ZnSO₄ + B).

It was revealed from the mean data that maximum uptake of Zn (123 g ha⁻¹) was recorded with RFD + ZnSO₄ + B followed by RFD + Zn-EDTA + S + B (106 g ha⁻¹). The former increased the uptake by 127.7 per cent and the later increased 96.3 per cent over RFD. Lowest grain uptake (54 g ha⁻¹) was recorded from T₁ (RFD) treatments T₂ and T₃ remained at par with each other.

Kharif straw

The zinc uptake by straw differed significantly among the treatments (Table 4.14a and Fig.4.17a. b). The straw absorbed more zinc than grain. It ranged from 70 to 132 g ha⁻¹ in 2010 and 52 to 135 g ha⁻¹ in 2011. Addition of FYM/ZnSO₄/Zn-EDTA/S and B increased zinc uptake by 10 to 49 g ha⁻¹ as compared with RFD. Application of RFD + ZnSO₄ + B recorded highest Zn uptake (133 g ha⁻¹) followed by RFD + Zn-EDTA + S + B recording Zn uptake of 116 g ha⁻¹. Both the treatments were found to be significantly superior over other treatments. Application of RFD decreased an uptake of 72 g ha⁻¹ in comparison to RFD + ZnSO₄ + B. However, addition of Zn-EDTA + S /Zn-EDTA + B/S + B and Zn-EDTA + S + B with RFD increased zinc uptake by 19 to 44 g ha⁻¹ in 2010 and 17 to 57 g ha⁻¹ in 2011 compared with T₁₀ (RFD + ZnSO₄ + B).

It was revealed from the mean data that application of RFD + ZnSO₄ + B recorded maximum straw uptake followed by application of RFD + Zn-EDTA + S + B. The former increased 118 per cent and the later increased 90 per cent over

recommended fertilizer dose (RFD) whereas addition of FYM increased 70 per cent zinc uptake over RFD.

Total zinc uptake

Total uptake was maximum (256 g ha^{-1}) by application of RFD + ZnSO₄ + B followed by RFD + Zn-EDTA + S + B (222 g ha^{-1}). Addition of FYM, ZnSO₄, Zn-EDTA /S and B increased the zinc uptake by 17 g to 95 g ha^{-1} compared with RFD. Application of RFD decreased 123 % in zinc uptake in comparison to RFD + ZnSO₄ + B, however, application of FYM with RFD increased 73 % zinc uptake than RFD.

Rabi grain

There was significant difference between treatments in respect of zinc uptake (Table 4.14b and Fig.4.18a,b). It was higher in 2010 than 2011. It ranged from 89 to 214 g ha^{-1} in 2010 and 75 to 205 g ha^{-1} in 2011.

Addition of FYM/ZnSO₄/Zn-EDTA /S/B increased the zinc uptake when compared with RFD. It increased by 9 to 84 g ha^{-1} in 2010 and 8 to 80 g ha^{-1} in 2011. The mean uptake was maximum (209 g ha^{-1}) with residual effect of ZnSO₄ + B applied along with RFD in Kharif followed by RFD + Zn-EDTA + S +B (176 g ha^{-1}). Application of RFD decreased the zinc uptake by 127 g ha^{-1} compared to RFD + ZnSO₄ + B, however, addition of FYM and ZnSO₄ increased uptake by 74 to 82 g ha^{-1} over RFD. Addition of Zn-EDTA +S/Zn-EDTA + B/S + B and Zn-EDTA + S + B with RFD in kharif increased grain uptake by 31 to 96 g ha^{-1} in 2010 and 35 to 90 g ha^{-1} in 2010 compared to RFD + ZnSO₄ + B.

It was revealed from the mean data that maximum uptake of Zn was recorded by RFD + ZnSO₄ + B followed by RFD + Zn-EDTA + S + B. The former increased 155 per cent and the later increased 115 per cent uptake compared to RFD. The treatments T₂ and T₃ remained at par with each other.

Table 4.14a Effect of integrated nutrient management on zinc uptake (g ha^{-1}) during kharif

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	61	47	54	70	52	61	115
T ₂	RFD+FYM	96	94	95	104	104	104	199
T ₃	RFD+ZnSO ₄	101	98	100	108	111	110	210
T ₄	RFD+Zn-EDTA	74	60	67	87	68	77	144
T ₅	RFD+S	77	64	71	89	73	81	152
T ₆	RFD+B	68	55	61	79	63	71	132
T ₇	RFD+Zn-EDTA+S	90	82	86	100	94	97	183
T ₈	RFD+Zn-EDTA+B	80	68	74	88	78	83	157
T ₉	RFD+S+B	85	74	80	96	88	92	172
T ₁₀	RFD+ ZnSO ₄ +B	123	123	123	132	135	133	256
T ₁₁	RFD+Zn-EDTA+S+B	105	107	106	113	118	116	222
	SE (m) ±	1.24	1.13	2.08	1.30	0.86	1.79	0.58
	CD (P= 0.05)	3.68	3.35	6.24	3.85	2.56	5.37	1.74

Table 4.14b Effect of integrated nutrient management on zinc uptake (g ha⁻¹) during rabi

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	89	75	82	107	95	101	183
T ₂	RFD+FYM	167	144	156	185	165	175	331
T ₃	RFD+ZnSO ₄	173	155	164	190	177	183	347
T ₄	RFD+Zn-EDTA	101	95	98	109	112	111	209
T ₅	RFD+S	105	103	104	120	118	119	223
T ₆	RFD+B	98	83	90	114	98	106	196
T ₇	RFD+Zn-EDTA+S	141	138	139	151	160	155	294
T ₈	RFD+Zn-EDTA+B	118	115	117	132	137	134	251
T ₉	RFD+S+B	125	124	124	137	143	140	264
T ₁₀	RFD+ ZnSO ₄ +B	214	205	209	234	226	230	439
T ₁₁	RFD+Zn-EDTA+S+B	183	170	176	199	196	197	373
	SE (m) ±	1.68	1.46	3.14	1.72	1.69	4.69	2.57
	CD (P= 0.05)	4.95	4.30	9.42	5.09	5.01	14.07	7.71

Rabi straw

The treatments differed significant in respect to zinc uptake (Table 4.14b and Fig. 4.18a,b). It ranged from 107 to 234 g ha⁻¹ in 2010 and 95 to 226 g ha⁻¹ in 2011. The straw took more zinc than grain. Addition of FYM/ZnSO₄/Zn-EDTA/S/B with RFD increased by 7 to 83 g ha⁻¹ in 2010 and 3 to 82 g ha⁻¹ in 2011 as compared to RFD. However, addition of FYM and ZnSO₄ increased uptake by an average of 74 to 82 g ha⁻¹ compared to RFD.

Residual effect of RFD + ZnSO₄ + B(T₁₀) recorded maximum Zn uptake (230 g ha⁻¹) followed by RFD+Zn-EDTA+S+B (T₁₁) recording an uptake of 197 g ha⁻¹. Application of RFD decreased an uptake of 129 g ha⁻¹ compared to RFD + ZnSO₄ + B. Addition of Zn-EDTA + S/Zn-EDTA + B/S + B and Zn-EDTA + S + B with RFD increased Zn uptake by 35 to 102 g ha⁻¹ in 2010 and 30 to 89 g ha⁻¹ in 2011 compared with T₁₀.

It was revealed from the mean data that residual effect of RFD + ZnSO₄ + B recorded maximum Zn uptake followed by RFD + Zn-EDTA + S + B. The former increased 127 per cent and the later by 95 per cent compared to RFD.

Total Zn uptake

The treatments differed significantly with respect to total zinc uptake (Table 4.14b). Application of FYM/ZnSO₄/Zn-EDTA/S and B with RFD increased to uptake by 7 to 90 per cent compared to RFD. Maximum uptake was observed with RFD + ZnSO₄ + B (439 g ha⁻¹) followed by RFD + Zn-EDTA + S + B (373 g ha⁻¹). The former increased 139.9 per cent and the later increased 104 % more zinc uptake compared to RFD.

4.3.6 Boron uptake

Kharif grain

There was significant difference between treatment in respect to B uptake (Table 4.15a and Fig.4.17a,b). It ranged from 33 to 67 g ha⁻¹ in 2010 and 36 g to 74 g ha⁻¹ in 2011. Addition of FYM/ZnSO₄/Zn-EDTA/S/B increased the zinc uptake

compared to RFD. It increased by 10 to 15 g ha⁻¹ in 2010 and 9 to 20 g ha⁻¹ in 2011. Application of RFD + ZnSO₄ + B recorded maximum boron uptake (72 g ha⁻¹) followed by RFD + Zn-EDTA + S + B (63 g ha⁻¹). Application of RFD decreased 37 g ha⁻¹ uptake compared to RFD + ZnSO₄ + B. However addition of FYM and ZnSO₄ increased boron uptake by 12 and 17 g ha⁻¹ respectively. Addition of Zn-EDTA + S/Zn-EDTA + B/ S + B/Zn-EDTA + S + B with RFD increased boron uptake by 6 to 23 g ha⁻¹ in 2010 and 10 to 26 g ha⁻¹ in 2011.

As earlier reported maximum boron uptake was recorded by RFD + ZnSO₄ + B followed by RFD + Zn-EDTA + S + B. The former increased 106 % uptake and the later increased 81 per cent compared to RFD. Lowest grain uptake (35 g ha⁻¹) was recorded by RFD.

Kharif straw

There was significant difference between various treatments due to imposition of treatments with respect to boron uptake (Table 4.15a and Fig.4.17a,b). It ranged between 59 to 102 g ha⁻¹ in 2010 and 67 to 108 g ha⁻¹ in 2011. The straw took more boron than grain. Addition of FYM/ZnSO₄/Zn-EDTA/S/B increased boron uptake by 10 to 16 g ha⁻¹ as compared to RFD.

Application of ZnSO₄ + B with RFD (T₁₀) recorded highest boron uptake (105 g ha⁻¹) followed by RFD + Zn-EDTA + S + B (95 g ha⁻¹). Application of RFD decreased 42 g ha⁻¹ compared to RFD + ZnSO₄ + B. However addition of FYM and ZnSO₄ increased boron uptake by 11 and 16 g ha⁻¹ respectively over RFD. Addition of Zn-EDTA + S/Zn-EDTA + B/ S + B/ Zn-EDTA+S+B to RFD increased boron uptake by 10 to 33 g ha⁻¹ in 2010 and 11 to 31 g ha⁻¹ in 2011 compared to RFD.

Total boron uptake

The treatments different among themselves with respect to boron uptake (Table 4.15a). Application of FYM/ZnSO₄/Zn-EDTA/S and B increased the uptake 19.4 to 33.6 per cent compared to RFD. Maximum uptake was recorded by RFD + ZnSO₄ + B (177 g ha⁻¹) followed by RFD + Zn-EDTA + S + B (158 g ha⁻¹). Application of RFD (98 g ha⁻¹) decreased 81 % boron uptake compared to RFD + ZnSO₄ + B.

Rabi grain

The treatments did differ significantly in respect to boron uptake (Table 4.15b and Fig.4.18 a, b). It ranged between 50 to 116 g ha⁻¹ in 2010 and 51 to 106 g ha⁻¹ in 2011. Single addition of FYM/ZnSO₄/ Zn-EDTA/ S/ B increased boron uptake compared to RFD. It increased from 17 to 19 g ha⁻¹ in 2010 and 11 to 27 g ha⁻¹ in 2011. Application of RFD + ZnSO₄ + B recorded maximum boron uptake (111 g ha⁻¹) followed by T₁₁ (RFD + Zn-EDTA + S + B) (98 g ha⁻¹). Application of RFD decreased 61 g ha⁻¹ uptake as compared to RFD+ZnSO₄+B. However, addition of FYM and Zn + ZnSO₄ + B. increased boron uptake by 20 and 23 g ha⁻¹, respectively compared to RFD. Addition of Zn-EDTA + S/Zn-EDTA + B/ S + B/ Zn-EDTA + S + B increased boron uptake by 12 to 53 g ha⁻¹ in 2010 and 15 to 39 g ha⁻¹ in 2011 compared to RFD. T₁₀ (RFD + ZnSO₄ + B) recorded 122 % and T₁₁ (RFD + Zn-EDTA + S + B) recorded 96 % boron uptake over RFD . The lowest grain uptake (51 g ha⁻¹) was recorded with application of RFD.

Rabi straw

There was significant difference between treatment with respect to boron uptake (Table 4.15b and Fig.4.18a,b) It ranged from 84 to 183 g ha⁻¹ in 2010 and 90 to 148 g ha⁻¹ in 2011. The straw took more boron than grain. Residual effect of FYM/ZnSO₄/Zn-EDTA/S and B increased boron uptake 20 to 27 g ha⁻¹ compared to RFD. Residual effect of ZnSO₄ + B along with RFD applied in kharif recorded maximum uptake (165 g ha⁻¹) followed by RFD + Zn EDTA + S + B (152 g ha⁻¹). Residual effect of RFD decreased 78 g ha⁻¹ compared to RFD + ZnSO₄ + B. However addition of FYM and ZnSO₄ increased boron uptake 20 g ha⁻¹ respectively compared to RFD. Addition of Zn-EDTA + S/Zn-EDTA + B/S + B/ Zn-EDTA+S+B to RFD increased boron uptake by 18 to 88 g ha⁻¹ in 2010 and 10 to 43 g ha⁻¹ in 2011. Residual effect of RFD/ZnSO₄ + B and RFD/Zn-EDTA + S + B recorded 89.7 and 75 per cent increase in boron uptake compared to RFD.

Table 4.15a Effect of integrated nutrient management on boron uptake (g ha⁻¹) during kharif

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	33	36	35	59	67	63	98
T ₂	RFD+FYM	45	50	47	70	77	74	121
T ₃	RFD+ZnSO ₄	48	56	52	73	86	79	131
T ₄	RFD+Zn-EDTA	37	41	39	62	72	67	106
T ₅	RFD+S	39	43	41	61	68	65	106
T ₆	RFD+B	44	45	44	68	77	73	117
T ₇	RFD+Zn-EDTA+S	44	48	46	69	77	73	119
T ₈	RFD+Zn-EDTA+B	51	54	52	79	88	83	135
T ₉	RFD+S+B	50	56	53	78	91	84	137
T ₁₀	RFD+ ZnSO ₄ +B	67	74	72	102	108	105	177
T ₁₁	RFD+Zn-EDTA+S+B	61	64	63	92	97	95	158
	SE (m) ±	0.57	0.62	1.33	1.03	0.72	4.87	0.88
	CD (P= 0.05)	1.69	1.84	3.99	3.05	2.12	14.61	2.64

Table 4.15b Effect of integrated nutrient management on boron uptake (g ha⁻¹) during rabi

Treatment		Grain			Straw			Total
		2010	2011	Mean	2010	2011	Mean	
T ₁	RFD	50	51	50	84	90	87	137
T ₂	RFD+FYM	65	74	70	104	110	107	177
T ₃	RFD+ZnSO ₄	69	78	73	99	115	107	180
T ₄	RFD+Zn-EDTA	52	55	53	87	96	91	145
T ₅	RFD+S	54	68	61	89	102	96	157
T ₆	RFD+B	77	60	69	131	98	114	183
T ₇	RFD+Zn-EDTA+S	63	67	65	95	105	100	165
T ₈	RFD+Zn-EDTA+B	84	76	80	131	120	123	203
T ₉	RFD+S+B	89	84	87	139	132	135	222
T ₁₀	RFD+ ZnSO ₄ +B	116	106	111	183	148	165	276
T ₁₁	RFD+Zn-EDTA+S+B	104	91	98	165	138	152	250
	SE (m) ±	0.72	0.71	2.68	0.55	1.17	5.29	2.68
	CD (P= 0.05)	2.13	2.13	8.04	1.65	3.46	15.87	8.04

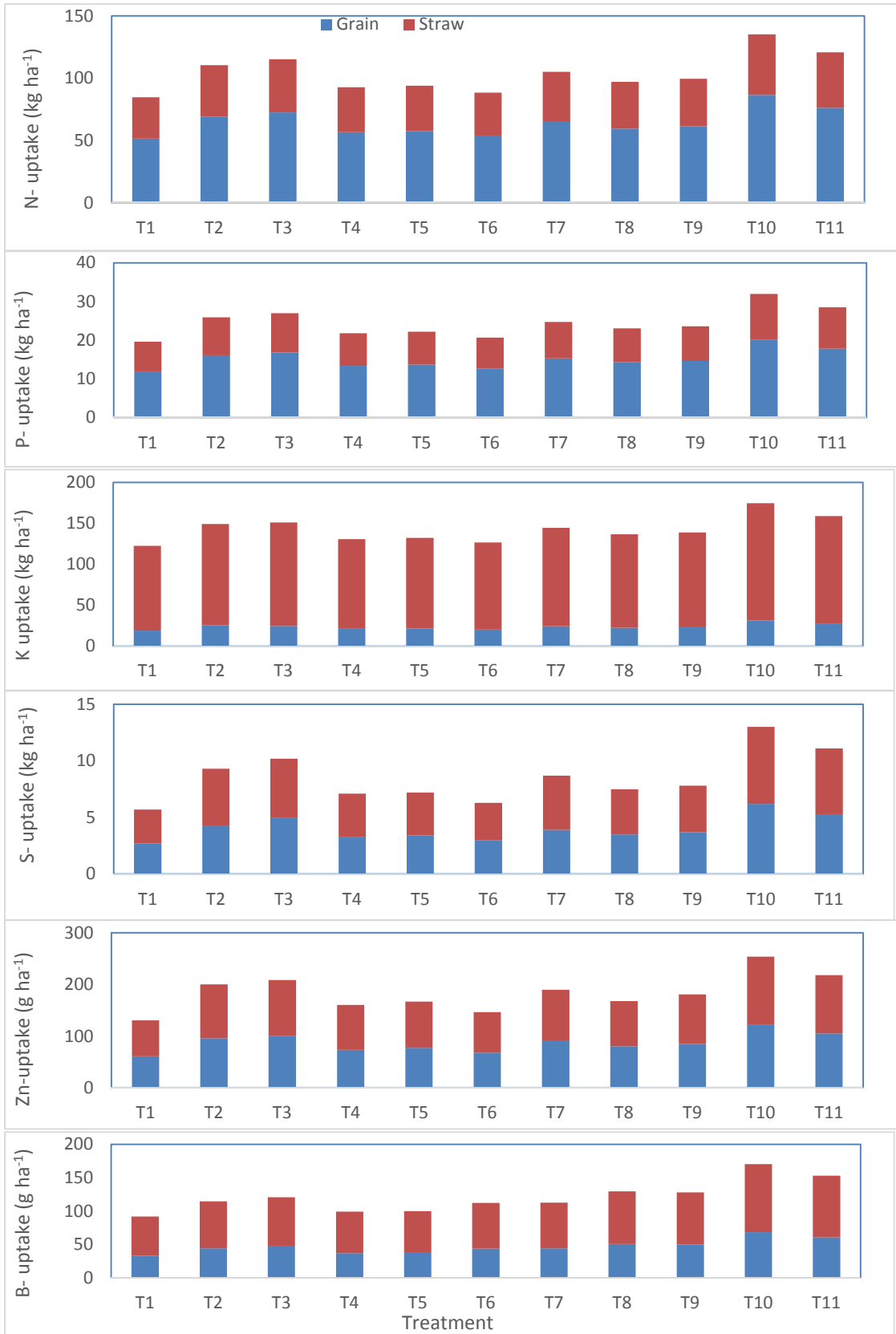


Fig. 4.17a Effect of integrated nutrient management on nutrient uptake during kharif, 2010

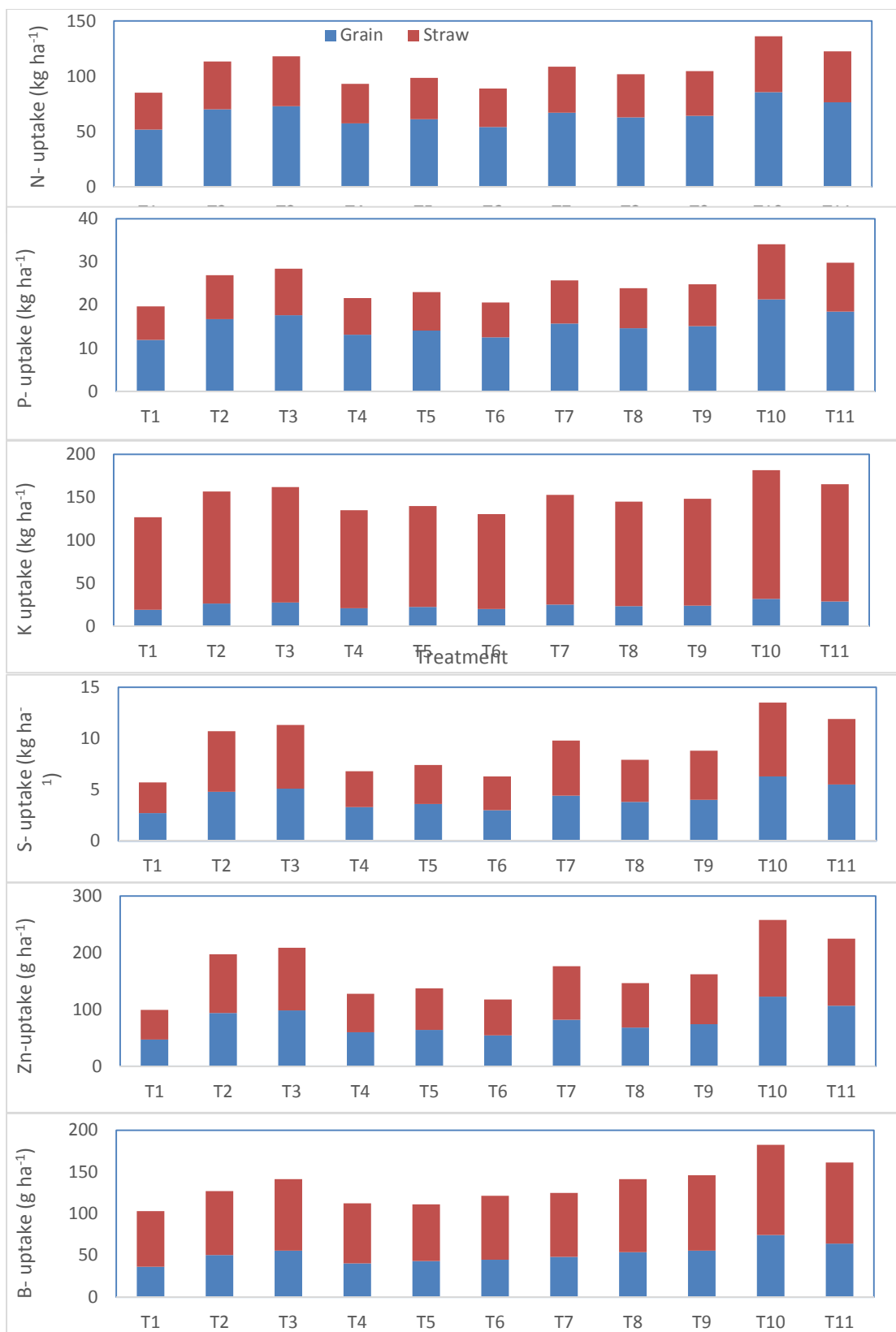


Fig. 4.17b Effect of integrated nutrient management on nutrient uptake during kharif, 2011

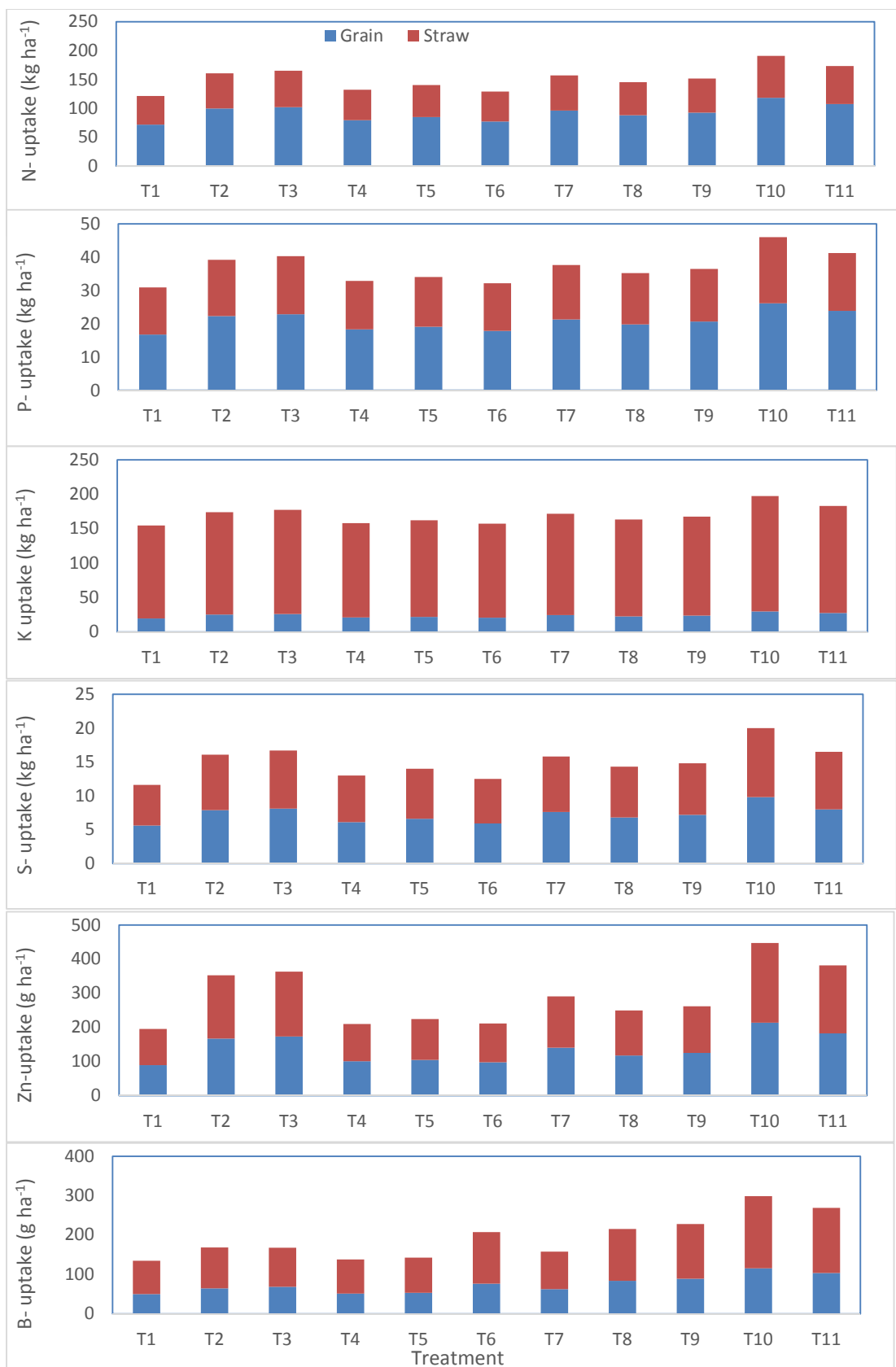


Fig. 4.18a Effect of integrated nutrient management on nutrient uptake during rabi, 2010

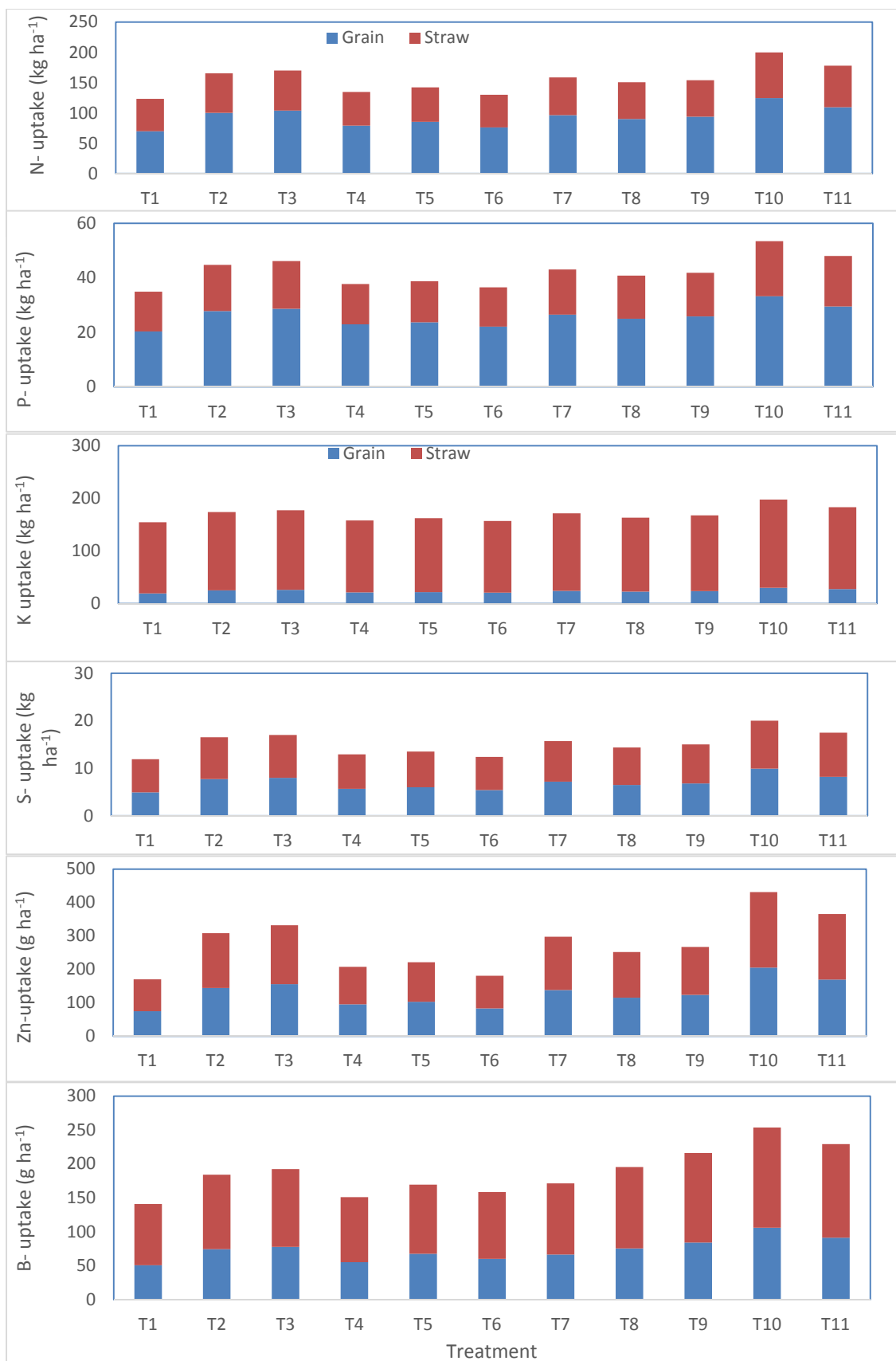


Fig. 4.18b Effect of integrated nutrient management on nutrient uptake during during rabi, 2011

Total B uptake

There was significant difference between treatments with respect to total boron uptake. Maximum uptake (276 g ha⁻¹) was observed with residual effect of RFD /ZnSO₄ + B followed by RFD + Zn-EDTA + S + B (250 g ha⁻¹). The former increased the boron uptake by 101.5 % and the later increased 82.5 % compared to RFD. Application of FYM increased 29 % in boron uptake over RFD. T1(RFD) recorded lowest total B uptake (137 g ha⁻¹).

4.4 Economics

The economics of production was influenced by different treatments have been worked out taking into account the cost of cultivation and the value of produce as per the prevailing farm and market price. The data are given in Table 4.16a, 4.16b and Fig, 4.19. The gross and net returns and the benefit:cost ratio were considerably influenced by different treatments. The gross and net returns and benefit:cost ratio were generally higher in 2011 than that of 2010.

4.4.1 Kharif season

From the mean data, it was evident that during Kharif season maximum gross return (₹ 63087 ha⁻¹) was obtained (Table 4.16a) from T₁₀ followed by T₁₁ (₹ 57154 ha⁻¹). From the Table 4.16a, it was evident that the gross return of ₹ 63087 ha⁻¹ obtained from T₁₀ was significantly superior over other treatments. The gross return obtained from treatment T₁₀ (RFD + ZnSO₄ + B) was significantly superior over single application of ZnSO₄ and B along with RFD recording a gross return of ₹ 55147 and ₹ 44667 ha⁻¹ and an increase of 14.3 and 41.2 % more in gross return respectively.

The gross return (₹ 57154 ha⁻¹) obtained from T₁₁ (RFD + Zn-EDTA + S + B) was also significantly superior over single application of Zn-EDTA, S and B along with RFD recording 22.9, 19.1 and 28 % per cent increase in gross return respectively.

Application of T₃ (RFD + ZnSO₄) recorded a gross return (₹ 55147 ha⁻¹) was significantly superior over T₄ (RFD + Zn-EDTA) recording a gross return of ₹ 46,504 ha⁻¹. It is due to the lower cost of ZnSO₄ as compared to Zn-EDTA and higher efficacy of ZnSO₄ over Zn-EDTA. T₃ recorded 18.5% more gross return over T₄.

Application of RFD along with FYM (T₂) recorded 14.5, 11 and 19.3% increase in gross return over T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD + B). The highest net return (₹ 39,312 ha⁻¹) was recorded from T₁₀ (RFD + ZnSO₄ + B) followed by T₁₁ (RFD + Zn-EDTA + S + B). T₁₀ recorded 23 and 78.5 % increase in net return over T₃ (RFD + ZnSO₄) and T₆ (RFD + B), respectively. Similarly T₁₁ (RFD + Zn-EDTA + S + B) recorded 35, 32 and 45 % increase in net return over single application of Zn-EDTA, S and B along with RFD. Application of RFD + FYM recorded 19.3, 19.4, 28.6 % increase on net return over T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD + B), respectively.

The highest B:C ratio was recorded in T₁₀ (1.65) followed by T₁₁(1.26). Sole application of Zn-EDTA/S/B applied along with RFD recorded lower B-C ratio of 0.97 to 1.04. Lowest B:C ratio (0.96) was recorded in T₁ (RFD).

4.3.2 Rabi season

From the pooled data, it was revealed that during rabi season, maximum gross return (₹ 74231 ha⁻¹) was recorded (Table 4.16b) by residual effect treatment T₁₀ (RFD + ZnSO₄ + B) followed by a gross return of ₹ 678111 ha⁻¹ by T₁₁ (RFD + Zn-EDTA + S + B). From the results of rabi, it was evident that the gross return was significantly superior over all other treatments T₁₀ recorded 13 and 37 % increase in gross return over treatment T₃ (RFD + ZnSO₄) and T₆ (RFD + B), respectively.

The gross return (₹ 67811 ha⁻¹) recorded from T₁₁ was also significantly superior over sole application of Zn-EDTA, S and B recording 28.5, 18.8 and 25.2 % increase, respectively. Lowest gross return (₹ 51920 ha⁻¹) was recorded from T₁ (RFD). Highest net return of (₹ 47231 ha⁻¹) was recorded from T₁₀ (RFD + ZnSO₄ + B) followed by T₁₁ (RFD + Zn-EDTA + S + B). T₁₀ recorded 20.7 and 74.1 % increase in net return over T₃ (RFD + ZnSO₄) and T₆ (RFD + B). T₁₁ (RFD + Zn-EDTA + S + B) recorded 43.9, 34.5 and 50.4 % increase in net return over sole application of Zn-EDTA, S and B along with RFD.

Application of RFD + FYM (T₂) recorded 32.3, 24.8 and 38.2% increase in net return over T₄ (RFD + Zn-EDTA), T₅ (RFD + S) and T₆ (RFD + B), respectively.

Table 4.16a Effect of integrated nutrient management on gross and net return and benefit cost ratio during kharif

Treatments		Gross return (₹ ha ⁻¹)			Net return (₹ ha ⁻¹)			B:C ratio		
		2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T ₁	RFD	43251	42952	43101	21251	20952	21101	0.97	0.95	0.96
T ₂	RFD+FYM	52206	54381	53293	27206	29381	28293	1.09	1.18	1.13
T ₃	RFD+ZnSO ₄	54134	56160	55147	31009	33035	32022	1.34	1.42	1.38
T ₄	RFD+Zn-EDTA	46530	46478	46504	23740	23688	23714	1.04	1.04	1.04
T ₅	RFD+S	47057	48903	47980	23257	25103	24180	0.98	1.05	1.01
T ₆	RFD+B	44658	44676	44667	22008	22026	22017	0.97	0.97	0.97
T ₇	RFD+Zn-EDTA+S	50874	52876	51875	26284	28286	27285	1.06	1.15	1.10
T ₈	RFD+Zn-EDTA+B	47970	50003	48986	24530	26563	25546	1.04	1.13	1.09
T ₉	RFD+S+B	48780	50938	49859	23830	25988	24909	0.97	1.06	1.02
T ₁₀	RFD+ ZnSO ₄ +B	62070	64105	63087	38295	40330	39312	1.61	1.70	1.65
T ₁₁	RFD+Zn-EDTA+S+B	56107	58202	57154	30867	32962	31914	1.22	1.30	1.26
SE(m)±		679	683	642	695	704	654	0.03	0.04	0.03
CD (0.05)		2004	2013	1892	2085	2112	1962	0.09	0.11	0.08

Table 4.16b Effect of integrated nutrient management on gross and net return and benefit cost ratio during rabi

Treatments		Gross return (₹ ha ⁻¹)			Net return (₹ ha ⁻¹)			B-C Ratio		
		2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
T ₁	RFD	52467	51373	51920	25467	24373	24920	0.94	0.90	0.92
T ₂	RFD+FYM	64212	64818	64515	37212	37818	37515	1.38	1.40	1.39
T ₃	RFD+ZnSO ₄	65329	66127	65728	38329	39127	38728	1.42	1.45	1.43
T ₄	RFD+Zn-EDTA	55344	55348	55346	28344	28348	28346	1.05	1.05	1.05
T ₅	RFD+S	57343	56767	57055	30343	29767	30055	1.12	1.10	1.11
T ₆	RFD+B	54540	53711	54126	27540	26711	27126	1.02	0.99	1.00
T ₇	RFD+Zn-EDTA+S	62600	62638	62619	35600	35638	35619	1.32	1.32	1.32
T ₈	RFD+Zn-EDTA+B	58794	59660	59227	31794	32660	32227	1.18	1.21	1.19
T ₉	RFD+S+B	60906	61235	61071	33906	34235	34071	1.26	1.27	1.26
T ₁₀	RFD+ ZnSO ₄ +B	73371	75091	74231	46371	48091	47231	1.72	1.78	1.75
T ₁₁	RFD+Zn-EDTA+S+B	68005	67618	67811	41005	40618	40811	1.52	1.50	1.51
SE(m)±		587	588	579	732	641	843	0.02	0.02	0.02
CD (0.05)		1730	1735	1707	2196	1923	2529	0.06	0.06	0.06

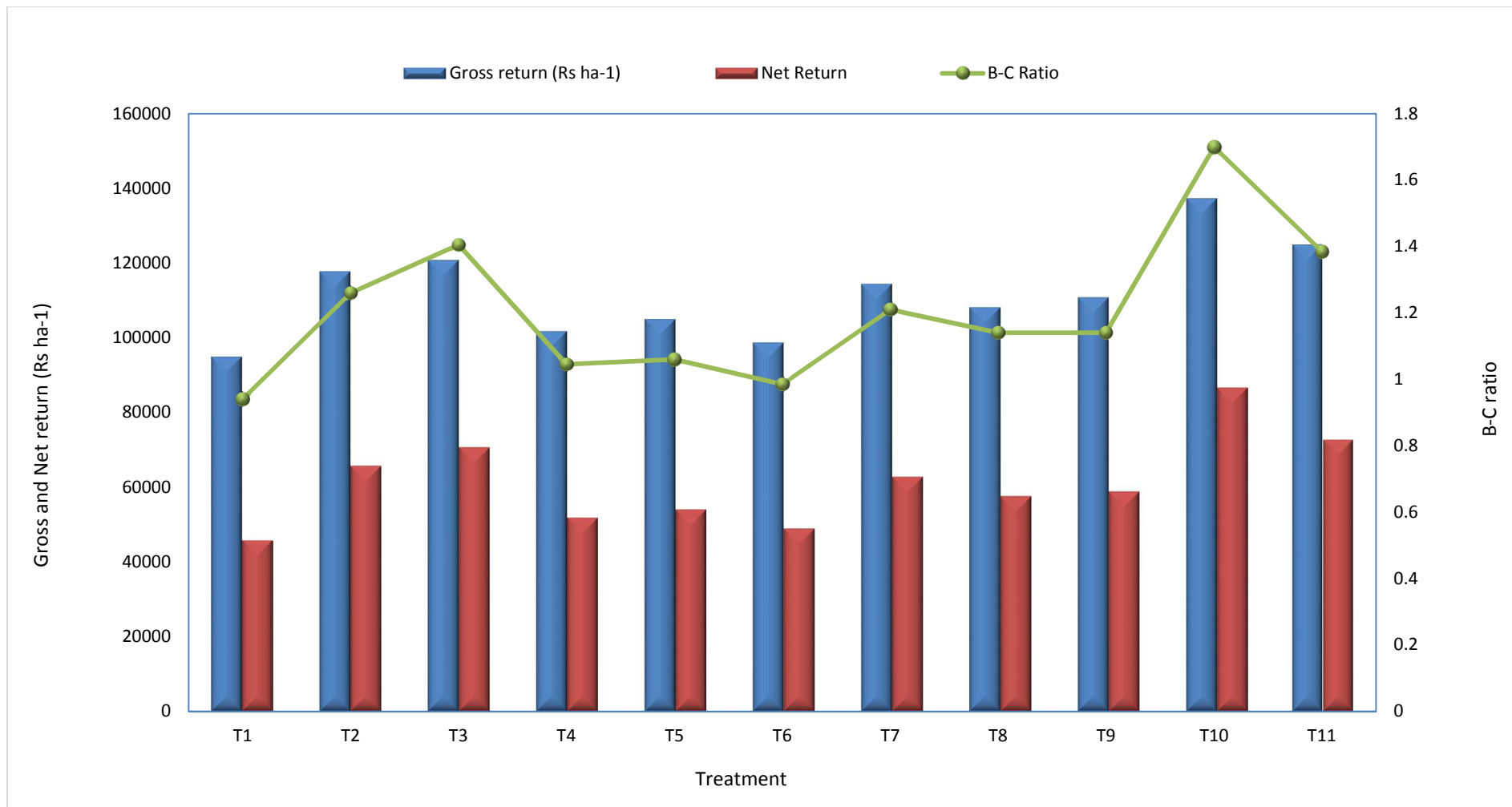


Fig. 4.19 Effect of integrated nutrient management on gross and net return and benefit cost ratio of the rice- rice cropping system

The benefit-cost (B:C) ratio was highest in T₁₀ (1.75), followed by T₁₁ (1.51) and T₃ (1.43). The B-C ratio obtained from T₁₀ was significantly superior over other treatments. The lower B:C ratio of T₁₁ recorded due to more cost of Zn-EDTA (₹ 790 kg⁻¹) included in T₁₁ along with S (₹ 60 kg⁻¹) and B (₹ 650 kg⁻¹) as compared with ZnSO₄ (₹ 45 kg⁻¹) in T₁₀ and T₃ which was lower in price. The B:C ratio of T₂ (1.39) was found to be superior over sole application of Zn-EDTA (1.05), S (1.11) and B (1.0) applied along with RFD. This was due to higher net returns by T₂. T₁ recorded lowest B:C ratio (0.92).



DISCUSSION

Fertilizer is an inescapable input in increasing production of rice. However, increasing cost of fertilizer has necessitated improving the efficiency of applied fertilizers which depends on adequate availability of most plant nutrients in a balanced proportion throughout the crop growth period. Indiscriminate use of high levels of N, P and K often leads to nutritional imbalance particularly micronutrients which ultimately cause deterioration of physicochemical properties of soil and steadily decrease in crop yield. (Gupta *et al.*, 2000). In view of the declining productivity and rise in fertilizer cost, emphasis is being given to integrated nutrient management system.

Use of chemical fertilizers though has raised crop yield but created several adverse effect on soil, environment and human health besides making crop productivity unsustainable (Mohanty *et al.*, 2013). Integrated use of chemical fertilizers along with organic manure, crop residues and biofertilizers has therefore, become need of the hour for improvement and maintenance of soil fertility leading to sustainable crop production.

Field experiments were conducted in the Instructional Farm, Department of Agronomy, College of Agriculture, OUAT, Bhubaneswar during kharif and rabi seasons of 2010 and 2011 to study the effect of “Integrated nutrient management in rice-rice cropping system”. The experimental findings have been presented in the previous chapter. The cause-effect relationship pertaining to various results on the present study have been described in this chapter. An attempt has been made to explain significant findings with critical analysis and assessment on the extent of variations among different treatments and corroborating it with experimental evidences obtained in the past investigations on the same study wherever relevant.

5.1 Crop-weather relationship

The rice cultivar ‘Lalat’ was the test variety during kharif (wet) and rabi (dry season) in 2010 and 2011 at the Instructional Farm, Department of Agronomy, College of Agriculture, OUAT, Bhubaneswar, Odisha. Rice is a crop that can be

cultivated under varied climatic conditions, therefore, it is difficult to define those conditions which are most suitable for proper growth and development. The various climatic parameters like temperature, solar radiation and rainfall and biotic factor like soil influence rice yield directly affecting the physiological processes associated with grain production.

Rice needs relatively high temperature ranging from 25°C to 35°C for optimum growth and development. A day temperature ranging from 25°C to 33°C and night temperature ranging from 15°C to 20°C is most suitable for higher growth yield. However, the critical low and high temperature below 20°C and above 30°C vary from the one growth stage to another. A higher mean temperature less than 15°C cause slow vegetative growth as a result flowering is affected. A good bright sunshine is essential for increasing photosynthetic activity that results in higher grain yield.

The mean annual rainfall of Bhubaneswar is 1451 mm of which 80 % is received during south-west monsoon period i.e., between June to September. The post- monsoon and summer showers contribute rest 20 per cent. Amount of rainfall received during the cropping season was 1133.3 mm in kharif 2010, 96.1 mm in rabi 2010-11, 1308.5 mm in kharif 2011 and 135.7 mm in rabi 2011-12. The mean temperature ranged from 21°C to 31.2°C in 2010 and 22.2 °C to 31.2°C in 2011. The bright sunshine hours per day was 4.7 to 6.2 in 2010 and 2.8 to 7.3 in 2011.

It was observed that rainfall was higher (1443.7 mm) during the year 2011. The rainfall during the year 2011 was more or less same to the average rainfall of Bhubaneswar, although rainfall during 2010 was less. The temperature and BSH was also almost same during the both years of cropping season. The growth and yield of the crop in general was better during 2011 than 2010, which might be due to good rainfall and other parameters prevailing during the growing season.

5.2 Growth and development

Among the sources of zinc (Zn), ZnSO₄ @ 25 kg ha⁻¹ performed better Zn-EDTA @ 1 kg ha⁻¹ in influencing the growth parameters which could be due to its higher content, solubility and availability to rice plant from the soil. The supplementary effect of sulphur (S), the key element in influencing the growth and metabolic activities of rice plant added the synergistic effect to Zn in boosting the

growth, specially to the height of plant. Besides addition of boron (B) @ 1 kg ha⁻¹ to this treatment of ZnSO₄ created favourable conditions for Zn and B uptake by the plant enabling quick synthesis of auxin at an early growth stages leading to enhanced plant growth in height. This might be due to its interrelationship with auxin, an important growth regulator regulating the stem elongation and cell enlargement (Ahmed *et al.*, 1981).

In general, the height of plant during rabi was less as compared to kharif which might be due to the effect of low temperature during rabi. The residual effect of ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ was found to be superior to Zn-EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹ and other combinations.

The leaf area index was favorably influenced by the application of ZnSO₄ + B along with RFD (80-40-40 kg N-P-K ha⁻¹). Application of ZnSO₄ + B along with RFD to soil encouraged better expansion of leaves and thus more photosynthetic area for dry matter production. This could be due to efficient utilization of nutrients resulting in production of surplus protein which enhance the photosynthetic area (leaf area and LAI). This is in conformity with results of Dixit and Taliwal, 1989.

ZnSO₄ in combination with B proved significantly superior to its sole application and Zn-EDTA and their combinations for producing more number of leaves and higher LAI, perhaps due to control of RNA degradation as reported by Dwivedi and Takkar, 1974. The control plot T₁ without Zn, S and B application had shorter plants with less number of leaves and leaf area index because of high RNase activity and disturbances in the metabolism of auxin and indole acetic acid (IAA) in particular.

In general, the leaf area index of plants during rabi was more as compared to kharif season which might be due to controlled management of nutrients and water along with maximum photosynthetic area. The residual effect of ZnSO₄ along with B also proved significantly superior over their single application of Zn-EDTA or their combinations. The application of ZnSO₄ + B also proved to be superior over RFD + FYM and only RFD in getting maximum LAI.

There was progressive improvement in dry matter accumulation in rice plant with advancement of crop growth. (Table 4.4a and 4.4b). Dry matter accumulation in

rice plant was more between 60-90 DAT coinciding the reproductive stage of the crop. It increased with the application of $\text{ZnSO}_4 + \text{B}$ along with RFD and resulted in better assimilations due to greater photosynthetic surface. Application of RFD with ZnSO_4 and B had synergistic effect in achieving higher dry matter production.

Accelerated physiological activities enhanced by enzyme activation due to application of ZnSO_4 integrated with B might be the probable reason for increased dry matter production in comparison to their single use and Zn-EDTA or their combinations because of increased plant height and higher photosynthetic surface and LAI. The application of RFD along with FYM @ 5 t ha^{-1} or only RFD produced lesser dry matter in comparison to application of ZnSO_4 and B along with RFD.

Dry matter production in rabi was comparatively more due to more tillers and expression of higher values of yield attributing characters. The residual effect of $\text{ZnSO}_4 + \text{B}$ was significantly superior over their sole application and Zn-EDTA or their combination. The same trend was observed in case of number of tillers m^{-2} during both the years. The findings are similar with evidences of Dravid and Gowswami (1987).

5.4 Yield attributes

The yield attributes was influenced by different treatments are presented in Table 4.5a and 4.5b. The number of panicles m^{-2} , length of panicle, panicle weight, number of fertile grains panicle⁻¹ and test weight were influenced significantly by different treatments.

Application of $\text{ZnSO}_4 + \text{B}$ along with RFD exhibited a favourable effect on yield attributes. It was due to better availability on Zn, S along with B in adequate amounts and their synergistic effect in improving yield attributes.

The sources of Zn as ZnSO_4 combined with B significantly influenced the yield attributing characters as compared with their single application, Zn-EDTA and their combination. This might be due to higher zinc use efficiency and consequent synthesis of better grain filling (Takaki and Kushizaki, 1970). The performance of ZnSO_4 was better than Zn-EDTA due to supplementary effect of S with higher percentage of Zn present in the former.

Application of $ZnSO_4 + B$ produced maximum panicle length, weight, more number of fertile grains panicle⁻¹ and higher test weight due to better absorption/availability of Zn and B throughout the growth period. This is in conformity with findings of Arif *et al.*, 2012.

Fertility percentage increased due to indirect role of Zn but direct role of B through enhancement of auxin synthesis which ultimately influenced fertilization. Pollen grains have a very high Zn content and in presence of B helping in fertilization, most of the Zn is incorporated into developing seed (Pollar, 1975).

Application of $ZnSO_4 + B$ along with RFD proved its superiority over single application of $ZnSO_4/B/S/ Zn-EDTA$ or their combinations along with RFD in improving the yield attributing characters. However single application of RFD or RFD along with FYM was found to be inferior over application of $ZnSO_4 + B$ along with RFD resulting in lesser yield attributes. This is supported by the findings of Khurana *et al.*, 2008.

The yield attributing characters were more pronounced during rabi than kharif which might be due to more translocation of photosynthates from source (leaf) to sink (seed). This was influenced by more light hours and higher temperature during reproductive stage of the crop. Residual effect of $ZnSO_4 + B$ during rabi proved superior to their sole application or $Zn-EDTA$ or their combinations. Similarly application of $ZnSO_4 + B$ proved its superiority over sole application of RFD/FYM.

5.5 Yield

The grain yield was significantly influenced by different treatments during kharif, (Table 4.6). Considering the data for individual years and the pooled data of grain yield, it was observed that application of $ZnSO_4 + B$ along with RFD enhanced the yield significantly as the inherent Zn status of the soil (0.33 ppm) was less and below the optimum level (0.6 ppm).

Application of $ZnSO_4 + B$ increased the grain and straw yield compared to no Zn/B application which might be due to better utilization of N and P to increased metabolic activities (Khanda and Dixit, 1991). Increase in yield due to $ZnSO_4 + B$

application might be attributed to its role in various enzymatic reaction and catalytic effect on growth process and hormone productions and protein synthesis (Channabasavanna *et al.*, 2001).

Application of $ZnSO_4 + B$ favoured the root growth with mobilization of plant nutrients at optimum levels and there by increased grain and straw yield of rice (Das and Singh, 1982).

The increase in grain yield in the present study was 48 per cent in kharif and 45 per cent during rabi as compared to RFD due to application of $ZnSO_4$ and boron. It might be due to the influence of Zn on the uptake of extra plant nutrients i.e., (NPK, Zn, S and B -62.1 kg ha⁻¹ during kharif and NPK, Zn, S and B-79.6 kg ha⁻¹ during rabi) through enzymatic action in metabolic process which ultimately accounted for the higher grain. Increased fertilization of flower due to Zn and B had also a favourable effect in the grain yield (Polar, 1975). It was observed that the effect of Zn and B was synergistic when integrated with RFD in enhancing the grain yield and the increase in yield was highest. Considering the treatment on application of Zn-EDTA + S+ B integrated with RFD, recording the second highest grain yield which was due to the effect of Zn, S along with B, but the availability of Zn and S was delayed as compared to $ZnSO_4$, and also the content of Zn in Zn-EDTA is less than $ZnSO_4$.

The effectiveness of elemental S is less in acidic soil as compared to calcareous soil. Promising grain yield was also observed in RFD incorporated with FYM during kharif season. This was due to the fact that organic manure (FYM) acts as the store house of plant nutrients which are readily available to the crop. Organic manure mobilizes the native Zn through chelation and complex formation, with organic ligands and thereby making better availability of native Zn which enhances the zinc use efficiency (ZUE). For higher grain yield, with reference to source, $ZnSO_4$ proved better than Zn-EDTA due to its slow and longer period of availability (Ratan *et al.* 1997).

Highest straw yield was recorded with the application of $ZnSO_4 + B$ integrated with RFD followed by application of Zn-EDTA + S + B integrated with RFD. The increase in straw yield followed the same trend as that of the grain yield.

Application of $ZnSO_4 + B$ integrated with RFD have produced more photosynthetic products due to integration of Zn, S and B causing greater availability of N, Zn and S for longer period, resulting in better vegetative growth. Similar results were obtained by Srivastava and Gangwar, 1987.

Grain yield during rabi season (Table 4.5) was higher than that of kharif which might be due to better translocation of photosynthates from source to sink. This was influenced by the favourable conditions (maximum day light hours and temperature), experienced by the crop during reproductive phase. Application of $ZnSO_4 + B$ integrated with RFD increased the grain yield significantly which was found to be superior over other treatments and similar trend was also observed in kharif season.

The residual effect of $ZnSO_4 + B$ during rabi season proved superior over sole use of $ZnSO_4/S/B$ or Zn-EDTA or their combinations. Organic sources of plants nutrients (FYM) applied to kharif rice benefitted the succeeding rabi rice due to residual effect which resulted in higher grain yield as compared to sole application to $S/B/Zn-EDTA$ and control (RDF). Pooled data on grain yield for rabi 2010 and 2011 revealed that highest increase yield (45 %) was recorded with residual effect of $ZnSO_4 + B$ over control (RFD). This was followed by the treatment of residual effect of Zn-EDTA + S + B recording an increase in yield (23 %) as compared to control. Sujathamma *et al.* (2013) reported the superiority of $ZnSO_4$ in improving rice yield in rice-rice cropping system.

The straw yield was influenced by the residual effect of different treatments imposed during the kharif and the trend was similar to that of grain yield. Highest straw yield was recorded due to the residual effect of $ZnSO_4 + B$ followed by residual effect of Zn-EDTA + S + B. The residual effect of $ZnSO_4 + B$ was significantly superior over sole application of $ZnSO_4/S/B/Zn-EDTA$ or their combined application. It was also superior over residual effect of FYM, while considering the source, $ZnSO_4$ proved superior over Zn-EDTA in increasing the straw yield.

5.6 Harvest index

Data on harvest index of the crop are presented in Table 4.8. It was significantly influenced by different treatment. Harvest index was highest with integrated application of RFD + ZnSO₄ + B followed by application of Zn-EDTA + S + B integrated with RFD.

During rabi season the residual effect of ZnSO₄ + B was superior over the residual effect of ZnSO₄ /Zn-EDTA/S/B. Harvest index increased due to increase in grain yield because of application of ZnSO₄ + B due to presence of higher level of Zn in ZnSO₄ and B increased the fertilization of reproductive organs which influenced in increasing the grain yield.

5.7 Correlation studies

The growth attributing characters like plant height, LAI, dry matter production, length of panicle, weight of panicle, number of fertile grains⁻¹, panicle m⁻², test weight and harvest index had a positive and significant correlation with grain yield both at 5 and 1 per cent levels during kharif and rabi seasons of 2010 and 2011. Similar results were recorded by Sahoo and Sahoo (2001) and Mohapatra (2003).

5.8 Nutrient uptake

During kharif season the effect of different treatments had a marked influence on the uptake of various nutrients is N, P, K, S, Zn and B by the plant. It was observed that application of ZnSO₄ + B integrated with RFD produced the highest grain yield and had the highest uptake of N, P and K both in grain and straw. This was followed by the treatment i.e., application of Zn-EDTA + S + B integrated with RFD during both the years of study. Application of ZnSO₄ along with RFD was significantly superior over sole application of ZnSO₄, B, Zn-EDTA or their combined application and FYM with respect to uptake of N, P and K.

The uptake of N, P and K by plant was more by application of ZnSO₄ + B along with RFD which might be due to synergistic effect of Zn with S and B in the uptake of plant nutrients. This is in conformity with findings of Pervaiz *et al.*, 2012. Addition of organic matter (FYM) also improved the uptake of N, P and K and

increased its use efficiency. Application of FYM along with N, P, K mineralized the organic matter rapidly and supplied adequate N, P and K and hence increased its availability. With respect of nutrient release and use efficiency, application of FYM proved superior over sole application of single nutrients because of quick decomposition and faster release of nutrients. Similar was the trend with regard to uptake of S, Zn and B. Application of $ZnSO_4 + B$ along with RFD was significantly superior over other treatments with regards to uptake of various nutrients because of higher grain and straw yield and higher concentration of nutrients i.e., (N, P, K, S, Zn and B) in the biomass.

The results are in agreement with the findings of Srivastava and Tripathy (1998). The uptake of nutrients i.e., (S, Zn and B) in the grain and straw and their total uptake were positively influenced by the use of these nutrients during both the years. The lowest uptake of S, Zn and B was recorded in control and highest in $ZnSO_4 + B$ along with RFD. The combined application of $ZnSO_4 + B$, Zn-EDTA + B, Zn-EDTA + S and S + B recorded higher uptake of S, Zn and B than their single application. Application of Zn-EDTA + S + B also recorded higher uptake of N, P, K, S, Zn and B in comparison to their sole application. Sahoo *et al.* (1994) and Islam *et al.* (1994) reported about synergistic effect of these nutrients on their uptake and correlated higher uptake with grain and straw yield.

During rabi season, the residual effect of $ZnSO_4 + B$ recorded highest N, P, K, S, Zn and B which was significantly superior over other treatments. The residual effect of $ZnSO_4 + B$ was significantly superior over sole effect of $ZnSO_4$ /B/S/ Zn-EDTA or their combination with regards to nutrient uptake (N, P, K, Zn, S and B). Highest uptake of nutrients due to residual effect of $ZnSO_4 + B$ was due to highest grain and straw and their concentrations in biomass. This was due to the synergistic effect of S, Zn and B on uptake of these nutrients. (Islam *et al.*, 1997). The lowest uptake of nutrients was recorded in control treatment (RFD).

5.9 Economics

Data on economics on production (Table 4.16a and 4.16b) indicated that among the treatments, T₁₀ (RFD + $ZnSO_4 + B$) gave the highest gross return (₹ 63087 ha⁻¹), net return (₹ 39312 ha⁻¹) and B:C ratio (1.65) during kharif and

during rabi, it recorded a gross return (₹ 74231 ha⁻¹), net return (₹ 47,231 ha⁻¹) and B:C ratio of 1.75 which was significantly superior over the sole application of ZnSO₄, B, Zn-EDTA, S and their combinations and FYM. During rabi season, it was due to residual effect of ZnSO₄ + B recording highest gross return, net return and B:C ratio.

Application of RDF +ZnSO₄ (T₃) recorded higher gross return (₹ 55,147 ha⁻¹), net return (₹ 32022 ha⁻¹) and B-C ratio (1.38) during kharif, while with this treatment the residual effect of ZnSO₄ during rabi season recorded a gross return (₹ 65,728 ha⁻¹), net return (₹ 38,728 ha⁻¹) and B-C ratio (1.43). Application of RFD + Zn-EDTA (T₄) recorded a gross return (₹ 46,504 ha⁻¹), net return (₹ 23,714 ha⁻¹) and B:C ratio (1.04) during kharif while these values were ₹ 55346 ha⁻¹, ₹ 28,346 ha⁻¹ and 1.05, respectively during rabi season.

It was evident from the study that the commercial grade of ZnSO₄ is less costly and simultaneously it has a great role in increasing the yield of the crop and there by influencing gross return, net return and B:C Ratio. But the commercial grade of Zn-EDTA is more costly (₹ 790 kg⁻¹) as compared to ZnSO₄ (₹ 45 kg⁻¹) and less efficient in improving the yield of the crop for which the net return and B:C ratio was less by applying Zn-EDTA in comparison with ZnSO₄. While comparing, T₁₀ (RFD + ZnSO₄) + B) with T₁₁ (RFD + Zn-EDTA + S + B), it was realized that higher gross return, net return and B-C ratio was obtained in T₁₀ as compared with T₁₁. Besides additional value for the cost of S was also imposed in T₁₁, which resulted in decreasing the gross return, net return and B:C ratio in the system. Application of RFD + FYM (T₂) recorded a gross return of ₹ 53,293 ha⁻¹, net return of ₹ 28,293 ha⁻¹ and B:C ratio (1.13) during kharif season and while the values were ₹ 64,515 ha⁻¹, ₹ 37,515 ha⁻¹, and 1.39 respectively during rabi season. It has been realized that the values of gross return, net return and B:C ratio were lower in case of T₂ as compared to the values obtained with RFD + ZnSO₄ (T₃) which was due to higher cost involved in application of FYM as compared to values of ZnSO₄ and better efficiency for applied ZnSO₄ in

comparison with FYM in improving the yield of the crop. Lowest gross return (₹ 43101 ha⁻¹), net return (₹ 21,101 ha⁻¹) and B:C ratio 0.96 were recorded in T₁ during kharif season, while the values were ₹ 51,920 ha⁻¹, ₹ 24,920 ha⁻¹ and 0.92 respectively for rabi season, where there was no additional application of either S, Zn and B. This resulted in recording lowest yield of the crop and lowest gross return, net return and B:C ratio as well.



SUMMARY AND CONCLUSION

The experiment was conducted in the Instructional Farm, Department of Agronomy, OUAT, Bhubaneswar during kharif and rabi seasons of 2010 and 2011 to study the effect of integrated nutrient management in rice-rice cropping system. It was laid out in Randomized Block Design with eleven treatments replicated thrice. The results have been furnished and discussed in the preceding chapters. The salient findings and broad conclusions are given below.

Kharif season

- Integrated application of RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ produced tallest plants (106 cm), highest LAI (3.28) maximum DMP (28.7 g hill⁻¹) and tillers hill⁻¹ (15) followed by integrated application of RFD + Zn-EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹.
- Integrated application of RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ produced longest (27 cm) and heaviest (2.74 g) panicle, highest test weight (24.14 g), maximum fertile grains panicle⁻¹ (157) and panicles m⁻¹ (307) followed by integrated application of RFD + Zn-EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹.
- Integrated application of RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ produced maximum grain (5.28 t ha⁻¹) and straw (6.33 t ha⁻¹) yield and harvest index (45.44 %)
- Among different sources ZnSO₄ @ 25 kg ha⁻¹ soil application recorded highest grain yield (4.60 t ha⁻¹) than Zn-EDTA @ 1 kg ha⁻¹ soil application (3.86 t ha⁻¹).
- Application of ZnSO₄ @ 25 kg ha⁻¹ with RFD (T₃) recorded higher grain yield (4.6 t ha⁻¹) as compared with application of FYM (4.44 t ha⁻¹), S (3.99 t ha⁻¹), B (3.71 t ha⁻¹), Zn-EDTA + S (4.32 t ha⁻¹), Zn-EDTA + B (4.07 t ha⁻¹) and S + B (4.14 t ha⁻¹) along with RFD.

- Application of ZnSO₄ alone could substitute over application of FYM, S, B, Zn-EDTA, Zn-EDTA+S, Zn-EDTA + B and S + B with RFD in terms of yield which also gave higher net return (₹ 32,022 ha⁻¹) and B:C ratio (1.38).
- Application of RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ recorded highest uptake of N (135.5 kg ha⁻¹), P (33.10 kg ha⁻¹), K (178.1 kg ha⁻¹), S (13.30 kg ha⁻¹), Zn (256 g ha⁻¹) and B (177 g ha⁻¹) followed by application of RFD + Zn – EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹.
- Integrated application of RFD + ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ recorded highest gross return (Rs.63,087 ha⁻¹), net return (₹ 39312 ha⁻¹) and B:C ratio (1.65) followed by application of RFD + ZnSO₄ @ 25 kg ha⁻¹.
- Application of only RFD recorded lowest values of growth parameters, yield attributes, grain yield (3.57 t ha⁻¹), straw yield (4.78 t ha⁻¹), net return (₹ 21,101 ha⁻¹) and B:C ratio (0.96) and lowest nutrient uptake of N, P, K, S, Zn and B.
- There did exist a positive correlation between grain yield and plant height, LAI at 60 DAT, DMP at 90 DAT, length of panicle, weight of panicle, fertile grains panicle⁻¹, test weight and harvest index.

Rabi Season

- Residual effect of ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ (T₁₀) produced tallest plant (104 cm), maximum LAI (5.10), dry matter (28.2 g hill⁻¹), maximum tillers hill⁻¹ (15.5). It also recorded longest (28.1 cm) and heaviest (2.65 g) panicle, test weight (24.58 g), more fertile grains panicle⁻¹ (166) and panicles m⁻² (331).
- Residual effect of ZnSO₄ @ 25 kg ha⁻¹ + B @ 1 kg ha⁻¹ (T₁₀) also recorded maximum grain yield (6.21 t ha⁻¹), straw yield (7.45 t ha⁻¹) with harvest index (45.46 %). This was followed by the residual effect of Zn-EDTA @ 1 kg ha⁻¹ + S @ 30 kg ha⁻¹ + B @ 1 kg ha⁻¹ (T₁₁) recording the next highest values in growth parameters, yield attributes, yield and harvest index.

- Considering the residual effect of different sources of Zn, residual effect of ZnSO₄ (@ 25 kg ha⁻¹ applied to Kharif rice) recorded more grain yield (5.48 t ha⁻¹) than Zn-EDTA (@ 1 kg ha⁻¹ applied to Kharif rice) recording grain yield of 4.59 t ha⁻¹.
- Residual effect of ZnSO₄ (T₃) recorded more grain yield (5.48 t ha⁻¹) as compared with residual effect of FYM (T₂) (5.38 t ha⁻¹), S (T₅) (4.73 t ha⁻¹), B (T₆) (4.48 t ha⁻¹), Zn-EDTA + S (T₇) (5.21 t ha⁻¹), Zn-EDTA + B (T₈), (4.92 t ha⁻¹) and S + B (T₉) (5.08 t ha⁻¹).
- The residual effect of ZnSO₄ alone was superior over the residual effect of FYM, S, B, Zn-EDTA, Zn-EDTA +S and Zn-EDTA + B in terms of yield, which also recorded higher net return (₹ 38,728 ha⁻¹) and B:C ratio (1.43).
- Residual effect of ZnSO₄ + B (T₁₀) recorded highest uptake of N (195.50 kg ha⁻¹), P (49.70 kg ha⁻¹), K (204.90 kg ha⁻¹), S (20.0 kg ha⁻¹), Zn (439 g ha⁻¹) and B (276 g ha⁻¹) followed by residual effect of Zn-EDTA + S +B (T₁₁).
- Residual effect of ZnSO₄ + B (T₁₀) recorded highest gross return (₹ 74231 ha⁻¹), net return (₹ 47,231 ha⁻¹) and B:C ratio (1.75) followed by residual effect of Zn-EDTA + S + B (T₁₁).
- The control plot (T₁) recorded the lowest value of growth parameters and yield attributes. It also recorded the lowest values of grain yield (4.28 t ha⁻¹), straw yield (6.11 t ha⁻¹), net return (₹ 24,920 ha⁻¹), B:C ratio (0.92).
- The control plot (T₁) also recorded the lowest values of uptake of N (122.50 kg ha⁻¹), P (32.90 kg ha⁻¹), K (157.50 kg ha⁻¹), S (11.75 kg ha⁻¹), Zn (183 g ha⁻¹) and B (137 g ha⁻¹).
- There did exist a positive correlation between grain yield and plant height, LAI at 60 DAT, DMP at 90 DAT, length of panicle, weight of panicle, fertile grains panicle⁻¹, test weight and harvest index.

CONCLUSION

From the result summarized above, it is concluded that combined application of recommended fertilizer dose (80-40-40 kg N-P₂O₅-K₂O ha⁻¹) along with ZnSO₄ @ 25 kg ha⁻¹ and B @ 1 kg ha⁻¹ increased the productivity of rice (Lalat) as well as higher net return and B-C ratio during Kharif season. It had also good residual effect on rabi rice grown on the same plot recording highest yield and profit.

FUTURE LINE OF RESEARCH

Integration of ZnSO₄ and B with RFD recorded increased production, productivity and profit of rice-rice system. Use of organic manure (FYM) only with RFD had also showed promising result in improving the production and productivity. Research work may be undertaken to study the chelating effect of organic manure, FYM or green manure integrated with ZnSO₄ and B for improving yield. The cost effectiveness and economics of the system may be studied thoroughly before recommending to the farming community to get maximum profit under rice-rice cropping system.



REFERENCES

- Ahmed S, Uddin M, Hashim A, Duuta RR and Rahman L. 1981. Studies on the response of rice plant to 2nd fertilization in some of soils of Bangladesh. International Rice commission Newsletter, **30**(1)23-26
- AICRPM, LTFE 2013-14. Annual Report of *All India Coordinated Research Project on Long Term Fertilizer Experiment*, OUAT, Bhubaneswar Centre p.8-11.
- AICRPMSPE 2009-10. Annual Report of the *All India Coordinated Research Project in Micro and Secondary Nutrients and Pollutant Elements* in soils and plants, IISS, ICAR, Bhubaneswar centre, pp.20-21.
- AICRPMSPE. 2008. Annual Report of the *All India Coordinated Research Project on Micro and Secondary Nutrients and Pollutant Elements* in soils and plants. IISS, ICAR, Bhubaneswar centre.
- Akhter S, Ali MI, Jahiruddin M, Ahmed S. and Rahman L. 1994. Main and interaction effect of sulphur and zinc on rice. *Crop Research*. (Hisar) **7**(1): 1-7.
- Alloway, BJ 2008. (Ed) *Micronutrient deficiencies in Global Crop Production*. Springer Verlag, Netherlands.
- Alloway, BJ. 2008. Zinc in Soils and crop Nutrition. IFA, Paris and IZA, Brussels: 135
- Arif Muhammad, Shehzad, MA, Bashir F, Tanseem M, Yasin G and Iqbal M. 2012. Boron, zinc and microtone effects on growth, chlorophyll contents and yield attributes in rice (*Oryza sativa* L.) cultivar. *African Journal of Biotechnology* **11**(48): 10851-10858.

- Bhuiya ZH, Idris, M and Uddin MJ. 1981. Response of IR-8 to zinc fertilizer. *International Rice Research News Letter* **10**:1-20.
- Bhuiyan NI and Islam MM 1989. Sulphur response of wetland rice in Bangladesh. *Sulphur in agriculture*, **13**:16-18
- Bhutto AM, Zahida T, Mazzood, Saquib A, Iqbal SR, Mahmood A, Akhlaq A, Butto R, Moheyuddin K, Mari AH, Panhwar RN and Salahuddin J. 2013. Effect of zinc and boron fertilizer application on uptake of some micronutrients into grain of rice varieties. In *American-Eurasian Journal Agriculture and Environment Science*, **13**(8): 1034-1042.
- Bhuvanewari R, Sriramachandrasekharan, MV and Ravichandran, M. 2007. Integrated use of farm yard manure and sulphur for growth and yield of rice. *Oryza*. **44**(2): 169-171.
- Biswal R. 2007. Response of rice to sources and levels of zinc application. M.Sc. (Ag.) Thesis. Department of Agronomy, College of Agriculture, OUAT, Bhubaneswar.
- Biswas BC and Tewatia RK. 1991a. Results of FAO sulphur trials network in India. *Fertilizer News*, **36**(4): 11-35.
- Biswas BC and Tewatia RK. 1991a. Results of FAO sulphur trial network in India, *Fertilizer News*, **36**(4):11-35.
- Biswas BC and Tewatia RK. 1991b. Role of sulphur in balanced plant nutrition. Indian experience. (In) S. Portch (Ed) Proc. International symposium on the role of sulphur, magnesium and micronutrients in Balanced plant Nutrition, Chngdu, Chiana, 98-106
- Biswas BC and Tewatia RK. 1992. Role of sulphur in balanced nutrition. Indian Experience. *International symposium on role of sulphur, magnesium and micronutrients in balanced plant nutrition.*: 98-106
- Biswas BC. and Tewatia, RK. 1988. Micronutrient status in Indian Agriculture. *Fertilizer News*, **33**(11): 29-35.

- Bouyoucos, GJ. 1962. Hydrometer method improved for making particle analysis of soil. *Agronomy Journal*, **54**(5):464-465
- Bray RH and Kurtz LT. 1945. Determination of total organic and available forms of phosphate in Soils. *Soil Science*, **59**:39-45.
- Chandrapala, A.G., Yakadri, M., Kumar, R.M. and Raj, G.B. 2010. *Indian Journal of Agronomy*, **55**(3): 171-176.
- Channabasavanna AS, Yelamali SG and Biradar DP, 2001. Response of rice to sources of organic manures and levels of zinc sulphate in deep black soils. *Indian Journal of Agronomy*. **46**(3):458-461
- Choudhary, M.A.H. and Majumdar, A.K. 1994. Effect of some sources of sulphur on the yield and yield attributes of rice. *Bangladesh Journal of Scientific and Industrial Research* **29**(3): 185-191.
- Das D Dwivedi BS, Meena MC, Singh VK and Tiwari KN. 2015. Integrated nutrient management for improving soil health and crop production, *Indian Journal of Fertilizer*, **11**(4): 64-83.
- Das DK and Singh MP. 1982. Effect of micronutrients on seedling growth and yield of low land rice in calcareous soil. *Oryza* **19**: 84-87.
- Das, SR 2012. Rice in Odisha, Technical Bulletin, No16, International Rice Research Institute, Philippines.
- De Datta, S.K. 1981. Principles and practices of Rice Production Wiley. Int. pp.618.
- Dell B, Brown PH and Bell RW. 2002. Boron in soils and plant: reviews. Kluwer, Dordrecht.
- Devarajan R and Krishnaswamy R. 1996. *Madras Agricultural Journal*, **83**(5): 280.
- Devranjan R and Ramanathan G. 1995. Direct, residual and cumulative effect of applied zinc to rice in red soils. *Madras Agricultural Journal*, **82**:90-92.
- Dixit L and Khanda CM. 1994. Effect of Zinc and nitrogen fertilization on yield and yield attributes of summer rice. *Orissa Journal of Agricultural Research*, **7**: 1-15.

- Dixit, PR and Taliwal AK. 1989. Effect of nitrogen and sulphur on the yield and quality of rice. *Agricultural Science Digest*, **9**(4):171-174
- Dravid MS and Goswami NN. 1987. Effect of FYM, P and Zn on dry matter yield and uptake of P, K, Zn and Fe by rice under non-saline and saline soil condition. *Journal of Nuclear Agriculture and Biology*, **16**(4): 201-205.
- DRR, 2011. Vision 2030. ICAR, Rajendra Nagar, Hyderabad.
- Dubey SB, Khanpuria RS, Sharma BL, Rathore GS and Singh P. 1981. Effect of zinc application on rice in alfisol and ultisol (red and yellow), soils of Alghat district of MP. *JNKV Reserch Journal*, **15**(3):78-82
- Dwivedi BS, Ram M, Singh BP, Das M and Prasad RN. 1990. Differential response of crops to boron fertilization in acid *alfisols*. *Indian Journal of Agricultural Sciences*, **60**(2): 122-127.
- Dwivedi RW and Takkar PN.1974. Ribonuclease activity as an index of hidden hunger of zinc in rice crop. *Plant and Soil*, **40**:173-181
- Fisher A, Ronald and Yates Frank. 1957. Statistical Tables for Biological, Agricultural and Medical Research, Oliver and Boyd Ltd., Edinburg, p.135
- Frageria NK, Buliagar VC and Clark RB. 2002. Micronutrients in crop production . *Advances in Agronomy*, **77**: 185-268.
- Government of India 2014 .Agricultural Statistics at a Glance, Ministry of Agriculture and Cooperation. Directorate of Economics and Statistics. Oxford University Press, New Delhi, 72-74.
- Gupta Lal, Bisht PS and Pandey PC. 2000. Integrated organic and inorganic N management in low land rice. *Oryza*, **75**(2):120-3
- Havlin JL, Tisdale SL, Nelson WL and Beaton JD. 2010. Soil fertility and fertilizers, Prentice Hall, New Delhi: 304-364.
- Islam MR, Raisat TM and Jahiruadin. 1997. Direct and residual effect of S, Zn and B on yield and nutrient uptake in rice-mustard cropping system. *Journal of Indian Society of Soil Science*, **45**(1): 126-129.

- Islam R, Hussain MSA, Howladev AS, Islam A, Mandal R and Haz SMI. 1987. Effect of sulphur on rice under flooded condition, *International Journal of Tropical Agriculture*, **5**(2): 93-101.
- Jackson ML. 1967. Soil chemical analysis. Prentice Hall of India Pvt. Ltd. New Delhi :. 498.
- Jayaraman S. and Ramiah S. 1989. Effect of zinc application on spikelet sterility in rice. *Indian Journal of Agronomy*, **34**(4): 487-488..
- Jena D, Sarangi DR. and Singh MV. 2006. Effect of different sources of and levels of sulphur on yield and uptake by groundnut-rice cropping system in *inceptisol* of Orissa, *Journal of Indian Society of Soil Science*, **54**(1):126-129
- Jena D, Singh MV, Pattanaik MR and Nayak SC. 2008. Management of acid soils for sustainable crop production. NAE Acid soil bulletin, Department of Soil Science and Agril. Chemistry, OUAT, Bhubaneswar, pp.12.
- Jena D, Singh MV, Pattnaik MR and Nayak SC. 2008. Scenario of micro and Secondary Nutrient Deficiencies in soils of Orissa and Management. Technical Bulletin No.1. AICRP on Micro and Secondary Nutrient and Pollutant Elements in Soils and Plants, ICAR-IISS, Department of Soil Science and Agricultural Chemistry1-42.
- John PS. 2006a. Sulphur fertilization in rice based cropping system in laterite soils of Keral. In. Proc. TSI-FAI-IFA Symposium cum workshop on sulphur, pp:163-184
- Katyal JC and Agarwal SC. 1982. Micronutrient research in India. *Fertilizer News*, **27**:66-86.
- Katyal JC and Ponnaperuma FN. 1974. Zinc deficiency a wide spread nutrient disorder of rice in Ayusam del Norte, *Philippine Agriculturist* **58**:79-89.
- Katyal JC and Rattan RK. 1990. Soil fertility and fertilizer use. Volume IV IFFCO, New Delhi, pp.119-135.

- Katyal JC. 1985. Research Achievement of the All India Coordinated Scheme on Micronutrients in Soils and Plants. *Fertilizer News*, **30**(4): 67-81.
- Katyal JC. and Sharma BD. 1989. Zinc deficiency in Indian soils and crops. Series on technologies for better crops. No. 43ICAR, New Delhi, pp.13.
- Khanda CM, Dixit L and Panda SC. 1997. Effect of zinc and graded levels of nitrogen on growth, yield and nutrient uptake of rice, *Oryza* **34**: 43-46.
- Khanda, C.M. and Dixit, L. 1991. Effect of soil and foliar application of zinc at graded levels of nitrogen on summer rice. M.Sc. (Ag.) thesis, Department of Agronomy, OUAT, Bhubaneswar.
- Khurana HS, Singh B, Bovermann A, Philip SB, Sidhu AS and Singh V. 2008. Site-specific nutrient management performance in rice-wheat cropping system. *Better Crops*, **92**(4): 26-28.
- Kumar D, Chauhan RPS and Singh BB. 1999. Response of rice to zinc sulphate incubated and blended with organic material on Sodic soil, *Indian Journal of Agricultural Science* **69**(6): 402-405.
- Maharana, D.P., Sarangi, S.K., Baliarsingh, R.N. and Ali, M.H. 1992. Response of rice to application of zinc sulphate in different broad soil groups of Orissa ((n.) *Proceedings of the Workshop on Micronutrients*, IBFEP and HPCL, 22-23 January, Bhubaneswar, Orissa, pp.228-237.
- Massoumi A and Cornfield, AH. 1963. A rapid method for determining sulphate in water extracts of soils. *Analyst*. **88**:321-322
- Massoumi A and Cornfield AH.1963.. A rapid method for determining sulphate in water extracts of soil. *Analyst*, **88**(1045):321-322.
- Maze, P. 1919. Zinc nutrition in higher plant. *Annals Inst. Pateur* **33**:139-173.
- Mishra D, Pradhan L, Rout D, Barik T and Patro GK. 1993. Response of rice to varying levels of NPK and zinc in cultivators field as rainfed conditions. *Environment and Ecology*, **11**(3):679-681

- Mohanty M, Nanda SS and Barik AK. 2013. Effect of integrated nutrient management on growth, yield, nutrient uptake and economics of wet season rice (*Oryza sativa*) in Odisha. *Indian Journal of Agricultural Science*, **83**(6): 599-604.
- Mohapatra, A.K. 2003. Studies on direct and residual effect of secondary and micronutrients in Rice (Hybrid) – rice cropping sequence. Ph.D. thesis. Department of Agronomy, OUAT, Bhubaneswar.
- Muralidharan P and Jose AI. 1995. Influence of applied micronutrients on the availability and uptake of Zn, Cu and Mn in rice. *Journal of Tropical Agriculture*, **33**(1): 89-91.
- Nambiar KKM and Abrol IP. 1992. Long term fertilizer experiments in India – An overview, *Fertilizer News*, **34**(1): 11-26.
- Nambiar, K.K.M. 1994. Soil fertility and crop production under long term fertilizer use in India, ICAR, New Delhi, pp.100.
- Nayar PK, Mishra AK and Patnaik S. 1984. Uptake of boron and molybdenum in relation to growth and yield of rice varieties of different duration. *Indian Journal of Agricultural Sciences*, **54**(6): 470-477.
- Page AL, Miller RH and Kenedy DR. 1982. Methods of soil analysis, Part-2: Chemical and biological properties. Am. Soc. Agron. Inc. and Soil Sci. Soc. Am. Inc., Madison, WI, USA
- Pandey N, Verma AK, Anurag and Tripathy RS. 2007. Integrated nutrient management in transplanted hybrid rice (*Oryza sativa*), *Indian Journal of Agronomy*, **52**(1): 40-42.
- Panse, V.G. and Sukhatme, P.V. 1978. Statistical method for agricultural workers. Indian Council of Agricultural Research, New Delhi
- Parihar SS. 2004. Effect of integrated sources of nutrient, puddling and variation schedule on productivity of rice (*Oryza sativa*)-Wheat (*Triticum aestivum*) cropping system, *Indian journal of Agronomy*, **49**(2):74-79

- Pattnaik MC and Bujapalraj G. 1999. Direct, residual and cumulative effects of zinc in rice-rice cropping system. *Oryza*, **36**(4): 331-334.
- Pervaiz K, Yousaf M, Imtiaz M, Debar M, Aslam M, Suleman M and Javed AS. 2012. Determining the zinc requirement of rice genotypes sarshar evolved at N.I.A. T. Jam., *Sarhad Journal of Agriculture*, **28**(1): 1-7.
- Piper CS. 1950. Soil and plant analysis. Academic press, New York
- Polar E. 1975. Zinc in Pollen and its incorporation in seeds. *Planta* **123**: 97-103.
- Prasad R, Kumar D, Shivaya YS and Raj R .2014.Integrated nutrient management. In Text Book of Plant Nutrient Management(Prasad *et al*, Ed).Indian Society of Agronomy, New Delhi, India :511-517
- Prasad R, Kumar D, Shivaya YS and Rana DS. 2014. Boron in Indian agriculture, *Indian Journal of Agronomy*, **59**(4):511-517
- Prasad R.1999. *A text Book of Rice Agronomy*. Jain Brothers, New Delhi:113
- Premila KS and Dale D. 1984. Introduction of resistance in rice plants to insect pests by the application of chelated metal complexes. *Crop protection* **3**(2): 187-192.
- Premkumar K, Raju MS and Reddy PJ. 1979. Response of transplanted rice to zinc application in transplanted rice to zinc application in Gangetic alluvial soil. *International Rice Research Newsletter* **4**:6-20.
- Ram Asha, Kumar D, Singh Nain and Anand A. 2014. Effect of sulphur on growth, productivity and economics of aerobic rice (*Oryza sativa*). *Indian Journal of Agronomy* **59** (3):404-409.
- Randhawa NS and Takkar PN. 1975. Micronutrient research in India. *Fertilizer News* **20**:11-18.
- Rattan RK, Dutta SP and Katyal JC. 2008. Micronutrient management –research achievements and future challenges. *Indian journal of Fertilizer*, **4**(12):92-118.

- Rattan RK, Dutta SP, Saharan N and Katyal JC. 1997. Zinc in Indian agriculture, *Fertilizer News*, **42**(12):75-89
- Sahoo A and Sahoo J. 2001. Integrated zinc management in wet season rice, M.Sc. (Ag.) Thesis. Department of Agronomy, OUAT, Bhubaneswar.
- Sahoo J. 2005. Integrated zinc management in rice-rice system, Ph.D. Thesis, Department of Agronomy, OUAT, Bhubaneswar.
- Sahu SK and Mishra GN. 1992. Micronutrient status of soils of Orissa and their management. Proceedings of workshop on Micronutrients. IBFEP and HFCL, 22-23 January, Bhubaneswar: 84-92
- Sahu SK, Mitra GN and Pani SC. 1994. Effect of Zn sources on uptake of zinc and other macro nutrients by rice on *vertisol*. *Journal of Indian Society of Soil Science*, **42**(3):793-804.
- Sakal R and Singh AP. 1995. Boron research and agricultural production, (In) Tandon. HLS. (Ed.). *Micronutrient Research and Agricultural Production*. FDCO, New Delhi, 1-31
- Sakal R and Singh BP. 1982. Determination of critical limit of zinc in soil and plant for response of rice to zinc application in calcareous soils. *Plant and Soils*, **60**(1):132-19
- Sakal R, Sinha RB and Singh AP. 1993. Evaluation of methods and time of zinc application ton rice. *Journal of Indian Society of Soil science*, **41**(1):195-196
- Sarkar AK and Singh S. 2003. Crop response to secondary and micronutrients in acidic soils of India. *Fertilizer News*, **48**(4): 47-54
- Sarkar BB, Nath SC and Bhattacharjee BK. 1989. Effect of zinc on the yield of transplanted paddy in Tripura, *Oryza*, **26**(4): 403-404.
- Sathya S, Pitchai GJ. and Indirani, R. 2009. Boron nutrition of crops in relation to yield and quality- *Agricultural Reviews* **30**(2):139-144.

- Sharma BD and Katyal JC. 2006. Water soluble boron in benchmark soils of India and its relationship with soil properties. *Journal of Society of Soil Science*, **54**(1):57-59.
- Sharma, DK and Singh KN, 1985 Response of rice to N, P & Zn in sodic soil. *International Rice Research Newsletter*, **10**(3):24-27
- Shukla A. 2009. Main role of micronutrient. *Indian Journal of Fertilizer*, 11-12: 15-18.
- Shukla, AK and Behera, SK. 2011. Zinc Management in Indian Agriculture. Past, Present and Future. *Indian Journal of Fertilizer*, **7** (10): 14-33.
- Singh BP, Sakal R and Singh AP. 1983. Relative performance of soil applied zinc sulphate and other zinc carriers used as coating of seeds of maize and rice. *Indian Journal of Agricultural Science*, **53**(10): 918-921
- Singh BP, Singh AP and Sakal R. 1983. Different response of crops to zinc application in Calcareous soils. *Journal of Indian Society of Soil Science*, **31**(4):534-538
- Singh M and Singh SP. 1983. Effect of zinc and phosphorus on absorption of iron and nitrogen by submerged paddy. *Journal of Soil Science*, 71-135
- Singh MV and Abrol P. 1985. Direct and residual effect of zinc application on yield and chemical composition of rice-wheat crops in an alkali soil. *Fertilizer Research*, **8**: 179-191.
- Singh MV. 2003. Crop response to secondary and micronutrients in Swell-shrink soils, *Fertilizer News*, **48**(4): 55-60, 63-68.
- Singh MV. 2012. Spread of micro-nutrient deficiencies specially boron in India and response of field crops” Brain storming workshop on soil test based nutrients including boron and other micronutrients” organized by ICRISAT-agriculture Directorate, Karnataka, Rio Tinto India at Bangalore, India.
- Singh, MV. 1990. Annual Progress Report, All India Coordinated Research Project on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants, IISS, Bhopal, pp.38-39..

- Singh, MV and Goswami V. 2014. *Indian Journal of fertilizer*, 109
- Singh, MV. 1999. Current status of micro and secondary deficiencies and crop response in different agro ecological regions. *Fertilizer News*, **44**(4):63-68.
- Singh SK, Thakur R, Singh MK, Singh CS and Pal SK. 2015. Effect of fertilizer level and sea weed sap on productivity and profitability of rice (*Oryza sativa*). *Indian Journal of Agronomy* **60** (3): 420-425.
- Singh, V.K., Kumar, v. and Govil, V. 2013. Assessing sulphur deficiencies in soils and on-farm yield response to sulphur under rice (*Oryza sativa*) – wheat (*Triticum aestivum*) system in Garhwal region, *Indian Journal of Agronomy* **58**(1):1-8.
- Soren Lukhimuni. 2003. Integrated management of zinc and sulphur in the medium land rice in wet season. M.Sc. (Ag) Thesis. Department of Agronomy. College of Agriculture, OUAT, Bhubaneswar.
- Srinivassan PS. 1984. Studies on physiological aspects of zinc nutrition in three rice cultivars, Ph.D. thesis, TNAU, Coimbatore.
- Srivastava GK and Tripathy RS.1998. Response of hybrid and composite rice to number of seedlings and planting geometry. *Annals of Agricultural Research*, **19**(2): 235-236.
- Srivastava PC and Gangwar MS.1987. Zinc supply parameter and its relation to zinc uptake by rice. *Journal of Indian Society of Soil Science*, **35**:672-676.
- Subbiah, BV and Asija, GL. 1956. A soil test procedure for determination of valuable nitrogen in soil, *Current Science*, **25**(8):259-260.
- Sujathamma P, Sheik M and Bhanumurthi V. 2013. Response of rice-rice cropping system to different agronomic management practices, *Oryza*, **50**(1): 88-89.
- Swain DJ. 1995. Trace elements variation in soils. Technical Bulletin. Commonwealth Bureau of Soil Science Technical Communications” p.84
- Swarup A. 2003. Crop response to secondary and micro-nutrients in salt affected soils of Indian. *Fertilizer News*, **48**(4): 83-88, 91-93.
- Tabassum, Shahina, Khamparia RS and Smita S. 2013. Effect of zinc and organic manures on yield attributes and yield of rice. *BIONFOLET* **10**(3A):879-881.

- Takaki H and Kushizaki M. 1970. Accumulation of free tryptophan in Zn deficient maize seedlings. *Plant Cell Physiology*, **2**:793-804
- Takkar PN. 1987. Economic of sulphur use in India. Proc. FADNAP-FAO-TSI-ICAR Symp. Fertilizer, sulphur requirements and sources of developing countries of Asia and Pacific, Bangkok, pp.123-127
- Tandon HLS, 1986b. Sulphur research and agricultural production in India, 3rd Edition, pp. 23-25.
- Tandon HLS. 2009. Micronutrient Hand Book –from research to practical application- FDCO, New Delhi:1-201
- Tandon HLS. 2011. Sulphur in soils, crops and fertilization -research to practical application –FDCO, New Delhi: 1-190
- Tiwari KN, Sharma SK, Singh VK, Dwivedi BS and Shukla AK. 2006. Site-specific nutrient management for increasing crop productivity in India; Results with rice-wheat and rice-rice system. PDCSR. Modipurama, PPIC India Programme. Gurgaon: 92
- Tiwari KN, Sharma SK, Singh VK, Dwivedi BS and Shukla AK. 2006. Site specific nutrient management for increasing crop productivity in India. Results with rice-wheat and rice-rice system. PDCSR, Modipuram, PPIC, India Programme, Gurgaon, **20**:60-70.
- Watson DJ. 1947. Comparative physiological studies on growth of field crops. *Annals of Botany*, **11**:41-76.
- Yadav DS and Kumar Alok. 2009. Long-term effect of nutrient management on soil health and productivity of rice (*Oryza sativa* L.) – wheat (*Triticum aestivum*) system, *Indian Journal of Agronomy*, **54**(1): 15-23.

