International Journal of Plant & Soil Science

Volume XXX, Issue XX, Page XX-XX, 20YY; Article no.IJPSS.125276
ISSN: 2320-7035

Multi-micronutrient (S, B & Zn) Doses on Yield and Residual Effect on Rice-groundnut Cropping System in Alfisols of Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. 'Author A' designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. 'Author B' and 'Author C' managed the analyses of the study. 'Author C' managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2024/XXXXX

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:

………… Article

Received: DD/MM/20YY
Accepted: DD/MM/20YY
Published: DD/MM/20YY

ABSTRACT

Orissa is the fourth largest state in India covering an area of 15.57 m ha out of which the net sown area is 6.13 m ha. Out of 8 broad soil groups found in the state, red and laterite groups of soil occupy more than 75% of total cultivable area. Low productivity of crops in red and laterite soils are associated with deficiency of Ca, Mg, S, B and Mo (Mitra and Sahu, 1988). The DTPA extractable Zn also indicates that red and laterite soils of Orissa is deficient in available Zn and respondent to Zn application to rice crop (Anonymous, 2002; Mandal et al., 2009). Next to Zn, the deficiency of B is wide spread in many districts of the state as well as contrary (Sharma et al., 2006). Rice-Groundnut is the most prevailing cropping pattern in red and Lateritic soils of Orissa. In spite of recommended dose of NPK fertilizer, the farmers get low yield. A field experiments were carried out

Cite as:

with rice-groundnut cropping systems in two successive cropping seasons each, to study the effect of S, B and Zn on grain yield, nutrient uptake and their accumulation. The experimental design included ten treatments, T_1: control, T_2 : S 40 kg/ha, T_3 : B 1 kg/ha, T_4 : Zn 5 kg/ha, T_5 : FYM 5 t/ha, T_6 : S+B, T_7 : S+Zn, T_8 : B+Zn, T_9 : S+B+Zn and T_{10} : S+B+Zn+FYM replicated thrice in randomized block design. Integrated use of S + B + Zn with FYM was the ideal combination for rice-groundnut cropping system as it was more sustainable, recorded the highest yield and SYI value along with higher accumulation and uptake of nutrients. The results revealed that red and lateritic soils are poor in S and B need integrated use of S, B and Zn along with recommended dose of NPK for getting synergistic and best effect in rice-groundnut cropping system.

Keywords: Red; laterite soil; nutrient deficiency; rice-groundnut cropping system; fertilizer application; yield improvement; nutrient uptake.

1. INTRODUCTION

Rice-groundnut is the prevailing cropping pattern in red and lateritic soils of Orissa.Low productivity of crops in red and laterite soils is associated with deficiency of Ca, Mg, S, B and Mo (Mitra and Sahu, 1988). Groundnut is a major oilseed crop in Odisha and occupies about 3 lakh hectares during Rabi season. During Rabi season, it is purely rain-fed crop and grown in red and lateritic soils of Western Odisha.

Use of high yielding crop varieties, intensive cropping areas, leads to successive depletion of micronutrients from soil (Dhaliwal et al., 2022). Visual symptom of sulphur deficiency in groundnut has been reported from a number of locations of Orissa (Jena et al., 2004). Report of soil analysis data revealed that about 28% of soils of Odisha are deficient in S, 44% in B and 19% in Zn (Jena et al., 2004).

Several studies indicated that rice responded well to Zn application (Anonymous, 2002; Mandal et al., 2009), groundnut to S and B in acid soils (Sharma and Katyal, 2006).

The micronutrient reserve of the soil has been depleted due to continuous intensive cropping with high yielding crop varieties, use of high mineral fertilizers free from micronutrients and decline in the use of organic manures. This is influencing the yield and quality of crops adversely and thereby invites much attention for the increased micronutrient malnutrition in soil-plant-animal and human continuum (Gupta et al., 2008; Jena, 2012; Sanyal et al., 2014).

2. MATERIALS AND METHODS

In rice experiment, three rice seedlings (cv. Pratiksa) of twenty five days old were transplanted with recommended dose of fertilizer (N, P, K 80-40-40 kg/ha). In groundnut experiments, four seeds of each crop, i.e. groundnut (cv. AK 12-24) were sown with recommended dose of fertilizer 20-40-40 kg NPK/ha.The crops received nutrients (N, P, and K) through reagent grade of urea, KH_2PO_4 and KCl. Two field experiments were carried out at the *Instructional Farm*of Krishi Vigyan Kendra Mayurbhanj, Shymakhunta (OUAT) during 2010 to 2013 with rice-groundnut cropping system, to study the effect of S, B and Zn on grain yield, nutrient accumulation and their uptake. There were ten treatments consisting ofT1: Control;T2: S40 kg/ha;T3: B1 kg/ha;T4: Zn5 kg/ha;T_5: FYM 5 t/ha;T6: S+B;T7: S+Zn;T8: B+Zn;T9: S+B+Zn;T10: S+B+Zn+FYM(S 40kg/ha,B1 kg/ha,Zn 5kg/ha and FYM 5t/ha).The experiments were laid out in a randomized block design with three replications each having plot size (5×3) m^2. In rice-groundnut cropping system, the treatments were imposed on rice (*Kharif*) and the residual effect, if any, was studied on groundnut grown during Rabi season. Rice received full dose of P and half dose of N and K through DAP and MOP at transplanting. Remaining amount of N and K was applied at tillers up stage. In case of groundnut, full dose of N, P and K were applied at sowing.

Required quantity of zinc sulphate, gypsum and borax were thoroughly mixed with soil before transplanting or at sowing. Plant protection measures were also taken as and when necessary.

For Biometric observations five plants in each treatment were selected at random and labeled for recording biometric observations. At physiological maturity the labeled plants were cut and number of effective tiller were counted per hill in rice crop. These selected plants at random and labeled panicles were cut and the length of panicles were expressed in centimeter. To accesses the effect of treatments, the chaff and grain number of the panicles were counted and the percentage of chaff was calculated. Crops were harvested and grain, straw/haulm and tuber yield were recorded. The sun dried bundles of paddy were threshed using pedal operated thresher. The grains were cleaned, sun dried and weighed. The yield was recorded in q/ha. In a similar manner rice straw was also recorded. In groundnut, similar procedure was followed and yield of pod and haulm were reported in q/ha.

Before initiation of the trial, soil samples were collected at random from 0-15cm depth from experimental plots. After the second crop, post harvest soil samples were collected treatment wise from rice-groundnut cropping system. The soil samples thus collected were air dried and grinded. The processed soil were then passed through a 10 mesh sieve (2mm) and kept in air tight polythene bags for further analysis after due labeling.

For rice, both straw and grain samples were collected for analysis. The collected samples were air dried for three days and then oven dried at 70°C till constant weight is obtained. The dried samples were ground and kept for further analysis. Similarly, the groundnut pod and haulms were collected treatment wise and kept for further analysis with due labeling.

Harvest index of rice and groundnut were calculated by using the formula (Nichiporovic, 1960).

$$\text{Harvest index (HI)} = \frac{\text{Grain/pod/tuber yield}}{\text{Total biomass yield}}$$

The maintenance and/or enhancement of productivity on a long term basis through integrated land management is evaluated by sustainable yield index proposed the SYI as a quantitative measure to assess sustainability of an agricultural practice. The SYI is computed using following formula:

$$\text{SYI} = \frac{A-Y}{\text{Ymax}}$$

Where, A=mean yield of a particular treatment, Y=standard deviation of a particular treatment, Y_{max}=potential yield in different years and treatments.

The particle size of soil was analyzed by hydrometer method (Bouyoucos, 1962), soil pH of the soil was determined in 1:2.5 soil water suspensions using a glass electrode digital pH meter (Jackson, 1973), electrical conductivity of 1:1.25 soil water suspensions was measured using conductivity meter. The organic carbon content of soil was determined by wet digestion method as outlined by Walkley and Black (1934). Available nitrogen content of soil was estimated by alkali permanganate method as outlined byand available phosphorus by Olsen's method (Olsen et al., 1954) using 0.5 N $NaHCO_3$ as extracting solution in 1:20 soil extractant ratio. Available potassium was determined by neutral normal ammonium acetate (NH_4OAc**)** extractant was determined flame photometrically.The available sulphur in soil was extracted with 0.15% $CaCl_2$ solution and determined by turbidometric method as suggested by Massoumi and Cornfield (1963).The available boron in soil was extracted by hot water reflux method and determined spectrophtomerically using azomethrin-H (Page et al., 1982).The available zinc in soil was determined by using DTPA extractant. Total N, P, K,S,B and Zn of all the three crops were estimated byusing standard procedures.Nitrogen was estimated by distillation in Kelplus in N estimator as suggested by [Tandon (1998). The total P was analyzed by vanadomolybdo-phosphoric acid yellow colour method as described by Jackson (1973).Total potassium was estimated by using Flame Photometer after diacid digestion (Jackson, 1973) and the total sulphur by turbidimetry.The total boroncontent in plant was estimated afterdry-ashing using colourimetric method, whereas the total zinc content was estimated byAtomic Absorption Spectrophotometer (Gupta, 2007) afterwet digestion in HNO_3: H_2SO_4: $HClO_4$ (9:4:1).

The field experiment data generated were analyzed statistically as per the analysis of variance technique applicable for randomized block design (Gomez and Gomez, 1976).

3. RESULTS AND DISCUSSION

The medium land site of the experimental area belonged to soil order Alfisol with sandy loam soil texture having sand 74.6%, silt 12% and clay 13.4% (Table 1). The soil was acidic in reaction (pH 4.96), nonsaline and medium in organic carbon (0.56 %). The soil was high in available P (36.4 kg/ha), but medium in available N (228.5 kg/ha) and potassium (167.4 kg/ha). The soil was rich in available S (75.1 kg/ha) and DTPA-Zn (0.71 mg/kg), but deficient in hot water extractable boron (0.46 mg/kg). In general, the experimental site had medium fertility status, and was deficient in boron.

3.1 Rice grain & Straw yield

The data on direct effect of B, Zn and S on rice grain yield is presented in Table 2. In rice-groundnut cropping system rice is grown as first crop and received B, Zn and S in addition to NPK. The residual effect of B, Zn and S was studied on succeeding groundnut crop. The data presented in Table 2 revealed that the grain yield varied between 78.1 to 107.4 q/ha during Kharif 2011 and 68.73 to 97.03 q/ha during Kharif 2012. The yield recorded in 2011 was higher than 2012 in all treatments. The yield recorded in B or S treatment was similar to control during 2011, but increased by 1-2 q/ha during 2012 indicating that rice did not respond to B and S application although the soil was deficient in B. However, although the experimental soil was rich in Zn, there was very good response to Zn application as the yield was increased over control by 4-5 q/ha during both years ([Hanifuzzaman et al., 2022). On an average (over two year), the yield was 6% higher over NPK alone. This indicated that rice responded to Zn fertilizer although the soil was rich in DTPA-Zn.

Integrated use of S, B and Zn was found beneficial and had significant effect on grain yield. Combined application of S and B resulted in 6.11% higher yield over NPK alone and the response was further increased when Zn was combined either with B or S. Among the three combinations (S×B, B×Zn, S×Zn), higher yield response of 15.17% was obtained when the crop received both B and Zn. Integrated application of B, Zn and S further increased the grain yield and about 35.41% higher yield response was achieved in this treatment. Highest significant yield response of 39-23% was recorded when FYM is integrated with B, Zn and S. But, when FYM was applied alone with NPK (T_5), the yield was similar to NPK treatment and only 2% yield response was recorded. This indicated that the yield can only be increased with combined application of NPK with B, Zn and S.

Table 1. Physico-chemical properties of the soils experimental site of rice-groundnut cropping system

Parameters	Analysis values
pH	4.96
Soil Texture	Sandy loam
EC (ds/m)	0.02
O.C (%)	0.56
Avail. P (kg/ha)	36.4
Avail. K (kg/ha)	167.4
Avail. N (kg/ha)	228.5
Avail. S (kg/ha)	75.1
Avail. B (ppm)	0.46
Avail. Zn(ppm)	0.71

Table 2. Direct effect of S, B and Zn on rice grain and straw yield (q/ha) in rice-groundnut cropping system

Treatments	Grain yield	Response (%)	HI	Mean	Response (%)
T_1 Control	73.41	-	0.48	79.25	-
T_2 S40 kg/ha	74.28	1.18	0.48	80.78	1.93
T_3 B1 kg/ha	74.43	1.38	0.48	80.01	0.95
T_4 Zn5 kg/ha	77.90	6.11	0.46	89.53	12.97
T_5 FYM5 t/ha	74.78	1.86	0.48	80.98	2.18
T_6 S+B	80.50	9.65	0.45	96.20	21.38
T_7S+Zn	81.81	11.44	0.46	96.25	21.45
T_8B+Zn	84.55	15.17	0.46	97.35	22.83
T_9S+B+Zn	99.41	35.41	0.49	102.66	29.53
T_{10}S+B+Zn+FYM	102.21	39.23	0.48	109.33	37.95
CD (0.05)	3.32				
CV (%)	2.23				

Table 3. Residual effect of S, B and Zn on groundnut pod yield (q/ha) in rice-groundnut cropping system

Treatments	Year		Mean	Response (%)
	Rabi-2011-12	Rabi-2012-13		
T_1 Control	7.8	8.1	7.91	-
T_2 S40 kg/ha	12.4	12.1	12.26	54.99
T_3 B1 kg/ha	10.7	10.3	10.53	33.12
T_4 Zn5 kg/ha	11.3	11.3	11.30	42.85
T_5 FYM5 t/ha	8.2	8.6	8.42	6.44
T_6 S+B	13.6	12.9	13.29	68.01
T_7S+Zn	14.2	13.5	13.86	75.22
T_8B+Zn	14.2	13.7	13.99	76.86
T_9S+B+Zn	16.6	16.1	16.36	106.82
T_{10}S+B+Zn+FYM	17.4	16.9	17.16	116.94
CD (0.05)	**0.47**	**0.64**		
CV (%)	**2.17**	**3.04**		

Table 4. Residual effect of S, B and Zn on groundnut haulm yield (q/ha) in rice-groundnut cropping system

Treatments	Year		Mean	Response (%)
	Rabi-2011-12	Rabi-2012-13		
T_1 Control	12.4	11.8	12.14	-
T_2 S40 kg/ha	27.6	23.0	25.31	108.48
T_3 B1 kg/ha	22.6	20.7	21.65	78.33
T_4 Zn5 kg/ha	26.2	22.8	24.53	102.05
T_5 FYM5 t/ha	17.6	16.7	17.16	41.35
T_6 S+B	28.5	24.3	26.44	117.79
T_7S+Zn	29.1	25.1	27.09	123.14
T_8B+Zn	30.3	25.9	28.13	131.71
T_9S+B+Zn	31.9	27.2	29.56	143.49
T_{10}S+B+Zn+FYM	35.2	30.2	32.76	169.85
CD (0.05)	**0.63**	**0.77**		
CV (%)	**1.39**	**1.97**		

Table 5. Cumulative effect of S, B and Zn on rice-groundnut cropping system yield (q/ha)

Treatments	1st crop Rice	3rd crop Rice	*2nd crop Ground Nut (REY)	4th crop Ground Nut (REY)	Mean of two years	Response (%)
T_1 Control	78.1	68.7	22.9	23.9	96.82	-
T_2 S40 kg/ha	78.6	69.9	36.8	35.8	110.58	14.2
T_3 B1 kg/ha	78.8	70.1	31.8	30.6	105.54	9.0
T_4 Zn5 kg/ha	82.1	73.7	33.4	33.4	111.34	15.0
T_5 FYM5 t/ha	79.1	70.5	24.3	25.6	99.70	2.5
T_6 S+B	84.7	76.3	40.3	38.4	119.84	23.8
T_7S+Zn	85.0	78.6	42.1	39.9	122.84	26.9
T_8B+Zn	88.6	80.5	42.1	40.7	125.96	30.0
T_9S+B+Zn	105.1	93.7	49.0	47.8	147.82	52.7
T_{10}S+B+Zn+FYM	107.4	97.0	51.6	50.7	153.36	58.4

**Minimum support price for rice: Rs1250/q; groundnut: Rs3700/q*
**REY-Rice equivalent yield*

Yield of rice: Straw yield of rice ranged between 81.4 to 109.9 q/ha in Kharif 2011 and 77.0 to 108.76 q/ha during 2012 (Table 2). Application of B or S alone did not influence the straw yield, whereas Zn application had significant beneficial effect and about 13% higher straw yield was recorded when the crop received Zn 5 kg/ha. Combined use of B×S, S×Zn or B×Zn had significant positive effect on straw yield. However, the integrated effect of B×Zn was found better than B×S or S×Zn.On the other hand, combined application of B, Zn and S recorded 29.53 higher yields over NPK (Hanifuzzaman et al., 2022). Inclusion of FYM with B, Zn and S further increased the straw yield over NPK (T_1) by 37.95%. The data also revealed that the interaction effect of S, B and Zn with FYM was synergetic in nature.

Pod yield of groundnut: It is grown after harvest of Kharif rice, where irrigation is available. The pod yield of groundnut under present study ranged from 7.8 to 17.4 q/ha during 2011-12 and 8.41 to 16.9 q/ha during 2012-13 (Table 3). The crop responded significantly to B, Zn and S application in both years (Hanifuzzaman et al., 2022). The preceding rice crop was fertilized with B, Zn and S along with NPK, where groundnut was grown with NPK fertilizer only. Although there was every possibility of leaching of S and B from the root zone due to high rain fall (1500 mm) during Kharif season, but its residual effect was clearly observed on succeeding groundnut. Among the three elements (B, Zn and S), the residual effect of S was higher than B and Zn, since the oilseed crop requires more S for synthesis of amino acids, Cystein and methionine. The pod yield of groundnut increased significantly over NPK (T_1) by 55% with S application as against 33.12% in B treatment (T_3) and 42.85% in Zn treatment (T_4). Application of FYM 5 t/ha alone has little effect on pod yield since only 6.44% higher yield was recorded in this treatment. On the other hand, the use efficiency of S, B and Zn was increased significantly when these fertilizers were applied with FYM. Highest significant mean yield of 17.16 q/ha was recorded when the crops received S+B+Zn+FYM and the yield was 117% higher over NPK. There was no significant difference in yield when the crops received S+B, S+Zn or B+Zn, although the yield in these treatments was increased over control by 68-76.86 % higher over control (NPK).

Haulm yield of groundnut: The data presented in Table 4 revealed that, the haulm yield of groundnut varied from 12.4 to 35.2 q/ha in 2011-12 and 11.8 to 30.2 q/ha in 2012-13. Residual effect of S, B and Zn alone or in combination significantly increased the haulm yield (Hanifuzzaman et al., 2022). Residual effect of S enhanced the haulm yield over NPK (12.14 q/ha) by 108.48% as against 78.33% in B and 102.05% in Zn treatment. Combined application of S+B, S+Zn or B+Zn increased the haulm yield by 117.79 to 131.71 % over control. On the other hand, integrated application of S+B+Zn increased the yield by 131.71% and further increased to 143.99% in presence of FYM. This showed that application of FYM helped to check the leaching loss of B and S and maintained soil fertility to sustain crop productivity.

Cumulative grain yield of rice-groundnut cropping system: Table 5 presents the cumulative grain yield of rice-groundnut cropping system over two years. The yield of groundnut was converted into relative rice yield taking the selling price of rice 1250/q and groundnut 3700/q. The data revealed that the mean yield of rice-groundnut cropping system over two years was 96.82 q/ha in control when the crop received the recommended dose of NPK (T_1). On application of B, Zn or S, the relative yield was increased over control by 9 to 15%, the highest being in Zn treatment followed by S and B. Considering the individual crop yield, rice responded to Zn application, whereas groundnut responded to S application, although the experimental soil was rich in SO_4^-S and DTPA-Zn. However, considering the whole cropping system of rice-groundnut, response to Zn application was superior to either S or B.

The study revealed that red and lateritic soils in Orissa are deficient in essential nutrients such as sulfur (S), boron (B), and zinc (Zn), leading to low crop productivity despite the application of recommended NPK fertilizers. Combined application of S+B, S+Zn or B+Zn enhanced the grain yield over control by 23.8-30.0%, which varied from 119.84-125.96 q/ha. However, combination of B+Zn was superior to S+B or S+Zn treatment. On the other hand, integrated use of S+B+Zn with FYM recorded the highest grain yield of 153.36 q/ha as against 147.82 q/ha in absence of FYM. This showed that the stability of yield was maintained when the crop received S+B+Zn and FYM since FYM enhances the use efficiency of fertilizers.

Jena (2010-11) observed that S 40 kg/ha recorded 32% higher groundnut yield in alluvial soils of Odisha. Application of 45 kg S/ha was found optimum to sustain higher productivity of rice-rice cropping system in laterite soil of

Bhubaneswar (Anonymous, 2006). Compiling the research results on S management, Tandon (1998) reported that wheat and rice responded to S application by 25 and 17 % respectively. However, in our study, rice did not respond well to S application and only 12% response was observed in case of groundnut might be due to high S status of soil.

In rice-wheat cropping system, fertilizing rice 5 kg Zn/ha annually can sustain wheat yield grown in sequence. Five kg Zn/ha also adequately met the Zn requirement of rice-rice cropping system in vertisols. Similar trend was also observed in our study. Application of Zn 5 kg/ha to rice was adequate enough to meet the Zn requirement of succeeding groundnut crop grown in sequence.

Extensive farm trials conducted in Assam, Bihar, Odisha and West Bengal responded positively to B application in 69, 70, 79 and 71% of the experiments, respectively (Ali, 1992). Positive response of cereals, pulses, oilseeds and cash crops have been reported from Bihar, Odisha, West Bengal, Assam and Punjab (Takkar et al., 1996). On B deficient coarse texture Tamil Nadu initial application of 2 kg B/ha followed by 0.5 kg B/ha to alternate crops of groundnut-maize cropping systems sustain highest systems productivity and total B uptake (Singh, 2000). However, the results of present study showed that rice did not respond to B application since only about 0.1ton higher yield per hectare was recorded. But, the residual effect of B on succeeding groundnut crop was positive and the yield was increased by 2.6 q/ha which is about 33% higher over control. The negative response of rice to B application indicates that a dose of 1 kg B/ha to rice-groundnut cropping system is either inadequate or the rice variety (CvPratiksha) is tolerant to B deficiency. Based on several studies, Jena et al. (2008) recommended a dose of 1 kg B/ha is optimum for rice, groundnut and sugarcane in B deficient soils. However, in present study, 1 kg B/ha applied to first crop in rice-groundnut system might be in adequate to meet B requirement of rice and groundnut.

Yield attributing characters of rice: The yield attributing characters of rice like plant height, number of effective tillers per hill, panicle length and chaff percent are discussed in this section.

Plant height: The plant height in different treatments ranged from 118.2 (control) to 122.6 cm in 2011 and 98.2 to 119.0 cm in 2012 with two years mean value of 108.18 to 1114.71 cm (Table 6). The treatment effect was insignificant during first year, whereas in second year significant increase in plant height recorded when the crop required B, Zn and S alone with FYM (Hanifuzzaman et al., 2022). Based on two years average, the plant height was increased over control (T_1) by 0.88 to 9.86 %, highest being in T_{10}.

Table 6. Direct effect of treatments on yield attributing character of rice in rice-groundnut cropping system

Plant height (cm):

Treatment	Year		Mean	Increase (%)
	Kharif-2011	Kharif-2012		
T_1 Control	118.2	98.2	108.18	-
T_2 S40 kg/ha	119.1	107.7	113.38	4.80
T_3 B1 kg/ha	119.8	109.5	114.65	5.98
T_4 Zn5 kg/ha	120.6	108.8	114.71	6.03
T_5 FYM5 t/ha	118.6	109.7	114.13	5.50
T_6 S+B	122.5	103.4	112.93	4.39
T_7S+Zn	122.6	102.7	112.63	4.11
T_8B+Zn	117.7	107.7	112.68	4.15
T_9S+B+Zn	119.6	98.7	109.13	0.88
T_{10}S+B+Zn+FYM	118.7	119.0	118.85	9.86
CD (0.05)	**7.26**	**13.15**		
CV (%)	**3.84**	**7.09**		

Table 7. No. of effective tiller/hill

Treatment	Year		Mean	Increase (%)
	Kharif-2011	Kharif-2012		
T_1 Control	8.06	9.33	8.69	-
T_2 S40 kg/ha	9.63	10.55	10.09	16.11
T_3 B1 kg/ha	9.16	9.88	9.52	9.55
T_4 Zn5 kg/ha	10.10	9.92	10.01	15.18
T_5 FYM5 t/ha	8.53	11.55	10.04	15.53
T_6 S+B	9.80	9.88	9.84	13.23
T_7S+Zn	10.30	10.55	10.42	19.90
T_8B+Zn	10.16	10.55	10.35	19.10
T_9S+B+Zn	10.50	10.77	10.63	22.32
T_{10}S+B+Zn+FYM	11.16	11.88	11.52	32.56
CD (0.05)	**0.36**	**1.2**		
CV (%)	**2.21**	**6.65**		

Table 8. Panicle length (cm)

Treatment	Year		Mean	Increase (%)
	Kharif-2011	Kharif-2012		
T_1 Control	28.6	23.8	26.20	-
T_2 S40 kg/ha	28.4	26.1	27.23	3.93
T_3 B1 kg/ha	28.4	27.7	28.02	6.94
T_4 Zn5 kg/ha	28.6	25.47	27.04	3.20
T_5 FYM5 t/ha	28.3	27.8	27.93	6.60
T_6 S+B	29.3	25.1	27.20	3.81
T_7S+Zn	28.3	25.4	26.81	2.32
T_8B+Zn	29.4	26.4	27.88	6.41
T_9S+B+Zn	28.5	24.87	26.66	1.75
T_{10}S+B+Zn+FYM	28.1	25.1	26.85	2.48
CD(0.05)	**1.40**	**1.88**		
CV (%)	**2.86**	**4.26**		

Table 9. Chaff percent

Treatment	Year		Mean	Reduction (%)
	Kharif-2011	Kharif-2012		
T_1 Control	36.0	35.3	35.62	-
T_2 S40 kg/ha	29.8	29.9	29.86	16.17
T_3 B1 kg/ha	16.8	16.8	16.84	52.87
T_4 Zn5 kg/ha	17.6	17.8	17.70	50.30
T_5 FYM5 t/ha	24.5	24.6	24.52	31.16
T_6 S+B	18.1	17.9	17.87	49.83
T_7S+Zn	18.2	18.1	18.15	49.04
T_8B+Zn	16.7	16.2	16.45	53.81
T_9S+B+Zn	15.0	15.0	15.03	57.80
T_{10}S+B+Zn+FYM	15.9	13.6	14.77	58.53
CD (0.05)	**0.27**	**0.67**		
CV (%)	**0.57**	**1.94**		

Effective tiller per hill: Table 7 presents the number of effective tillers per hill in different treatments over two years. The data revealed that the values varied between 8.06-11.16 during 2011 and 9.33-11.88 during 2012 with over all mean value of 8.69-11.52. During first year there was significant increase in number of tillers per hill with application of B, Zn or S alone or in combination, whereas FYM application did not yield any positive impact (Hanifuzzaman et al., 2022). But during second year, there was significant effect of FYM on tiller number. Based on two years data, it was further observed that the number of tiller per hill was increased by

9.55-32.56 % over control, the highest being in T_{10} and the lowest in T_3.

Panicle length: The data presented in Table 8 revealed that the panicle length of rice varied between 28.1 to 29.4 cm and all the treatments behaved equally without much difference during first tear. However, during second year there was significant increase in panicle length when the crop received S or B (Hanifuzzaman et al., 2022). Application of FYM recorded significantly higher panicle length of 27.8 cm as against 23.8 cm in control. Based on two years data, the maximum panicle length was recorded in B treatment (T_3) which was about 6.94% higher over control (T_1) followed by 6.60% in FYM and 6.41% in B+Zn treatment.

Chaff percent: Boron and zinc play a vital role in grain formation in absence of which the grain become chaffy and yield reduces (Hanifuzzaman et al., 2022). In absence of S, B and Zn, the chaff content in control (T_1) varied between 35.3 and 36.0% with mean value of 35.62% (Table 9.). There was significant reduction in chaff content over control by 16.17, 52.87 and 50.30% when the crop received S, B or Zn respectively. Maximum reduction of 58% was observed when the crop received S+B+Zn and FYM.

Accumulation of nutrients in rice: Accumulation of nutrients *viz.* N, P, K, S, B and Zn in rice grain and straw is presented in Table 10 and 11. Concentration of N in grain (0.82-0.92%) was higher than straw (0.41-0.56%). Application of B or Zn alone or in combination significantly increased the N accumulation both in grain and straw, whereas S had marginal effect. Since, the values in this treatment were at par with control. Integrated application of S+B, S+Zn or B+Zn behaves equally as compared to their individual application although the combination of Zn either with B or S was found better than B+S treatment. This showed that Zn plays a vital role in N accumulation as compared to B or S. Similar results were reported by Ali et al. (2013) and Roy et al. (2014). They observed that application of Zn increases the concentration of N, P, K and Zn in faba bean and rice.

Table 10. Effects of treatments on N, P, K, S, B and Zn concentration in rice grain

Treatments	N	P	K	S	B	Zn
			%			mg/kg
T1-Control	0.82	0.37	0.35	0.10	28.17	17.13
T2-S40 kg/ha	0.85	0.49	0.43	0.22	32.05	26.53
T3-B1 kg/ha	0.88	0.41	0.42	0.15	39.83	24.55
T4-Zn5 kg/ha	0.92	0.42	0.44	0.15	34.10	30.63
T5-FYM5 t/ha	0.83	0.41	0.35	0.12	29.92	24.61
T6-S+B	0.90	0.40	0.42	0.16	34.37	33.40
T7-S+Zn	0.91	0.37	0.42	0.20	34.44	38.87
T8-B+Zn	0.90	0.39	0.41	0.17	31.18	37.91
T9-S+B+Zn	0.92	0.37	0.43	0.19	38.42	37.51
T10-S+B+Zn+FYM	0.92	0.43	0.43	0.21	41.00	39.98
CD (5%)	**0.05**	**0.08**	**0.03**	**0.05**	**6.17**	**8.37**
CV (%)	**3.56**	**1.24**	**3.61**	**18.88**	**10.48**	**16.14**

Table 11. Effects of treatments on N, P, K, S, B and Zn concentration in rice straw

Treatments	N	P	K	S	B	Zn
			%			mg/kg
T1-Control	0.41	0.13	1.32	0.13	30.91	49.00
T2-S40 kg/ha	0.43	0.11	1.37	0.20	38.23	60.83
T3-B1 kg/ha	0.45	0.19	1.40	0.18	43.05	60.78
T4-Zn5 kg/ha	0.45	0.12	1.40	0.14	38.78	60.58
T5-FYM5 t/ha	0.42	0.11	1.35	0.15	32.57	53.97
T6-S+B	0.52	0.16	1.45	0.16	38.12	62.43
T7-S+Zn	0.56	0.12	1.43	0.14	36.21	63.00
T8-B+Zn	0.55	0.12	1.44	0.15	43.56	66.63
T9-S+B+Zn	0.55	0.10	1.42	0.17	46.18	69.03
T10-S+B+Zn+FYM	0.56	0.10	1.45	0.18	51.18	69.65
CD (5%)	**0.04**	**0.02**	**0.02**	**0.05**	**4.2**	**0.34**
CV (%)	**5.32**	**10.36**	**0.90**	**16.36**	**6.18**	**2.36**

Table 12. Effects of treatments on N, P, K, S, B and Zn concentration in groundnut kernel

Treatments	N	P	K	S	B	Zn
			%			mg/kg
T1-Control	5.46	0.28	0.68	0.18	25.12	24.80
T2-S40 kg/ha	5.83	0.34	0.57	0.36	27.62	32.10
T3-B1 kg/ha	5.41	0.41	0.63	0.24	33.37	32.02
T4-Zn5 kg/ha	5.04	0.32	0.61	0.29	28.00	35.26
T5-FYM5 t/ha	5.93	0.32	0.63	0.28	28.17	28.10
T6-S+B	5.56	0.38	0.75	0.37	34.68	35.43
T7-S+Zn	5.76	0.32	0.59	0.37	34.11	36.23
T8-B+Zn	5.21	0.33	0.64	0.34	34.34	35.16
T9-S+B+Zn	5.14	0.35	0.58	0.39	34.70	37.10
T10-S+B+Zn+FYM	5.77	0.36	0.67	0.41	35.91	40.33
CD (5%)	**0.725**	**0.051**	**0.096**	**0.060**	**0.763**	**0.442**
CV (%)	**7.67**	**8.71**	**8.84**	**10.82**	**1.41**	**0.767**

Table 13. Effects of treatments on N, P, K, S, B and Zn concentration in groundnut husk

Treatments	N	P	K	S	B	Zn
			%			mg/kg
T1-Control	1.98	0.10	1.38	0.32	42.98	54.70
T2-S40 kg/ha	1.95	0.15	1.18	0.40	52.22	62.10
T3-B1 kg/ha	2.55	0.16	1.16	0.29	55.93	63.83
T4-Zn5 kg/ha	2.49	0.11	1.03	0.44	47.59	68.13
T5-FYM5 t/ha	2.59	0.06	1.42	0.29	43.47	58.83
T6-S+B	2.27	0.12	1.46	0.45	54.09	66.93
T7-S+Zn	2.44	0.08	1.21	0.41	51.81	69.00
T8-B+Zn	2.63	0.11	1.65	0.30	55.78	65.30
T9-S+B+Zn	3.07	0.13	1.05	0.44	61.99	66.13
T10-S+B+Zn+FYM	3.53	0.14	1.57	0.48	65.35	67.20
CD (5%)	**0.339**	**0.017**	**0.365**	**0.085**	**0.413**	**1.736**
CV (%)	**7.86**	**8.62**	**16.21**	**12.8**	**0.454**	**1.576**

Table 14. Effects of treatments on N, P, K, S, B and Zn uptake by rice

Treatments	N	P	K	S	B	Zn
			$kgha^{-1}$			gha^{-1}
T1-Control	97.63	40.74	134.39	19.0	473.0	533.7
T2-S40 kg/ha	102.33	48.68	146.05	33.9	567.9	710.1
T3-B1 kg/ha	106.03	48.21	147.60	26.6	664.9	688.6
T4-Zn5 kg/ha	116.33	46.46	162.50	25.3	631.3	800.3
T5-FYM5 t/ha	100.88	41.97	140.99	22.4	510.5	647.9
T6-S+B	125.36	50.15	173.13	29.5	651.4	872.6
T7-S+Zn	130.64	43.73	171.53	31.3	637.5	930.1
T8-B+Zn	132.82	46.44	175.60	30.2	696.4	978.6
T9-S+B+Zn	152.35	49.78	188.94	37.2	872.0	1093.2
T10-S+B+Zn+FYM	160.38	58.43	208.71	42.4	1003.7	1195.5
CD (5%)	**7.59**	**7.75**	**9.85**	**7.65**	**73.18**	**20.40**
CV (%)	**3.61**	**9.52**	**3.50**	**14.99**	**6.36**	**1.41**

Concentration of P in rice grain (0.37-0.49%) was higher than straw (0.10-0.13%). Accumulation of P was significantly higher in grain when the crop received S fertilizer, whereas the values in other treatment were at par with control. But in case of straw, B has significant effect on P accumulation when it was applied alone or with S.

Accumulation of K in straw was higher than grain. It varied between 0.35-0.44% in grain and

1.32-1.45% in straw. Application of B, Zn or S alone or in combination significantly increased the K accumulation both in grain and straw (Patel et al., 2023).

Concentration of S in grain (0.10-0.22%) was higher than that of straw (0.13-0.20%). Maximum S concentration of 0.22% in grain and 0.20% in straw was recorded where the crop received S fertilizer.
Application of B in control treatment was 28.17 mg/kg in grain and 30.91 mg/kg in grain. Concentration of B in straw was higher than grain in all treatments. Integrated use of B, Zn, S and FYM recorded the maximum B accumulation both in grain and straw.

Concentration of Zn in control crop was 17.13 mg/kg in grain and 49.0 mg/kg in straw. In treatment crops it varied between 24.55-39.98 mg/kg in grain and 53.97-69.65 mg/kg in straw. Integrated use of B, Zn, S and FYM recorded the maximum accumulation in both grain and straw as compared to their individual application.

Accumulation of nutrients in groundnut: The data on residual effect of S, B and Zn on nutrient accumulation in groundnut kernel and haulm are presented in Tables 12 and 13. Accumulation of N in kernel was higher than haulm. It varied between 5.04-5.93% in kernel and 1.95-3.53% in haulm. Residual effect of combined application of S+B+Zn with FYM recorded the maximum N concentration both in kernel and haulm as compared to their individual application since FYM increases the use efficiency of these elements through chelating action.

Concentration of P in groundnut kernel and haulm varied between 0.28-0.16% and 0.06-0.16%, respectively. Individual application of S or B has significant effect on P accumulation, whereas Zn has antagonistic effect. Several authors have demonstrated the antagonistic effect of high soil P on Zn accumulation in plants (Reddy et al., 1973; Takkar et al., 1976; Verma and Tripathy, 1986). The results of present study indicated that the magnitude of P concentration in Zn treatments was at par with control indicating the antagonistic effect of P×Zn at higher soil P and Zn. Application of Zn 5 kg/ha further induced the negative effect.

Accumulation of K was higher in haulm than kernel. It varies between 0.57-0.75 in Kernel and 1.03-1.57% in haulm. Concentration of K in control was higher than B, Zn or S treatment might be due to dilution effect, since the biomass yield in these treatments were quite higher than control. However, combined application of S+B or B+Zn recorded maximum accumulation although it was at par with other treatments.

Concentration of S in control plants was 0.18% in kernel and 0.32% in haulm. In other treatments, it varied between 0.24-0.41% in kernel and 0.29-0.48% in haulm. Application of S alone or in combination with B or Zn recorded significantly higher S accumulation over control. Integrated application of B+Zn+S alone or with FYM recorded highest S accumulation among the treatments.

Accumulation of B in kernel was lower than haulm. Its level was 25.12-35.91 mg/kg in kernel and 42.98-65.35 mg/kg in haulm. When B was applied alone, higher concentration of B was observed in kernel and haulm as compared to Zn or S treatment. However, the accumulation was increased when these elements were applied in combinations. Highest significant accumulation was recorded when the crop received B+Zn+S along with FYM.

Zinc content in kernel and haulm varied between 24.80-40.33 mg/kg and 54.70-69.0 mg/kg, respectively. Application of B, Zn or S alone or in combination recorded significantly higher values over control. However, the highest accumulation was recorded when the crop received B+Zn+S along with FYM.

Nutrient uptake by rice: The uptake of N, P, K, S, B and Zn by rice is presented in Table 14. Nitrogen uptake by rice in control treatment was 97.63 kg/ha and increased by 3.7% when FYM was applied. Sole application of S, B or Zn increased the uptake by 5.6 to 20.9%, the highest being in Zn treatment followed by B and S. Combined application of S+B, S+Zn or B+Zn further increased the N uptake over control by 32.2 to 40.0%, the highest being in B+Zn followed by B+S treatment indicating that Zn plays a vital role in nitrogen accumulation and uptake by rice. Integrated application of B+Zn+S with FYM recorded the highest N uptake, which was 98% higher over control.

Phosphorus uptake in control crop was 40.71 kg/ha followed by 41.97 kg/ha in FYM treatment. Single application of B, Zn or S increased the P uptake to 46.46-48.68 kg/ha, the highest being in S treatment. Antagonistic effect between P and Zn was observed, since the P uptake in Zn treatment was lower as compared to B or S treatment. Similar trend was also observed when Zn was combined with either S or B. Among the three combinations (S+B, S+Zn, B+Zn), higher P uptake (50.15 kg/ha) was achieved in B+S treatment. However, integrated application of B+Zn+S with FYM recorded maximum P uptake (58.43 kg/ha), which was 46% higher than control.

Potassium uptake of rice can be compared with N uptake and the values were 134.4 to 208.7 kg/ha. Among the three treatments (B, Zn, S) the effect of Zn was higher than B or S, since this treatment recorded higher K uptake. Combined application of S+B, S+Zn or B+Zn recorded higher K uptake, which varied between 171.5 to 175.6 kg/ha. Integrated application of S+B+Zn with FYM recorded the maximum K uptake (208.7 kg/ha) which was 55.4% higher over control.

Sulphur uptake by rice in control crop was 19.0 kg/ha and varied between 25.30 and 33.90 kg/ha in B, Zn or S treatment. The uptake was higher when the crop was fertilized with S followed by B and Zn. However, combined application of S+B, S+Zn or B+Zn further increased the S uptake which varied between 29.50-31.30 kg/ha. Integrated application of S+B+Zn recorded maximum S uptake (37.20 kg/ha) which is about 106% higher over control. The data further indicated that application of FYM with S+B+Zn increased the fertilizer use efficiency by 11%.

Boron uptake by rice in control treatment was 473.0 g/ha and increased by 21.0-41.8% when the crop received B, Zn or S fertilizer. However, B fertilization recorded higher B uptake as compared to Zn or S. Combined application of S+B, S+Zn or B+Zn further increased the B uptake over control by 39.5-52.2%. Integrated use of B+Zn+S recorded maximum B uptake (872.0 g/ha) which is 89.5% higher over control. Application of FYM with B+Zn+S increased the fertilizer use efficiency by 14.3%.

Zinc uptake by rice in control treatment was 533.7 g/ha and increased to 668.0-800.3 g/ha when the crop received B, Zn or S. Combined application of S+B, S+Zn or B+Zn increased the uptake which varied between 872.6-978.6 g/ha. Integrated use of B+Zn+S further increased the Zn uptake over control by 110.4%. Application of FYM with B+Zn+S further increased the Zn uptake over control by 110.4%. Application of FYM with B+Zn+S enhanced the fertilizer use efficiency by 8.2% (Patel et al., 2023).

Nutrient uptake by groundnut: Table 15 presents N, P, K, S, B and Zn uptake by groundnut. Nitrogen uptake by groundnut was higher than rice. Nitrogen uptake in control was 67.10 kg/ha and increased significantly to 115.80-126.5 kg/ha when the crop received S, B or Zn, higher being in S treatment followed by Zn and B. Synergistic effect of S on N uptake was higher than B or Zn. Combined application of S+B, S+Zn or B+Zn further increased the N uptake which varied between 140.7-154.1 kg/ha. Integrated use of B+Zn+S increased the uptake over control by 160%. Application of FYM with B+Zn+S increased the fertilizer use efficiency by 22.8%.

Table 15. Effects of treatments on N, P, K, S, B and Zn uptake by groundnut

Treatments	N	P	K	S	B	Zn
			$kgha^{-1}$			gha^{-1}
T1-Control	67.1	3.4	22.6	5.5	73.0	87.3
T2-S40 kg/ha	126.4	8.5	39.6	15.8	178.5	211.3
T3-B1 kg/ha	115.8	8.2	33.2	9.4	162.2	178.7
T4-Zn5 kg/ha	121.5	6.6	33.9	14.9	156.5	218.6
T5-FYM5 t/ha	88.3	3.9	30.3	7.5	99.5	126.4
T6-S+B	140.7	8.7	52.1	18.1	201.6	239.3
T7-S+Zn	149.6	7.0	43.4	17.1	197.1	250.0
T8-B+Zn	154.1	8.3	59.4	14.2	217.9	247.9
T9-S+B+Zn	184.4	10.2	43.7	20.9	257.3	274.6
T10-S+B+Zn+FYM	225.4	11.6	67.9	24.3	293.1	307.3
CD (5%)	**17.23**	**0.91**	**10.52**	**2.60**	**5.05**	**6.84**
CV (%)	**7.31**	**6.96**	**14.42**	**10.61**	**1.6**	**1.86**

Phosphorus uptake by groundnut was lower than rice. It was 3.40 kg/ha in control and varied between 6.0-8.5 kg/ha when the crop received B, Zn or S fertilizer. Combined application of S+B, S+Zn or B+Zn behaved equally as compared to their sole application. Higher P uptake was recorded when they received S+B+Zn along with FYM.

Potassium uptake by groundnut in control was 22.13 kg/ha and increased to 31.74-36.85 kg/ha when the crop was fertilized with B, Zn or S. Combined application of S+B or B+Zn was found superior to S+Zn. Integrated application of B+Zn+S with FYM recorded the highest K uptake as compared to other combinations (Patel et al., 2023).

Sulphur uptake by groundnut in control group was 5.3 kg/ha and increased significantly when the crop received S (14.53 kg/ha) or Zn (14.07 kg/ha). Contribution of B towards S uptake was inferior to S or Zn. However, combined application of S+B, S+Zn or B+Zn was found better than their sole application. Integrated use of S+B+Zn with FYM recorded the highest S uptake (22.75 kg/ha) as compared to other treatment combinations.

Boron uptake by groundnut was 72.0 g/ha and varied between 148.5-166.0 g/ha when the crop received S,B or Zn. Impact of S was found superior to B or Zn. Combined application of S+B, S+Zn or B+Zn was better than their sole application. The highest significant uptake of 275.7 g/ha was recorded when the crop received S+B+Zn along with FYM as against 240.0 g/ha in S+B+Zn treatment (T_9).

Zinc uptake by groundnut in control treatment was 86.0 g/ha and significantly increased to 207.0 g/ha when the crop received Zn fertilizer. Combined application of S+B, S+Zn or B+Zn was found better than their individual application since the Zn uptake in these treatments varied between 224.0 to 237.1 g/ha. Integrated use of S+B+Zn along with FYM recorded the highest Zn uptake (307.3 g/ha) as compared to other treatment combinations.

4. CONCLUSION

Field experiments demonstrated that the integrated application of S, B, Zn, and farmyard manure (FYM) significantly improved nutrient uptake, accumulation, and grain yield in the rice-groundnut cropping system.

Among the treatments, the combination of S + B + Zn with FYM resulted in the highest yield and sustainability yield index (SYI) values. The application of these nutrients with NPK fertilizer creates a synergistic effect, addressing soil deficiencies and promoting long-term soil health and fertility in Orissa's red and lateritic soils for sustainable agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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