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Research Paper

Effect of nutrient omission plot technique based nutrient management in *rabi* rice (*Oryza sativa*) on crop productivity, nutrient uptake and soil health

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ABSTRACT

A field experiment was conducted at M.S. Swaminathan School of Agriculture's post-graduate research farm in Gajapati, Odisha, during the *rabi* season of 2021–22 and 2022–23 to investigate the influence of nutrient omission plot technique (NOPT) based nutrient management on performance of *rabi* rice. The trial was laid in randomized complete block design with three replications. The treatment comprised of seven nutrient management practices, viz. T_1, $N_{120}P_{60}K_{60}Zn_{05}S_{25}$; T_2, $N_0P_{60}K_{60}Zn_{05}S_{25}$; T_3, $N_{120}P_0K_{60}Zn_{05}S_{25}$; T_4, $N_{120}P_{60}K_0Zn_{05}S_{25}$; T_5, $N_{120}P_{60}K_{60}Zn_0S_{25}$; T_6, $N_{120}P_{60}K_{60}Zn_{05}S_0$ and T_7, absolute control. The treatment T_1 resulted the significant highest plant height, dry-matter accumulation (1282.2 g/m^2), leaf area index, tillers/m^2 (287.6), panicle/m^2 (206.2), spikelets/panicle (149.7), filled grains/panicle (124.1), panicle length and grain yield (4.89 t/ha). The significant highest amount of total N (99.4 kg/ha) and Zn uptake (781.9 g/kg) was noticed under T_1 as compared to the other treatments. The maximum total P (30.3 kg/ha) and total S uptake (27.1 kg/ha) was recorded under T_1 which was statistically at par with T_5 and significantly higher than remaining treatments, respectively. Similarly, treatment T_1 also resulted significant highest amount of total K uptake (125 kg/ha) followed by T_5 and T_6. Thus, the conjoint application of $N_{120}P_{60}K_{60}Zn_{05}S_{25}$ is a viable and suitable alternative technology for sustainable rice production in Orissa or other similar ecoregions.

Key word: Growth, Nutrient uptake, Productivity, Soil health

INTRODUCTION

Rice (*Oryza sativa* L.) holds significant importance as a cereal crop, both in India and globally. It serves as a staple food grain for over 50% of the global population. India, specifically, boasts the largest rice cultivation area spanning 46.38 million hectares, making it the second-largest producer worldwide with a production volume of 130.29 million tonnes. The average productivity in India stands at 2,809 kg/ha (GOI, 2022). In the state of Odisha, rice cultivation covers approximately 3.94 million hectares, resulting in a production of 9.14 million tonnes and with a 2,318 kg/ha productivity, which is far below the national average. Various reasons for low productivity of rice such as cultivation of long duration local varieties, non-availability of quality seeds of high-yielding varieties, low solar radiation, high incidence of insect-pests, diseases and weeds, and poor nutrient management (Avasthe *et al*., 2020). Rice is the well-established cereal crop, have high nutrient requirements, particularly for primary nutrients. Effective nutrient management is a crucial aspect of modern farming practices. The application of primary nutrients, including N, P, and K, significantly influences rice productivity (Majumder *et al*., 2023). Additionally, the inclusion of secondary nutrients like S and micronutrients such as Zn can contribute to improved yield attributes and quality (Shankar *et al*., 2021). Sulphur plays a vital role in amino acid and protein synthesis, as well as enzymatic and metabolic activities in plants. Approximately 90% of organic S in plants is accounted for by these functions (Luo *et al*., 2019). The requirement for sulphur in rice varies

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depending on nitrogen supply. When S becomes limited, the addition of N does not impact yield or protein levels in plants. Early in the growth of rice plants, sulphur is particularly important. If sulphur is limited during the early growth stage, it can result in a reduction in tiller number and, consequently, final yield. Zinc is an essential micronutrient, particularly for rice grown under submerged conditions. Zinc deficiency remains a critical factor affecting rice production in various parts of the country. It is the most prevalent micronutrient disorder in lowland rice, and the application of Zn in combination with NPK fertilizer significantly enhances grain yield in most cases. Apart from major nutrients, zinc plays a crucial role in numerous enzymes and is essential for DNA transcription. Similar to sulphur, zinc deficiency is widespread in lowland rice, and the application of Zn along with NPK fertilizer leads to a substantial increase in grain yield in most scenarios (Singh *et al*., 2021).

The exploitation of the full yield potential of rice varieties is hindered by nutrient deficiencies and inadequate nutrient management practices (Biswas *et al*., 2020, Keerti *et al*., 2024). Nutrients such as N, P, K, S and Zn are vital for plant growth and development. Furthermore, the specific nutrient deficiencies can vary depending on soil types and crop cultivation practices. To achieve maximum crop yields, it is essential to provide the right balance of nutrients. Understanding the nutrient uptake patterns of *rabi* rice can provide insights into its nutrient requirements at different growth stages for developing targeted fertilization strategies. Nutrient omission studies involve intentionally excluding specific nutrients from the soil to observe the impact on plant growth. This helps identify which nutrients are most limiting and need to be supplemented. This technique provides an effective approach to examine crop responses to individual nutrient . Nutrient omission studies on *rabi* rice provide essential data that informs better nutrient management practices. This leads to increased crop productivity, improved soil health, reduced environmental impact, and the promotion of sustainable agricultural practices. By leveraging the insights gained from these studies, farmers can achieve higher yields and contribute to long-term agricultural sustainability. In this context, a field experiment was conducted for two consecutive years using the nutrient omission plot technique to assess the impact of each primary nutrient, as well as zinc and sulphur, on rice crops.

MATERIALS AND METHODS

A study was conducted for two consecutive years during the *rabi* season of 2021–22 and 2022–23 at the Post Graduate Research Farm of M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, located in Gajapati district, Odisha. The experimental site is situated at a (23°39'N and 87°42'E, with an altitude of 145 m above mean sea level). In the first season, the maximum and minimum temperatures ranged from 27.4°C to 38.1°C and 15°C to 26.7°C, respectively, during the crop growth period. In the second season, the maximum and minimum temperatures ranged from 28.4°C to 35.6°C and 13.1°C to 24.9°C, respectively. The total rainfall received during the cropping period was 123 mm in the first season and 127 mm in the second season. Relative humidity in the morning varied from 87.7% to 96.6%, and in the afternoon it ranged from 33.9% to 74.6% during the first season. In the second season, relative humidity in the morning varied from 79.9% to 90.8%, and in the afternoon it ranged from 37.1% to 68.4%. The experiment was designed in randomized complete block

Table 1. Effect of nutrient omission plot technique based nutrient management on growth parameters of *rabi* rice

Treatment	Plant height at harvest (cm)			Dry matter accumulation at harvest (g/m^2)			Leaf area index at 60 DAT			Tiller at 60 DAT ($No./m^2$)		
	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean
100% (NPKZnS)	110.6^{a}	115.4^{a}	113.0^{a}	1275.3^{a}	1289.4^{a}	1282.2^{a}	4.8^{a}	4.9^{a}	4.8^{a}	290.6^{a}	284.5^{a}	287.6^{a}
(-N)	89.7^{cd}	94.2^{b}	91.9^{c}	829.7^{cd}	824.6^{cd}	827.1^{cd}	3.4^{bc}	3.3^{bc}	3.3^{b}	218.3^{cd}	212.4^{de}	215.4^{de}
(-P)	96.3^{bc}	102.5^{ab}	99.4^{bc}	1036.0^{b}	1029.1^{b}	1032.6^{b}	4.1^{ab}	4.3^{a}	4.2^{a}	246.7^{bc}	233.3^{cd}	240.0^{cd}
(-K)	99.2^{abc}	108.7^{ab}	104.0^{ab}	991.0^{bc}	984.6^{bc}	987.8^{bc}	4.1^{a}	4.4^{a}	4.3^{a}	254.3^{b}	247.4^{bc}	250.9^{bc}
(-Zn)	106.3^{ab}	112.2^{a}	109.3^{ab}	1169.0^{ab}	1161.2^{ab}	1165.1^{ab}	4.4^{a}	4.6^{a}	4.5^{a}	274.2^{ab}	265.8^{ab}	270.0^{ab}
(-S)	103.0^{ab}	109.4^{a}	106.2^{ab}	1181.0^{ab}	1174.2^{ab}	1177.6^{ab}	4.2^{a}	4.1^{ab}	4.1^{a}	266.6^{ab}	251.4^{bc}	259.0^{bc}
Control	79.3^{d}	70.1^{c}	74.7^{d}	642.0^{d}	647^{d}	644.5^{d}	3.2^{c}	3.1^{c}	3.1^{b}	201.6^{d}	206.8^{e}	204.2^{e}
SEm±	4.00	4.8	3.3	63.92	62.60	63.14	0.25	0.27	0.25	10.1	8.10	8.40
CD (p=0.05)	12.2	14.6	10.1	193.9	189.9	191.5	0.8	0.8	0.8	30.5	24.6	25.4

design with 3 replications. The treatment details are as follows T_1, $N_{120}P_{60}K_{60}Zn_{05}S_{25}$; T_2, $N_0P_{60}K_{60}Zn_{05}S_{25}$; T_3, $N_{120}P_0K_{60}Zn_{05}S_{25}$; T_4, $N_{120}P_{60}K_0Zn_{05}S_{25}$; T_5, $N_{120}P_{60}K_{60}Zn_0S_{25}$; T_6, $N_{120}P_{60}K_{60}Zn_{05}S_0$ and T_7, absolute control. The nursery was raised using a seed rate of 30–35 kg/ha, uniformly distributed in a well-prepared seed bed. Rice seedlings of variety Naveen was transplanted on 20th January, 2022 and 7th January, 2023 respectively with the spacing of 20 cm × 10 cm and were harvested on 9th May 2022 and 18th April 2023. In the treatments of the 100% recommended dose of fertilizer, 120 kg of N, 60 kg of P_2O_5, 60 kg of K_2O, 5 kg of Zn, and 25 kg of S were used for the purpose. The sources of fertilizers were urea, single superphosphate, muriate of potash, zinc EDTA, and bentonite sulphur. In all the nutrient management treatments, full doses of phosphorus, potassium, zinc, and sulphur were applied as basal. Nitrogen is applied in split doses. A basal dose of fertilizer (half of nitrogen) was applied at the time of sowing, and the remaining half of nitrogen was applied in two equal splits of 25% (at tillering and panicle initiation stages). The data collected of different parameters were subjected to appropriate statistical analysis under randomized complete block design by following the procedure of ANOVA analysis of variance (SAS Software packages, SAS EG 4.3). Significance of difference between means was tested through 'F' test and the least significant difference (LSD) was worked out where variance ratio was found significant for treatment effect. The treatment effects were tested at 5% probability level for their significance. Duncan's Multiple Range Test (DMRT) and Web Agri Stat Package 2.0 (https://ccari.icar.gov.in/wasp/index.php) was used for statistical analysis.

RESULTS AND DISCUSSION

Growth parameters

In both seasons, the treatment using 100% NPKZnS (T_1) exhibited the tallest plant height at harvest (110.6 cm and 115.4 cm, respectively). The nutrient omission treatments involving sulphur, zinc, and potassium showed similar plant height results to the 100% NPKZnS treatment during the first year. This trend was consistent when considering the average values of both seasons. However, in the *rabi* season of 2022-23, the treatment that omitted P, along with S, Zn, and K, also demonstrated statistically similar plant height to the 100% NPKZnS treatment (T_1). The control treatment, which received no fertilizer, resulted in the shortest plant height (79.3 cm and 70.1 cm, respectively) in both seasons. The combined application of nutrients using the omission plot technique, including N, P, K, Zn and S, proved to be highly effective in increasing plant height. This success can be attributed to the stimulation of vegetative growth and elongation of rice plants through adequate nitrogen supply, which ultimately leads to increased plant height (Luo *et al*., 2020). In both the *rabi* seasons treatment (T_1) that received 100% application of all nutrients demonstrated the highest DMA at harvest (1275.9 g/m^2 and 1289.4 g/m^2, respectively). The DMA values obtained in treatment (T_1) were statistically at par to the omission of Sand Zn, both in individual seasons and when considering the mean values. The data indicated that providing an adequate dose of nutrients led to higher dry matter accumulation (DMA) compared to omitting specific nutrients. The likely explanation for this is that macronutrients are necessary for essential physiological processes such as photosynthesis, energy transfer, and nutrient transport, which directly contribute to biomass production (Gangaiah, 2019; Jiaying *et al*., 2022). The treatment with 100% application of NPKZnS resulted in the highest LAI at 60 DAT, and this value was statistically at par to the omission of S, Zn, K, and P in both the years of experimentation. The same pattern was observed when considering the average values across both seasons. Similar observations on effect of nutrient omission on LAI were also reported by several workers (Shankar *et al*., 2021).

Yield attributes

The omission of major plant nutrients along with micronutrients had a significant impact on yield parameters such as number of tillers/m^2, number of panicles/m^2, spikelets/panicle, filled spikelets/panicle, percentage of filled spikelets, panicle length and test weight (Table 2). In both seasons, the treatment (T_1) that received 100% NPKZnS application exhibited the highest number of tillers per square meter at 60 DAT (290.6 and 284.5, respectively). The treatments omitting S and Zn showed comparable results to the highest number of tillers in both seasons. The observed outcome can be attributed to the significant role of nitrogen in promoting tillering in rice. N is recognized as a crucial nutrient that stimulates vegetative growth and influences the initiation and development of tillers. Research indicates that N deficiency in rice plants often leads to a reduction in tiller numbers, as the plant's capacity to generate new tillers is constrained by insufficient N levels. Additionally, P is essential for optimal tiller development (Wang *et al*., 2017). Micronutrients like Zn and S also contribute to the promotion of tillering in rice. The treatment receiving 100% NPKZnS application resulted in the highest number of panicles per square meter in both seasons. In the first season, the treatment with the highest number of panicles per square meter was comparable to the treatments omitting Zn and S, while in the sec-

Table 2. Effect of nutrient omission plot technique based nutrient management on yield attributes of *rabi* rice

Treatment	Panicles/m^2			Spikelets/panicle			Filled grains/panicle			Filled grains (%)			Panicle length (cm)			Test weight (g)		
	2021–22	2022–23	Mean	2021–22	022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean
100% (NPKZnS)	204.6^{a}	207.8^{a}	206.2^{a}	148.7^{a}	150.8^{a}	149.7^{a}	122.7^{a}	125.6^{a}	124.1^{a}	82.5	83.4	83.0	24.3^{a}	24.7^{a}	24.5^{a}	21.5	22.2	21.9
(-N)	140.4^{c}	137.5^{e}	139.0^{e}	127.0^{bc}	124.7^{cd}	125.9^{bc}	107.7^{bc}	109.2^{bc}	108.4^{cd}	84.9	87.5	86.2	19.0^{b}	19.2^{b}	19.1^{b}	20.7	20.5	20.6
(-P)	165.7^{b}	167.5^{cd}	166.6^{cd}	132.0^{bc}	135.6^{bc}	133.8^{b}	112.0^{abc}	115.6^{ab}	113.8^{abc}	85.0	85.6	85.3	21.0^{ab}	21.2^{ab}	21.1^{ab}	21.3	21.5	21.4
(-K)	165.3^{b}	163.8^{d}	164.6^{d}	134.0^{abc}	137.5^{abc}	135.8^{ab}	114.3^{abc}	111.6^{bc}	113.0^{bcd}	85.6	82.0	83.8	21.5^{ab}	21.1^{ab}	21.3^{ab}	21.2	20.8	21.0
(-Zn)	181.7^{ab}	183.5^{bc}	182.6^{bc}	138.7^{ab}	141.5^{ab}	140.1^{ab}	118.7^{ab}	120.5^{ab}	119.6^{ab}	85.7	85.2	85.5	23.2^{a}	23.5^{a}	23.4^{a}	21.6	21.7	21.7
(-S)	190.3^{a}	188.5^{b}	189.4^{ab}	136.7^{ab}	131.5^{bc}	134.1^{b}	116.7^{ab}	113.7^{ab}	115.2^{abc}	85.6	86.5	86.0	23.6^{a}	23.4^{a}	23.5^{a}	21.4	21.1	21.2
Control	110.3^{d}	108.8^{f}	109.6^{f}	118.7^{c}	115.2^{d}	116.9^{c}	103.7^{c}	101.2^{c}	102.4^{d}	88.0	88.2	88.1	18.7^{b}	18.5^{b}	18.6^{b}	20.2	20.1	20.1
SEm±	7.85	5.60	5.61	5.18	4.89	4.70	3.64	3.96	3.53	3.71	4.21	3.70	1.26	1.32	1.28	1.25	1.25	1.24
CD (P=0.05)	23.8	17.0	17.0	15.7	14.8	14.3	11.0	12.0	10.7	NS	NS	NS	3.8	4.0	3.9	NS	NS	NS

ond season, the treatment (T_1) outperformed the other treatments significantly. The treatment applying 100% NPKZnS recorded the highest number of spikelets per panicle in the first season. In the same season, the treatments omitting S, Zn, and K were statistically at par to the highest recorded value. Similar trends were observed in the second season and the overall mean, where the treatments omitting Zn and K were statistically comparable to the highest value. These findings are consistent with the studies conducted by Biswas *et al*. (2020). In the *rabi* season of 2021–22, the treatment that received 100% NPKZnS showed the highest number of filled spikelets per panicle. This result was statistically similar to all other treatments, except for the treatment where N was omitted and the control treatment. These two treatments had fewer filled spikelets per panicle compared to the other treatments. In the following *rabi* season of 2022–23, a similar trend was observed, where the treatment that omitted S, Zn, and P was statistically similar to the treatment with the highest recorded number of filled spikelets. The results also indicated that applying an ample dose of fertilizer was more effective than omitting important macronutrients and micronutrients. The control treatment had the lowest recorded value in both seasons. There were no significant variations observed in the percentage of filled spikelets among the different omission treatments in both seasons. However, the treatment that received 100% NPKZnS demonstrated some superiority over the other treatments. It is worth noting that the control treatment had the lowest percentage of filled spikelets, although the difference among the treatments was not statistically significant. These findings align with previous research conducted by Shwe *et al*. (2019). Regarding panicle length, both seasons and their mean analysis exhibited a similar trend. The treatment (T_1) that received all the nutrients displayed the highest panicle length, which was statistically similar to all treatments except the control treatment and the treatment with N omission. As anticipated, the control treatment had the lowest panicle length in both seasons. This decrease in panicle length could be attributed to nutrient deficiencies or imbalances, which can result in reduced panicle elongation, shorter panicles, and diminished yield potential. A similar trend to the percentage of filled grain was observed in the test weight of rice grains. The different treatments employed in the study did not show significant variations in both seasons. Test weight is a genetically influenced characteristic and, due to the implementation of distinct management practices, it does not exhibit substantial differences. These findings match up with previous findings from other studies (Bhakkar *et al*., 2022). In the case of rice, the harvest index did not show significant variations among the different nutrient omission treatments in both seasons. Conversely, the control treatment (no fertilizer) resulted in reduced harvest index due to low grain yields. Similar findings were observed by Bekele *et al*. (2022).

Productivity

Both the *rabi* seasons of 2021–22 and 2022–23 exhibited a similar pattern, where the treatment receiving 100% NPKZnS resulted in higher grain yields (4.97 t/ha and 4.81 t/ha, respectively). These values were statistically similar to the treatments with sulphur omission and Zn omission. Conversely, the control treatment, followed by the N omission treatment, yielded the lowest grain production in both seasons (2.20 t/ha and 2.12 t/ha, respectively). The mean analysis of grain yield also reflected a similar trend. The most likely explanation is that, the omission of specific macronutrients from the nutrient supply can disrupt the nutrient balance in the plant and significantly impact the grain yield of rice. Nutrient deficiencies, particularly N, P, and K, can limit plant growth, reduce the number of panicles, impair grain filling, and result in lower grain yield. In addition to macronutrients, micronutrients such as Zn and S also play a crucial role in rice productivity. Application of 100% NPKZnS resulted in the highest straw yield. In the first year, the treatments with S, Zn, and P omission were statistically similar to the highest value while during the second year, it was observed that the treatments with sulphur omission and Zn omission remained statistically similar to the highest value. The findings are in line with Biswas *et al*. (2020).

Nutrient uptake

The omission of nutrients had significant impacts on the nutrient uptake of rice, as shown in Table 4. It was observed that N and P uptake in the grain was higher than in the straw, while K, Zn, and S uptake in the straw was considerably greater than in the grain. Adequate crop nutrition played a crucial role in enhancing nutrient uptake in both the grain and straw of rice. In both seasons, treatment T_1 (100% NPKZnS) exhibited the highest uptake of N, P, K, Zn, and S in both the grain and straw. These values were significantly higher than those of all other treatments. In terms of K total uptake, treatment T_1 was statistically at par to the treatment with Zn and S omission in both seasons, and in terms of S total uptake, it was similar to the treatment with Zn omission in the *rabi* season of 2021–22. The control treatment without fertilizer application consistently had the lowest total nutrient uptake in both seasons. The data clearly indicated that applying an ample dose of fertilizer resulted in the highest nutrient uptake, which aligns with the findings of Sahu *et al*. (2017) and .

Agronomic efficiency

The treatment that received 100% of NPKZnS had the highest value of agronomic efficiency; this treatment was closely followed by the treatment that did not receive Zn or S compared to the other omitted treatment, they were better. Lower agronomic efficiency values were observed with omission treatments, presumably because adequate nutrient supply promotes better nutrient uptake, utilisation, and allocation, which in turn leads to improved agronomic efficiency. The results showed that providing an ample dose of fertilizer was conducive to improving AE. Shankar *et al*. (2020) made a similar observation.

Fertility status of soil after harvest of crop

The nutrient build up in post-harvest soil was signifi-

Table 3. Effect of nutrient omission plot technique based nutrient management on yield of *rabi* rice

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Biological yield (t/ha)			Harvest index (%)		
	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean
100% (NPKZnS)	4.97[a]	4.81[a]	4.89[a]	7.50[a]	7.61[a]	7.56[a]	12.5[a]	12.4[a]	12.4[a]	39.9	38.7	39.3
(-N)	3.15[d]	3.09[c]	3.12[c]	5.12[cd]	4.96[cd]	5.04[cd]	8.3[cd]	8.1[c]	8.2[c]	38.0	38.3	38.1
(-P)	3.93[c]	3.76[bc]	3.85[b]	6.27[abc]	6.32[b]	6.30[b]	10.2[bc]	10.1[b]	10.1[b]	38.5	37.2	37.9
(-K)	4.00[bc]	3.90[bc]	3.95[b]	5.95[bc]	6.02[bc]	5.99[bc]	9.9[bc]	9.9[b]	9.9[b]	40.3	39.5	39.9
(-Zn)	4.74[ab]	4.72[a]	4.73[a]	7.13[ab]	7.24[ab]	7.19[ab]	11.9[ab]	12.0[a]	11.9[a]	39.9	39.5	39.7
(-S)	4.68[abc]	4.55[ab]	4.61[a]	7.04[ab]	6.96[ab]	7.00[ab]	11.7[ab]	11.5[a]	11.6[a]	40.0	39.5	39.8
Control	2.20[e]	2.12[d]	2.16[d]	4.10[d]	4.06[d]	4.08[d]	6.3[d]	6.2[d]	6.2[d]	35.6	34.8	35.2
SEm±	0.18	0.26	0.19	0.40	0.40	0.40	0.44	0.45	0.43	2.04	2.52	2.18
CD (P=0.05)	0.5	0.8	0.6	1.2	1.2	1.2	1.3	1.4	1.3	NS	NS	NS

Table 4. Effect of nutrient omission plot technique based nutrient management on nutrient uptake of *rabi* rice

Treatment	Total N uptake (kg/ha)			Total P uptake (kg/ha)			Total K uptake (kg/ha)			Total Zn uptake (g/ha)			Total S uptake (kg/ha)		
	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean	2021–22	2022–23	Mean
100% (NPK ZnS)	98.8^{a}	99.9^{a}	99.4^{a}	28.9^{a}	31.8^{a}	30.3^{a}	123.6^{a}	126.5^{a}	125.0^{a}	781.8^{a}	782.0^{a}	781.9^{a}	27.0^{a}	27.3^{a}	27.1^{a}
(-N)	46.0^{d}	45.1^{d}	45.6^{d}	18.6^{d}	16.5^{e}	17.6^{e}	81.0^{c}	80.1^{c}	80.6^{c}	511.8^{c}	485.1^{c}	498.4^{c}	16.8^{c}	16.6^{c}	16.7^{d}
(-P)	70.7^{c}	67.0^{c}	68.8^{c}	18.9^{d}	17.1^{e}	18.0^{de}	98.6^{bc}	99.6^{b}	99.1^{b}	630.8^{bc}	629.0^{d}	629.9^{b}	21.3^{bc}	21.2^{b}	21.2^{bc}
(-K)	74.6^{bc}	75.8^{bc}	75.2^{bc}	21.3^{cd}	20.3^{d}	20.8^{cd}	83.2^{c}	79.5^{c}	81.3^{c}	597.9^{bc}	595.9^{bc}	596.9^{bc}	20.7^{bc}	21.4^{b}	21.0^{bc}
(-Zn)	84.6^{b}	84.1^{b}	84.4^{b}	26.6^{b}	27.6^{b}	27.1^{b}	110.6^{ab}	108.5^{ab}	109.5^{ab}	611.2^{bc}	591.7^{bc}	601.4^{b}	23.8^{ab}	23.5^{b}	23.6^{ab}
(-S)	83.0^{b}	80.7^{b}	81.8^{b}	24.1^{bc}	23.4^{c}	23.8^{c}	112.6^{ab}	110.3^{ab}	111.4^{ab}	666.9^{b}	638.4^{b}	652.7^{b}	18.6^{c}	18.0^{c}	18.3^{cd}
Control	33.2^{e}	29.5^{e}	31.3^{e}	11.0^{e}	9.4^{f}	10.2^{f}	54.2^{d}	51.4^{d}	52.8^{d}	304.8^{d}	287.8^{d}	296.3^{d}	10.3^{d}	9.0^{d}	9.7^{e}
SEm±	2.89	4.15	3.19	1.24	0.87	0.99	6.00	6.03	5.68	39.04	36.06	32.57	1.63	0.91	1.17
CD (P=0.05)	8.8	12.6	9.7	3.7	2.6	3.0	18.2	18.3	17.2	118.4	109.4	98.8	4.9	2.8	3.6

cant for N, P, K, Zn and S in the ample dose application plot over the respective nutrient omission plot (Table 5). The highest available content in soil was obtained with the omission of P in both the seasons and it was statistically at par with the omission of K, S and Zn in the *rabi* season of 2021-2022 and in the second season, i.e. *rabi* season of 2022–23 the highest recorded treatment was statistically at par with the omission of K. The lowest available N content in soil was recorded with the omission of N in both seasons. The available P content in soil was recorded at its maximum with the omission of N and it remained statistically at par with the omission of Zn, K and S during the first season. In the next season, it also remained statistically at par with the application of 100% NPKZnS along with K, Sand Zn. The lowest value was recorded with the control treatment in both seasons. The available K content in soil obtained the highest value with the omission of N during both seasons, and it was statistically at par with the omission of Zn, S, and P and the application of 100% NPKZnS in the first season and in the second season, it remained at par with the application of 100% NPKZnS. The control treatment recorded the lowest soil available K content in both seasons. The available Zn content in soil was significantly higher with the omission of N followed by omission of P and S in the first season and it remained statistically at par with the omission of P, K, S and 100% NPKZnS application during the second season.

The control treatment obtained the lowest available Zn in the soil. The available S content in soil was recorded at its maximum with the omission of N and it remained statistically at par with the application of 100% NPKZnS in the first year of cultivation. It also remained statistically at par with the omission of Zn in the second year of cultivation. For both seasons, the lowest available S content in the soil was recorded in the control treatment. The application of balanced nutrients increased the availability of nutrients in post-harvest soil. However, there was a decline in the available nutrient status in the nutrient omitted and control plots. This might be due to higher nutrient uptake in balanced nutrient applied plots compared to the unfertilized control plot. The data corresponds to the findings of Tripathi *et al*. (2018), Singh *et al*. (2021).

Based on the findings of present study, plot received 100% of NPKZnS (T_1) recorded the significant improvement of plant height by 51.2%, DMA by 98.9%, LAI by 54.8%, number of tillers/m^2 by 40.9%, number of panicles/m^2 by 88%, spikelet/spike by 28%, filled grain/penicle by 21.6% and grain yield by 126.4% as compared to the control plot. Similarly, maximum nutrient uptake, protein yield, agronomic efficiency and soil health was noticed with the application of 100% of NPKZnS as compared to the control plot. Thus, the integrated nutrient application represented by T_1 is a viable and sustainable nutrient management practice for enhancing *rabi* rice productivity in Odisha and similar agro-ecological zones. This approach not only improves growth and yield attributes but also optimizes nutrient uptake, supporting sustainable intensification of rice production in the region.

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