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Effect of nitrogen fertilization and soil amendments on nutrient uptake by rice

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Abstract
The experiment was conducted during *Kharif* - 2022 and *Kharif* - 2023 to study the nutrient uptake by rice influenced by nitrogen fertilization and soil amendments in lateritic soil. The experiment was laid out in factorial randomized block design with two factors. The first factor comprised of 100 kg N ha^{-1} through Urea, 100 kg N ha^{-1} through Ammonium Sulphate, 100 kg N ha^{-1} through Calcium Nitrate, 100 kg N ha^{-1} through 16:16:16 (50% Ammonical and 50% Nitrate N), 100 kg N ha^{-1} through Vermicompost and RDN through Konkan Annapurna Briquettes along with control. However, second factor consisting Orthosilicic Acid 0.08% @ 15 kg ha^{-1}, Rice Husk Biochar @ 5 t ha^{-1} and Neem Cake @ 1 t ha^{-1} along with control. The experimental results indicate that, the nitrogen uptake by rice, significantly increased by application of RDN Konkan Annapurna Briquettes along with orthosilicic acid 0.08% @ 15 kg ha^{-1}. The phosphorous and potassium uptake by rice significantly improved by 100 kg nitrogen through 16:16:16 granular fertilizer along with orthosilicic acid 0.08% @ 15 kg ha^{-1}. The silicon and sulphur uptake by rice enhanced significantly by application of 100 kg N through urea along with orthosilicic acid 0.08% @ 15 kg ha^{-1}.

Keywords: Rice, nutrient, uptake, nitrogen, silicon, Biochar, Neem cake

Introduction

As a primary cereal crop, rice (*Oryza sativa* L.) serves as the fundamental dietary staple food for more than 50% of the global population. However, the dual pressures of a surging human population and environmental degradation have placed global food security under significant strain. Consequently, maximizing rice productivity within the constraints of diminishing land and natural resources has become the paramount objective for modern agriculture.

In the context of Indian rice production, nitrogen (N) stands as a primary limiting factor, making its management crucial for crop success. Providing an optimal nitrogen supply is essential for robust plant development, as sub-optimal applications lead to stunted growth and significant yield losses. Nitrogen directly governs the formation of effective tillers and overall grain productivity by influencing key biochemical and physiological pathways. A deficit in this nutrient during critical growth stages restricts dry matter accumulation and interferes with grain filling, resulting in a higher proportion of unfilled grains.

Similarly, phosphorus (P) is a vital macronutrient that follows nitrogen in importance for maximizing yields. Phosphorus is a fundamental component of ATP, fueling essential processes such as photosynthesis, protein synthesis, and nutrient transport (Yuan, 2002) [3]. Because both excessive and insufficient applications of N and P can negatively impact grain quality and yield, precise nutrient management is imperative. Therefore, determining the ideal application rates for these nutrients is necessary to ensure sustainable, environmentally friendly, and economically viable rice cultivation (Moro *et al*., 2008) [4].

Despite the heavy application of chemical fertilizers by farmers, rice systems often suffer from poor nutrient recovery. This inefficiency is largely attributed to nitrogen loss through volatilization and leaching (Zhu and Chen, 2002) [5]. The rising cost and environmental footprint of these fertilizers necessitate a shift toward more sustainable practices. Utilizing organic inputs like poultry manure and vermicompost can bridge the nutrient gap while restoring soil quality. By promoting an equilibrium between restorative and degenerative soil processes, various soil amendments provide a sustainable alternative that secures both productivity and soil vitality.

As the second most prevalent element in the Earth's crust, silicon (Si) is vital for improving crop yields and providing resistance against both biological and environmental stressors (Jawahar & Vaiyapuri, 2013) [6]. In cereal production, Si is particularly valued for its ability to reduce lodging. By increasing leaf erectness and reinforcing air canals, silicon optimization enhances oxygen delivery to the roots and minimizes water loss via evapotranspiration. Research by Chanchareonsook *et al.* (2002) [7] indicates that combining Si with standard NPK fertilizers boosts tiller production in rice. Furthermore, Jawahar and Vaiyapuri (2013) [6] demonstrated that a specific application of 120 kg ha^{-1} of Si (via fly ash) alongside 45 kg ha^{-1} of sulfur significantly improves growth metrics, including plant height, leaf area index, and grain yield, ultimately leading to a higher benefit-cost ratio.

Biochar is a carbon-rich material produced with high temperature through the thermochemical conversion of biomass under low-oxygen conditions, a process known as pyrolysis. Preliminary research suggests that soil amendment with biochar significantly modifies soil physiochemical properties, offering a dual benefit of improved agricultural yields and mitigated greenhouse gas emissions. Specifically, empirical evidence indicates that biochar supplementation elevates soil organic carbon (SOC), the C/N ratio, and ammonium-nitrogen (NH_4) levels, while simultaneously reducing nitrate-nitrogen (NO_3-N) and lowering soil bulk density (Sun *et al.*, 2016) [8]. Zhang *et al.* (2017) noticed that biochar addition increased soil organic carbon, C/N, and NH_4^+-N and decreased soil bulk density and NO_3-N. Randolph *et al.* (2017) [10] discovered that incorporation of biochar in soil increased soil pH and improved water retention, electrical conductivity, aggregate stability, and micronutrient contents.

Neem seed cake, the solid byproduct of oil extraction from neem seeds, possesses a superior nutrient profile compared to traditional organic sources like sewage sludge or farmyard manure. Specifically, it contains higher concentrations of nitrogen (2-5%), phosphorus (0.5-1.0%), calcium (0.5-3%), magnesium (0.3-1%), and potassium (1-2%) (Radwanski and Wickens, 1981). Beyond its role as a nutrient-dense natural fertilizer, it is recognized for its inherent pesticidal characteristics (Soon and Bottrel, 1994) [12]. This unique combination of fertilizing and protective properties makes it a highly effective and preferred input in sustainable agriculture. Moreover, Parmar (1986) [13] reported that Neem seed cake exhibits the properties of insecticides, nitrification retardation and inhibiter of pesticide degradation. Neem seed cake admixed with urea fertilizer significantly improves efficiency of fertilizer utilization in crop production by radual release of nitrogen to crops (Ketkar, 1983) [14].

In this study, we aimed to determine the effects of different nitrogen fertilizers along with various soil amendments on yield as well as nutrient uptake by rice.

The results of this study helps to establish sustainable cropping system which support crop yield as well as soil fertility.

Material and Methods

The impact of different nitrogen fertilizers along with different soil amendments on yield as well as nutrient uptake by rice was evaluated in lateritic soils of Konkan region of Maharashtra. The experiment was conducted at Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.

The field experiment consisted of two successive field trial which were conducted at the research farm Department of Soil Science and Agricultural Chemistry, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli during *Kharif* - 2022 and *Kharif* - 2023, respectively. The experiment was laid out in Randomized Block Design with two factors which comprising 28 treatment combinations. The treatments indicating different nitrogenous fertilizers were applied at recommended dose consisted first factor whereas another comprised from different soil amendments. The details of treatments and notations are described in table 1.

Table 1A: Nitrogen Sources

Symbols	Nitrogen Source
N_0	Control
N_1	100 kg N ha^{-1} through Urea
N_2	100 kg N ha^{-1} through Ammonium Sulphate
N_3	100 kg N ha^{-1} through Calcium Nitrate
N_4	100 kg N ha^{-1} through 16:16:16 (50% Ammonical and 50% Nitrate N)
N_5	100 kg N ha^{-1} through Vermicompost
N_6	RDN through Konkan Annapurna Briquettes

Table 1B: Mitigation Sources

Symbols	Mitigation Source
M_0	Control
M_1	Orthosilicic Acid 0.08% @ 15 kg ha^{-1}
M_2	Rice Husk Biochar @ 5 t ha^{-1}
M_3	Neem Cake @ 1 t ha^{-1}

The 100 kg N ha^{-1} through different treatments was applied in three splits 40% at the time of transplanting, 40% at tillering stage and 20% at panicle initiation stage of rice; whereas, application of soil amendments was carried out at the time of transplanting. However, 50 kg P ha^{-1} and 50 kg K ha^{-1} was applied as basal at the time of transplanting. The vermicompost @ 4 ton ha^{-1} applied at the time of transplanting of rice.

The Karjat - 3 rice variety selected as test crop grown for one month on nursery bed. The well grown healthy seedlings transplanted at the spacing of 20 x 15 spacing into well puddled soil. The crop was harvested after attaining maturity; grains were threshed, cleaned, sun dried and recorded for weight treatment wise separately. After separation of grains the straw from each plot sun dried and weighted.

The straw and grain samples of rice were collected at harvest stage were oven dried and ground into fine powder. The processed samples were subjected to the analysis of individual nutrient composition viz. nitrogen, phosphorous, potassium, silicon, sulphur as well as micronutrients viz. zinc, copper, iron and manganese. The methods used for plant analysis were described in table 2.

Table 2: Methods used for plant analysis

Sr. No.	Properties	Name of method	Reference
a.	Total nitrogen	Micro-Kjeldahl method	Tandon (1993)
b.	Total phosphorous	Vanadomolybdate yellow colour method	Tandon (1993)
c.	Total potassium	Flame photometry	Tandon (1993)
d.	Total sulphur	Turbidimetric method	Chesnin and Yien (1950)
e.	Total silicon	Rapid micro-determination method	Korndorfer *et al.* (2001)

a) Nutrient Uptake

For calculating nutrient uptake, dry matter weight was multiplied representative nutrient content in grain. In addition to this similarly nutrient uptake of straw was also calculated.

$$\text{Nutrient Uptake for Macronutrient} = \frac{\text{Nutrient Content (\%) x Yield (kg /ha)}}{100}$$

Result and Discussion

Effect on Nitrogen Uptake

Data on nitrogen uptake by rice as influenced by nitrogen sources and mitigation source applications during the years 2022 and 2023 are presented in table 1 The application of nitrogen sources showed a significant effect on nitrogen uptake by rice grain during both the year 2022 and 2023; observed highest (64.74 and 66.97 kg ha^{-1}) under N_6 treatment application indicating RDN through Konkan Annapurna Briquettes. In the year 2022, straw nitrogen uptake ranged from 18.20 to 47.17 kg ha^{-1}, with N_6 (RDN through Konkan Annapurna Briquettes) recorded the highest uptake (47.17 kg ha^{-1}), whereas, during the year 2023, straw uptake observed highest under treatment N_1 (37.05 kg ha^{-1}). The total nitrogen uptake by rice varied significantly under different nitrogen sources. The highest uptake recorded under N_6 treatment comprising RDN through Konkan Annapurna Briquettes (111.90 and 102.48 kg ha^{-1} during the year 2022 and 2023) for both year of experimentation.

The application of different mitigation sources showed a significant effect on nitrogen uptake by grain, the M_1 treatment consisting of orthosilicic acid @ 0.08% at 15 kg ha^{-1} recorded significantly superior nitrogen uptake by grain (58.27 and 58.08 kg ha^{-1}) over rest of the mitigation sources during the year 2022 and 2023, respectively. The application of M_1 treatment was found to be significantly superior in nitrogen uptake by straw, recording 40.42 and 31.81 kg ha^{-1} during the year 2022 and 2023, respectively. The highest total nitrogen uptake (98.69 and 89.89 kg ha^{-1}) by rice was achieved by orthosilicic acid @ 0.08% at 15 kg ha^{-1} (M_1) and evidenced superior over the rest of the treatments during the year 2022 and 2023, respectively.

The interaction between nitrogen and mitigation sources observed non-significant regarding nitrogen uptake by rice during both the years of experimentation.

The glance look at the data revealed that, the nitrogen uptake was strongly influenced by Konkan Annapurna Briquettes. This is probably due to, the slow and steady supply of nitrogen throughout the crop growth stages through Konkan Annapurna Briquettes which improved the nitrogen content in grain and straw. Similar results were recorded by Darade and Bankar, 2009; Roy *et al.* (2018); Patil *et al.* (2025) [19, 20, 21]. The enhanced nitrogen uptake of by silica application through orthosilicic acid might be due to synergistic effect between nitrogen and silica (Prakash *et al*. 2011) [26]. Similar results were stated by, Deren *et al.* (1994) [22].

Effect on Phosphorous Uptake

The data presented in table 4 showed that, the phosphorus uptake by rice grain ranged from 4.98 to 9.07 kg ha^{-1} and 4.85 to 9.18 kg ha^{-1} during the year 2022 and 2023 due to the application of various nitrogen sources (table 4). The treatment N_4 recorded the significantly highest phosphorus uptake by rice grain (9.07 and 9.18 kg ha^{-1}) during 2022 and 2023 respectively. In case of phosphorous uptake by rice straw the N_4 treatment remained the top-performing treatment (11.67 and 11.57 kg ha^{-1}), was statistically superior over remaining treatments. The total phosphorus uptake by rice showed a marked response to different nitrogen sources with treatment N_4 registering the significantly highest total phosphorus uptake (20.74 and 20.75 kg ha^{-1}) during the year 2022 and 2023.

The phosphorus uptake by grain was significantly influenced by the mitigation sources in both years, 2022 and 2023 (table 4.42). Among the mitigation sources, the application of orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) consistently recorded the highest phosphorus uptake by grain, with values of 7.32 kg ha^{-1} in 2022 and 7.31 kg ha^{-1} in 2023. The phosphorus uptake by straw was observed significant and recorded highest with orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1), recording 8.44 kg ha^{-1} in the year 2022 and 8.86 kg ha^{-1} in the year 2023. Similarly, the highest total uptake was recorded under orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) with values of 15.77 kg ha^{-1} in the year 2022 and 16.17 kg ha^{-1} in the year 2023.

The findings confirm the superior effectiveness of N_4 i.e. 16:16:16 $N:P_2O_5:K_2O$ fertilizer in maximizing overall phosphorus uptake in rice when compared to other nitrogen sources. The enhanced phosphorous content in grain and straw due to high supply of phosphorous in soil, was the probable reason behind highest uptake under this treatment. The similar results were quoted by Rao and Shukla, 1999; Mohapatra and Jee, 1993; Islam *et al.* (2011) [24, 25].

Prakash *et al.* (2011) [26] reported the highest phosphorous uptake by application of silicate fertilization. The application of orthosilicic acid influenced the yield as well as phosphorous content therefore recorded highest uptake of rice grain and straw.

Effect on Potassium Uptake

The potassium uptake by rice as affected by various nitrogen and mitigation sources during the year 2022 and 2023 is mentioned in table 5. The Grain uptake of potassium by rice showed significant variation in the year 2022 and 2023 and the highest grain uptake (23.68 and 23.43 kg ha^{-1}) was recorded with N_4 treatment application. In the year 2022, the highest straw uptake was observed under N_1 treatment (93.51 kg ha^{-1}), however during the year 2023, N_4 treatment recorded the highest uptake (88.93 kg ha^{-1}) by rice straw. The highest total potassium uptake recorded with N_1

treatment (116.75 kg ha⁻¹) in the year 2022. Similarly, during 2023, the N_4 treatment had the highest total uptake (112.36 kg ha⁻¹), which was statistically superior over the remaining treatments.

The grain potassium uptake by rice was influenced by mitigation sources during both the year 2022 and the year 2023. In the year 2022, orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) recorded the highest value for grain uptake. Similarly, in the year 2023, significantly highest grain uptake observed with M_1 treatment. The potassium uptake by straw ranged from 68.40 to 76.77 kg ha^{-1} and 59.19 to 68.20 kg ha^{-1}, with orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) being significantly superior during 2022 and 2023, respectively. The total potassium uptake was observed significantly highest (97.58 and 87.92 kg ha^{-1}), with orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) during the year 2022 and 2023 respectively.

The interaction between nitrogen and mitigation sources was non-significant during both the year of experimentation. The highest potassium uptake was found under 16:16:16 N: P2O5:K2O application, which increased potassium content in soil as well as plant, also reported the similar results; high potassium uptake by higher potassium application. Cuong *et al.* (2017) [2] noticed that application of the silicon increase potassium uptake in the rice. The increased potassium uptake might be due to synergistic effect between applied fertilizers and silicon in the soil system which increases availability of nutrient in the soil

Effect on Sulphur Uptake

Glimpses of data presented in table 6 observed that the sulphur uptake by rice grain was significantly influenced due to the nitrogen sources during the year 2022 and 2023 the grain sulphur uptake recorded highest due to N_1 treatment application. Similarly, the straw sulphur uptake showed a significant response with N_1 treatment application recorded significantly highest uptake during the year 2022, whereas in the year 2023, straw sulphur uptake .recorded significantly highest with N_2 treatment application. The total sulphur uptake by rice, varied significantly achieving the significantly highest uptake with N_1 treatment during both year of experimentation.

The sulphur uptake by rice grain was significantly influenced by different mitigation sources during both years of the study. In the year 2022 the application of orthosilicic acid @ 15 kg ha^{-1} (M_1) showed significantly highest value for grain uptake and the similar trend was observed during 2023. In both years, orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) recorded significantly higher straw uptake compared to other mitigation sources. The total sulphur uptake by rice showed significant improvement with M_1 treatment application which resulted highest uptake over mitigation sources during the year 2022 and 2023. The interaction effect remained non significance regarding sulphur uptake by grain, straw and total uptake by rice.

The results recorded that, silicon application significantly increased the uptake of sulphur; which is might be due to impact of silicon of physiological activities of rice which enhanced uptake of available nutrients from soil (Singh *et al*. 2006) [1].

Effect on Silicon Uptake

Data regarding the uptake of silicon by rice as affected by nitrogen and mitigation sources application mentioned in table 7. During the year 2022, the highest silicon uptake (66.57 kg ha^{-1}) by grains was observed with the application of N_1 (100 kg N ha^{-1} through urea) during the year 2022, However during the year 2023 the highest grain uptake (57.46 kg ha^{-1}) was seen in the N_6 treatment. The highest uptake by straw was recorded in N_1 treatment indicating 100 kg N ha^{-1} through urea (103.04 and 94.55 kg ha^{-1} during the year 2022 and 2023). The total silicon uptake by rice during the year 2022 was observed highest (169.61 kg ha^{-1}) by N_1 treatment and recorded superior. Similarly, during 2023, the highest value again found in treatment N_1 (106.69 kg ha^{-1}).

The mitigation sources significantly influenced grain silicon uptake in both the years of experimentation. The application of orthosilicic acid (M_1) consistently resulted in the highest grain uptake (73.24 kg ha^{-1} in the year 2022 and 66.86 kg ha^{-1} in the year 2023), indicating its superior ability to enhance silicon availability and absorption by rice grains. Similarly, the application of orthosilicic acid 0.08% @ 15 kg ha^{-1} (M_1) recorded the highest straw uptake of 116.49 kg ha^{-1} in the year 2022 and 105.85 kg ha^{-1} in the year 2023 as well as highest (189.73 kg ha^{-1} and 172.70 kg ha^{-1}) total uptake by rice.

The application of silicon and nitrogen reported synergistic for the content and uptake by the rice plants (Pati *et al*., 2018) [27]. It was reveals from the previous studies that application of silicon enhances the uptake of the silicon by the rice straw and grain. Increment in the silicon uptake due to silicon application was also reported by Cuong *et al*., 2017; Pati *et al*., 2018 and Singh *et al*., 2006 [2, 27, 1].

Table 3: Effect of different nitrogen and mitigation sources on nitrogen uptake (kg ha^{-1}) by rice

2022															
Treatments	**Grain Uptake**					**Straw Uptake**					**Total Uptake**				
	M_0	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**
N_0	26.79	38.92	27.49	30.08	30.82	17.05	21.12	16.38	18.24	18.20	43.84	60.04	43.86	48.32	49.02
N_1	53.98	75.77	45.74	61.60	59.27	36.13	52.83	45.28	42.44	44.17	90.11	128.60	91.02	104.03	103.44
N_2	34.90	43.07	36.40	34.67	37.26	17.91	30.03	20.55	26.24	23.68	52.80	73.10	56.95	60.91	60.94
N_3	47.70	68.86	49.33	59.48	56.34	32.81	49.51	33.22	41.95	39.37	80.51	118.37	82.56	101.44	95.72
N_4	50.82	67.51	55.90	61.11	58.83	31.92	43.32	39.96	33.19	37.10	82.73	110.83	95.86	94.30	95.93
N_5	33.10	41.21	32.09	38.51	36.23	24.90	28.85	25.16	25.75	26.17	58.00	70.06	57.26	64.26	62.39
N_6	58.71	72.58	62.06	65.59	64.74	41.42	57.27	41.44	48.54	47.17	100.13	129.85	103.51	114.13	111.90
Mean	43.71	58.27	44.15	50.15	49.07	28.88	40.42	31.71	33.76	33.69	72.59	98.69	75.86	83.91	82.76
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	3.58		2.71		7.16	2.44		1.85		4.88	5.00		3.78		10.01
C.D.@ 5%	10.38		7.85		NS	7.08		5.35		NS	14.52		10.97		NS
2023															
Treatments	**Grain Uptake**					**Straw Uptake**					**Total Uptake**				

	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean
N_0	28.82	37.87	32.08	33.83	33.15	16.08	22.75	16.15	19.65	18.66	44.90	60.62	48.23	53.49	51.81
N_1	62.40	71.94	65.53	61.33	65.30	33.10	41.77	34.58	38.74	37.05	95.50	113.71	100.11	100.07	102.35
N_2	33.80	46.49	40.67	39.11	40.02	19.41	24.55	20.78	22.75	21.87	53.21	71.04	61.46	61.87	61.89
N_3	57.01	62.87	57.48	56.85	58.55	28.14	32.37	30.17	31.47	30.54	85.15	95.24	87.65	88.32	89.09
N_4	53.52	68.00	56.67	55.98	58.55	26.35	36.32	29.94	31.43	31.01	79.88	104.32	86.61	87.42	89.56
N_5	39.63	48.78	42.19	44.51	43.78	16.87	23.25	23.74	21.96	21.45	56.50	72.03	65.93	66.47	65.23
N_6	61.86	70.59	63.56	71.87	66.97	31.87	41.69	32.67	35.79	35.51	93.73	112.29	96.23	107.66	102.48
Mean	48.15	58.08	51.17	51.93	52.33	24.55	31.81	26.86	28.83	28.01	72.69	89.89	78.03	80.75	80.34
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	1.87		1.42		3.75	1.30		0.98		2.60	2.52		1.90		5.03
C.D.@ 5%	5.43		4.11		NS	3.77		2.85		NS	7.30		5.52		NS

Table 4: Effect of different nitrogen and mitigation sources on phosphorous uptake (kg ha^{-1}) by rice

2022															
Treatments	**Grain Uptake**					**Straw Uptake**					**Total Uptake**				
	M_0	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**
N_0	4.91	5.79	4.38	5.32	5.10	5.52	7.18	6.13	6.48	6.33	10.43	12.97	10.51	11.81	11.43
N_1	6.58	7.98	5.92	6.52	6.75	9.00	10.31	9.31	8.74	9.34	15.58	18.29	15.23	15.26	16.09
N_2	4.50	5.51	4.40	5.52	4.98	5.95	6.54	5.62	5.44	5.89	10.45	12.05	10.01	10.96	10.87
N_3	6.29	7.58	6.08	7.12	6.77	7.58	9.30	7.72	7.33	7.98	13.87	16.88	13.79	14.45	14.75
N_4	7.79	10.64	8.81	9.06	9.07	11.33	13.07	11.03	11.24	11.67	19.12	23.70	19.84	20.30	20.74
N_5	4.97	5.94	5.46	5.06	5.36	4.94	5.24	5.08	5.71	5.24	9.91	11.18	10.54	10.78	10.60
N_6	6.01	7.83	6.63	6.94	6.85	7.84	7.47	7.21	7.42	7.48	13.85	15.30	13.84	14.37	14.34
Mean	5.87	7.32	5.95	6.51	6.41	7.45	8.44	7.44	7.48	7.70	13.32	15.77	13.40	13.99	14.12
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	0.45		0.34		0.91	0.39		0.30		0.79	0.44		0.33		0.88
C.D.@ 5%	1.31		0.99		NS	1.14		NS		NS	1.27		0.96		NS
2023															
Treatments	**Grain Uptake**					**Straw Uptake**					**Total Uptake**				
	M_0	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**
N_0	4.55	5.84	4.93	4.76	5.02	5.75	6.59	5.88	6.21	6.11	10.31	12.44	10.81	10.97	11.13
N_1	6.74	8.04	7.14	7.61	7.39	8.52	9.69	7.64	9.07	8.73	15.27	17.73	14.79	16.68	16.12
N_2	4.47	5.72	4.74	5.27	5.05	5.62	6.86	6.10	6.38	6.24	10.09	12.58	10.84	11.65	11.29
N_3	5.93	7.30	6.76	6.63	6.66	7.78	9.00	7.45	7.77	8.00	13.71	16.30	14.20	14.40	14.65
N_4	8.59	9.84	9.11	9.18	9.18	10.22	14.44	10.17	11.46	11.57	18.81	24.28	19.28	20.64	20.75
N_5	4.50	5.54	4.37	4.98	4.85	5.11	5.93	4.82	5.85	5.43	9.60	11.47	9.19	10.84	10.27
N_6	6.00	8.90	6.46	6.99	7.09	8.05	9.53	8.41	8.88	8.71	14.05	18.43	14.87	15.87	15.80
Mean	5.83	7.31	6.22	6.49	6.46	7.29	8.86	7.21	7.95	7.83	13.12	16.17	13.43	14.44	14.29
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	0.34		0.25		0.67	0.31		0.23		0.61	0.53		0.40		1.05
C.D.@ 5%	0.98		0.74		NS	0.89		0.67		NS	1.53		1.15		NS

Table 5: Effect of different nitrogen and mitigation sources on potassium uptake (kg ha^{-1}) by rice

2022															
Treatments	**Grain Uptake**					**Straw Uptake**					**Total Uptake**				
	M_0	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**
N_0	15.66	16.70	16.21	16.43	16.25	51.28	63.80	63.09	61.07	59.81	66.93	80.50	79.30	77.50	76.06
N_1	22.23	24.59	22.61	23.54	23.24	90.99	97.14	94.61	91.31	93.51	113.22	121.73	117.21	114.85	116.75
N_2	16.01	17.72	16.77	17.43	16.98	54.38	60.37	57.18	59.53	57.87	70.39	78.09	73.96	76.96	74.85
N_3	20.23	22.57	22.07	22.13	21.75	76.94	84.99	77.10	81.08	80.03	97.17	107.55	99.17	103.21	101.77
N_4	22.61	24.37	23.53	24.19	23.68	82.64	93.05	85.89	93.94	88.88	105.25	117.42	109.42	118.12	112.55
N_5	15.69	16.71	16.02	16.07	16.12	50.29	55.54	51.05	58.25	53.78	65.98	72.25	67.07	74.32	69.90
N_6	20.90	23.00	20.68	21.22	21.45	72.31	82.53	70.66	74.63	75.03	93.21	105.54	91.34	95.85	96.48
Mean	19.05	20.81	19.70	20.14	19.92	68.40	76.77	71.37	74.26	72.70	87.45	97.58	91.07	94.40	92.62
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	0.61		0.46		1.22	2.51		1.90		5.02	2.63		1.99		5.25
C.D.@ 5%	1.77		NS		NS	7.28		5.51		NS	7.62		5.76		NS
2023															
Treatments	**Grain Uptake**					**Straw Uptake**					**Total Uptake**				
	M_0	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**	**M_0**	**M_1**	**M_2**	**M_3**	**Mean**
N_0	14.05	15.82	15.02	15.49	15.10	47.96	56.43	47.00	53.34	51.18	62.02	72.26	62.02	68.83	66.28
N_1	20.84	22.21	21.29	21.84	21.55	70.33	78.39	74.34	75.62	74.67	91.17	100.60	95.63	97.46	96.22
N_2	14.60	16.34	15.37	15.49	15.45	48.67	53.79	50.12	51.58	51.04	63.27	70.13	65.48	67.06	66.49
N_3	20.07	21.61	20.97	20.08	20.68	63.19	79.59	65.07	69.51	69.34	83.26	101.20	86.04	89.58	90.02
N_4	22.37	24.78	22.92	23.63	23.43	83.31	94.91	90.73	86.76	88.93	105.68	119.69	113.66	110.39	112.36
N_5	14.74	15.97	14.80	15.38	15.22	40.87	46.71	42.47	44.07	43.53	55.61	62.68	57.27	59.45	58.75

N_6	19.26	21.29	19.71	19.86	20.03	60.03	67.57	61.71	61.18	62.62	79.29	88.86	81.42	81.05	82.65
Mean	17.99	19.72	18.58	18.82	18.78	59.19	68.20	61.63	63.15	63.04	77.18	87.92	80.22	81.98	81.82
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	0.35		0.26		0.69	1.61		1.22		3.22	1.64		1.24		3.28
C.D.@ 5%	1.00		0.76		NS	4.68		3.53		NS	4.76		3.60		NS

Table 6: Effect of different nitrogen and mitigation sources on sulphur uptake (kg ha^{-1}) by rice

2022															
Treatments	Grain Uptake					Straw Uptake					Total Uptake				
	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean
N_0	7.91	8.78	8.07	8.34	8.28	2.00	3.07	2.42	2.95	2.61	9.91	11.85	10.49	11.29	10.89
N_1	11.45	12.65	11.65	12.06	11.95	3.87	4.73	3.48	4.21	4.07	15.32	17.38	15.14	16.27	16.03
N_2	9.84	10.72	10.13	10.56	10.31	3.59	4.25	3.88	4.15	3.97	13.43	14.97	14.01	14.72	14.28
N_3	10.52	11.88	10.82	11.14	11.09	2.93	3.70	3.08	3.24	3.23	13.45	15.58	13.90	14.38	14.32
N_4	10.57	11.67	10.84	11.26	11.09	3.52	4.24	3.66	4.09	3.88	14.10	15.91	14.50	15.35	14.96
N_5	8.61	9.14	8.69	8.85	8.82	2.77	3.00	2.86	3.02	2.91	11.38	12.14	11.55	11.87	11.73
N_6	10.40	11.76	10.47	10.81	10.86	3.27	3.75	3.46	3.46	3.49	13.67	15.51	13.94	14.27	14.35
Mean	9.90	10.94	10.10	10.43	10.34	3.14	3.82	3.26	3.59	3.45	13.04	14.76	13.36	14.02	13.79
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	0.35		0.26		0.70	0.20		0.15		0.41	0.42		0.32		0.83
C.D.@ 5%	1.01		0.77		NS	0.59		0.45		NS	1.21		0.92		NS
2023															
Treatments	Grain Uptake					Straw Uptake					Total Uptake				
	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean
N_0	7.45	8.55	7.94	8.23	8.04	2.96	3.42	2.96	3.11	3.11	10.41	11.97	10.90	11.34	11.15
N_1	11.34	12.41	11.65	11.65	11.77	3.90	4.42	4.19	4.79	4.33	15.24	16.83	15.85	16.44	16.09
N_2	9.75	10.94	10.26	10.43	10.35	3.94	5.51	4.55	4.77	4.69	13.69	16.45	14.81	15.20	15.04
N_3	10.85	11.36	11.35	10.87	11.11	3.73	4.26	3.47	4.00	3.87	14.58	15.62	14.82	14.87	14.97
N_4	10.85	11.70	11.05	11.28	11.22	4.09	4.90	4.25	4.41	4.41	14.95	16.59	15.30	15.69	15.63
N_5	8.54	9.36	8.82	9.07	8.95	3.01	3.85	3.20	3.90	3.49	11.55	13.20	12.02	12.97	12.44
N_6	10.54	11.88	10.96	11.61	11.25	4.09	4.54	4.18	4.43	4.31	14.63	16.42	15.14	16.04	15.56
Mean	9.90	10.88	10.29	10.45	10.38	3.67	4.41	3.83	4.20	4.03	13.58	15.30	14.12	14.65	14.41
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	0.30		0.22		0.60	0.22		0.16		0.44	0.43		0.32		0.85
C.D.@ 5%	0.86		0.65		NS	0.63		0.48		NS	1.24		0.94		NS

Table 7: Effect of different nitrogen and mitigation sources on silicon uptake (kg ha^{-1}) by rice

2022															
Treatments	Grain Uptake					Straw Uptake					Total Uptake				
	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean
N_0	44.40	56.02	41.11	40.45	45.50	54.76	86.53	57.28	59.22	64.45	99.16	142.55	98.39	99.68	109.95
N_1	58.36	83.32	60.51	64.10	66.57	85.38	152.58	82.83	91.37	103.04	143.73	235.90	143.33	155.47	169.61
N_2	40.26	59.06	48.80	46.34	48.61	57.31	95.18	57.45	61.45	67.85	97.57	154.24	106.25	107.79	116.46
N_3	53.56	85.25	60.00	54.59	63.35	73.52	136.53	79.85	78.75	92.17	127.08	221.78	139.86	133.34	155.52
N_4	52.31	81.10	58.91	58.70	62.76	77.46	123.69	79.45	84.83	91.36	129.77	204.79	138.36	143.52	154.11
N_5	40.44	61.82	46.31	39.50	47.02	55.08	103.93	58.46	59.16	69.16	95.52	165.75	104.77	98.67	116.18
N_6	62.19	86.13	57.97	54.97	65.31	77.23	116.98	80.51	77.55	88.07	139.42	203.11	138.48	132.52	153.38
Mean	50.22	73.24	53.37	51.24	57.02	68.68	116.49	70.83	73.19	82.30	118.89	189.73	124.21	124.43	139.31
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	3.16		2.39		6.32	4.03		3.04		8.05	4.49		3.39		8.98
C.D.@ 5%	9.17		6.93		NS	11.68		8.83		NS	13.03		9.85		NS
2023															
Treatments	Grain Uptake					Straw Uptake					Total Uptake				
	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean	M_0	M_1	M_2	M_3	Mean
N_0	34.99	54.94	37.77	35.42	40.78	59.61	92.93	58.09	55.65	66.57	94.60	147.87	95.86	91.07	107.35
N_1	49.65	78.84	50.11	50.88	57.37	85.28	122.61	82.71	87.59	94.55	134.93	201.44	132.82	138.47	151.92
N_2	36.52	48.88	35.23	39.75	40.10	55.31	91.55	60.80	58.71	66.60	91.84	140.43	96.04	98.45	106.69
N_3	43.76	72.79	50.33	43.15	52.51	80.32	115.88	88.58	85.62	92.60	124.08	188.67	138.91	128.77	145.11
N_4	48.59	81.29	51.32	44.70	56.47	85.05	113.28	84.89	89.57	93.20	133.65	194.57	136.20	134.27	149.67
N_5	37.20	55.11	36.44	38.77	41.88	62.21	87.96	58.76	62.17	67.77	99.41	143.06	95.19	100.93	109.65
N_6	48.81	76.15	55.62	49.24	57.46	78.98	116.72	80.50	75.90	88.03	127.80	192.87	136.12	125.14	145.48
Mean	42.79	66.86	45.26	43.13	49.51	72.40	105.85	73.48	73.60	81.33	115.19	172.70	118.74	116.73	130.84
	N		M		N x M	N		M		N x M	N		M		N x M
S.E.±	2.14		1.62		4.28	3.80		2.87		7.59	4.55		3.44		9.11
C.D.@ 5%	6.21		4.70		NS	11.01		8.32		NS	13.21		9.99		NS

Conclusion

It is concluded from the data that, the nitrogen uptake by rice, significantly increased by application of RDN Konkan Annapurna Briquettes along with orthosilicic acid 0.08% @ 15 kg ha^{-1}. The phosphorous and potassium uptake by rice significantly improved by 100 kg nitrogen through 16:16:16 granular fertilizer along with orthosilicic acid 0.08% @ 15 kg ha^{-1}. The silicon and sulphur uptake by rice enhanced significantly by application of 100 kg N through urea along with orthosilicic acid 0.08% @ 15 kg ha^{-1}.

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