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Rice Growth and Production Response with Additional doses of Nitrogen and Sulfur Fertiliser in the Kashmir Valley

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rice is a nutritional staple food which provides instant energy as its most important component is carbohydrate (starch). It provides about 700 calories per day per person for about 3000 million people living mostly in developing countries. Nitrogen influences rice yield by playing a major role in photosynthesis, biomass accumulation and spikelet formation. Furthermore, excessive use of high-analysis fertilisers in the recent past for improved cultivars has led to nutrient imbalance in soil, particularly to the deficiency of secondary nutrients like sulphur. Realising the importance of sulphur and nitrogen on growth and yield in rice, a field experiment was conducted at the Crop Research Farm of the Division of Agronomy, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during *Kharif*, 2021. The soil of the experimental field was silt clay loam with neutral pH, low in available nitrogen, medium in phosphorus, potassium and organic carbon, however, sufficient in sulphur. The experiment consisted of two factors: Factor A being Nitrogen Levels (kg ha^{-1}) as Control, N_{60}, N_{80}, N_{120}, and Factor B being Sulphur Levels (kg ha^{-1}) as Control, S_{15}, S_{30}, S_{45} laid out in Factorial Randomised Complete Block Design with three replications. Plant height was recorded from the ground level to the tip of the tallest leaf during vegetative stages, and up to the tip of the tallest panicle at maturity. Economic analysis was performed based on prevailing input and output prices, computing gross return, net return, and benefit-cost ratio for each treatment. Significant variations in growth parameters, yield attributes, and yield were recorded among different levels of nitrogen and sulphur management practices under investigation. Significantly higher plant growth parameters, yield attributes, and yield were recorded in the 80 kg ha^{-1} level of nitrogen and the 30 kg ha^{-1} level of sulphur. Significant interaction was also seen between nitrogen (80kg N ha^{-1}) and sulphur (30kg S ha^{-1}) on panicle no m^{-2}, filled grains per panicle and grain yield. Among the various treatments, treatment combination N_2S_2 (80kg N ha^{-1} and 30 kg S ha^{-1}) revealed the highest B: C ratio of 2.23, followed by N_3S_3 (120kg N ha^{-1} and 45 kg S ha^{-1}) with a B: C ratio of 2.22. For the final recommendation, the experimental findings should be validated at other locations in the Kashmir valley. The reduced application will reduce losses of different forms of nitrogen to surface water, ground water and to the atmosphere.

Keywords: Rice; yield; nitrogen; sulphur; staple food.

1. INTRODUCTION

"Rice (*Oryza sativa* L.) is one of the important staple food crops for the world's population. More than 90% of the world's rice is produced and consumed in Asia. Although there are more than 110,000 cultivated varieties of rice that vary in quality and nutritional content, after post-harvest processing, rice can be categorised as either white or brown. Regional and cultural preferences, as well as the need for stability during storage and transport, are the final determinants of market availability and final consumption" (Fukagawa & Ziska, 2019). "Out of 782 million tonnes of global rice production from 167.1 million hectares, India produced 116.42 million tonnes in 44.5 million hectares" (FAO, 2020). "In Jammu and Kashmir, rice has been grown from immemorial times and stands as the principal staple food crop. The total rice area of the UT of Jammu and Kashmir is around 0.28 million hectares with a production and productivity of 0.55 million tonnes and 2.1 tonnes per hectare, respectively" (DES, 2018).

"Rice is a nutritional staple food which provides instant energy as its most important component is carbohydrate (starch). It provides about 700 calories per day per person for about 3000 million people living mostly in developing countries" (USDA 2020). "It is also used in the manufacturing of paper pulp and livestock bedding. According to a nutrient impact assessment, rice accounts for 715 kcal/capita/day in developing countries, 27% of dietary energy, about 20% of dietary protein, and 3% of dietary fat in developing countries. In certain South Asian regions, rice accounts for>50% of per capita dietary energy and protein, while 17–27% of dietary fat" (Sen et al., 2020). "The per capita food intake in India is 2234 calories per day, of which 30 per cent comes from rice only. Its protein is highly digestible with excellent biological values and protein efficiency ratio owing to the presence of a higher concentration (4%) of lysine" (Oko et al., 2012). Nitrogen and Sulphur both are involved in plant protein synthesis, a process that determines the crop yields. Nitrogen is the main factor to improve the rice grain nutritional quality, which positively affects the protein fraction of glutelin rich in essential amino acids (Mingotte et al., 2012) and is also involved in productivity (Fageria and Filho, 2010). Inadequate nitrogen application may limit rice productivity, resulting in nutrient deficiency symptoms such as chlorosis and reduced tillering (Akter et al., 2024). Sulphur fertilisation improves the nutrient uptake and fertiliser use efficiency of N, P, K and Zn because of the synergistic relationship of sulphur with these nutrients (Bisilki et al., 2021). Sulphur tends to increase the yield in cereals up to a certain limit (Ying-xing et al., 2017). “Nitrogen is considered the most yield-limiting nutrient in irrigated rice production around the world” (Samonte et al., 2006). “Nitrogen is the most limiting nutrient for rice crop growth and yield, which is required in higher amounts compared to other nutrients” (Djaman et al., 2018).

“Nitrogen is one of the most important plant nutrients and plays a vital role in plant photosynthesis and biomass production. Increasing panicle numbers per unit area is the main factor of yield increment as a result of nitrogen application” (Bindra et al., 2000; Laroo and Shivay, 2011). “Nitrogen influences rice yield by playing a major role in photosynthesis, biomass accumulation and spikelet formation” (Yoshida et al., 2006). Furthermore, excessive use of high-analysis fertilisers in the recent past for improved cultivars has led to nutrient imbalance in soil, particularly to the deficiency of secondary nutrients like sulphur. After N, P, and K, sulphur has long been acknowledged as the fourth most important nutrient for plants. According to Prasad (2004), sulphur is moving up from fourth to third on the list of essential nutrients in India. Both inorganic and organic forms of sulphur are found in soils, with organic sulphur accounting for more than 93% of all sulphur in soils from humid and semi-humid locations. However, depending on the kind of soil and sampling depth, there are significant differences in the percentage of inorganic and organic sulphur in a soil sample. Sulfate-S is continuously present in soil solution at very low concentrations, depending on the balance of S plant uptake, fertiliser input, immobilisation, and mineralisation at any given time (Balik et al., 2009). Realising the importance of sulphur and nitrogen on growth and yield in rice, the study was conducted during 2021.

2. MATERIALS AND METHODS

The present investigation was conducted at the Agronomy Research Farm, Faculty of Agriculture, Wadura (Sopore), Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, during the *kharif* season of 2021. The experimental site is situated in the temperate zone between 34º35/ N latitude and 74º40/ E longitude at an altitude of 1584 meters above mean sea level. The region falls under the mid-altitude temperate agro-climatic zone, characterised by hot summers and extremely cold winters. The area receives an average annual precipitation of 812 mm (20-year average), primarily during winter and early spring in the form of snow and rain.

The soil of the experimental field was classified as silty clay loam, with medium levels of available phosphorus, potassium, sulphur, and organic carbon, but low in available nitrogen. The experiment was laid out in a factorial randomised complete block design (FRBD) with three replications, including graded levels of nitrogen and sulphur.

Plant height was recorded from the ground level to the tip of the tallest leaf during vegetative stages, and up to the tip of the tallest panicle at maturity. The height was calculated as the average of five randomly selected hills per treatment. For dry matter accumulation, five hills were sampled at 15-day intervals, sun-dried for 3–4 days, and then oven-dried at 60–65°C for 48 hours until a constant weight was achieved. The dry weight was expressed in q ha^{-1}. Leaf area index was recorded at 15-day intervals using a canopy analyser (AccuPAR LP-80, Decagon Devices, USA) from five representative hills. Panicle density was assessed by counting the number of panicles within a 0.25 m^2 quadrant per plot and extrapolated to per square meter. Panicle length was measured from the neck node to the tip of six randomly selected panicles. Similarly, spikelets and filled grains per panicle were counted from six panicles and averaged. Grain samples were dried and used to determine 1000-grain weight. Grain yield (kg/plot) was recorded post-threshing and converted into t ha^{-1}. Straw yield was calculated by subtracting grain yield from the total biological yield. Economic analysis was performed based on prevailing input and output prices, computing gross return, net return, and benefit-cost ratio for each treatment.

3. RESULTS AND DISCUSSION

3.1 Plant Height (cm)

The data revealed that the graded levels of nitrogen and sulphur had a significant effect on the periodic plant height of rice (Table 1). Among different treatments of nitrogen levels, 120 N ha^{-1} recorded significantly taller plants at different growth stages (15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at harvest) compared to no application of nitrogen N_0 and 60 N kg ha^{-1} (N_{60}) and was at par to 80 kg N ha^{-1} (N_{80}) application. However, at different growth stages of 75 DAT, 90 DAT, 105 DAT and at harvest, 120 kg N ha^{-1} recorded taller plants. Sulphur application of 45 kg S ha^{-1} (S_{45}) recorded taller plants compared to 15 kg S/ha (S_{15}) and no application of sulphur (Table 1) at all growth stages. However, 45kg S/ha (S_{45}) and 120kg N/ha (N_{120}) applications recorded significantly taller plants than 30 kg S ha^{-1} (S_{30}) application at all growth stages (15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at harvest). Significant effect on increased plant height of rice with higher rates of nitrogen may be attributed to the fact that nitrogen, being an essential constituent of plant tissue, favours rapid cell division and enlargement. These results are in accordance with the findings of Dahipahle and Singh (2018), Balasubramanian (2002) and Walker et al. (2008).

3.2 Leaf Area Index

The data pertaining to leaf area index is presented in Table 2 and the results of the reveal that higher levels of nitrogen application (80 kg N/ha and 120 kg N/ha) significantly recorded higher leaf area index compare to lower doses of N application and this may be attributed to optimum availability of nitrogen at higher doses and higher photosynthetic rate, that leads to better development of LAI. Further, it was recorded that 120 kg N ha^{-1} was at par with 80 kg N ha^{-1}. The lowest LAI was recorded under N_0 treatment, where no nitrogen was applied (0 kg N ha^{-1}). It was possibly due to the poor plant height with no application of nitrogen. Almost the same finding was reported by Gupta et al. (2011) and Uddin et al. (2013)**.** The results of the present study also indicated that at all the growth stages of the crop, application of 45 kg S ha^{-1} recorded the highest LAI as compared to the rest of the treatments, while at par with 30 kg S ha^{-1}. This indicated that higher levels of sulphur application at 45 kg S ha^{-1} and 30 kg S ha^{-1} helped to better develop of leaf area index. An increase in the functional leaf area of rice due to the application of 'S' has been reported by Sumathy et al*.* (1999) and Martin et al*.* (2010).

3.3 Yield Attributes

The significant yield contributing characters, namely*,* number of panicles m^{-2}, panicle length, spikelets $panicle^{-1}$, number of filled grains $panicle^{-1}$ and 1000 grain weight, displayed substantial variation due to the effect of different doses of nitrogen and Sulphur (Table 3). The application of 60 kg N ha^{-1} and no application (control) resulted in suggestively lower numbers of panicles m^{-2} and significantly lower panicle length, spikelets $panicle^{-1}$, number of filled grains per panicle and test weight. These characters were improved with the corresponding increase in nitrogen levels from 80 to 120 kg N ha^{-1} being the maximum with 120 kg N ha^{-1}. Though a significant increase in yield attributes was up to 80 kg N ha^{-1}. The decreased growth parameters of the rice plants under a lower dose of nitrogen, *i.e* and 60 kg N ha^{-1} and under no application were due to less availability of nitrogen from the soil, which has resulted in decreased yield attributing characters. However, the case was just opposite for the plots receiving nitrogen at

Table 1. Plant height (cm) of Rice as influenced by graded levels of nitrogen and Sulphur

Treatments	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	Harvest
N_0	23.68	37.53	54.81	78.47	92.24	98.93	99.98	100.07
N_{60}	26.25	43.47	61.98	85.13	98.07	107.03	108.64	109.12
N_{80}	28.08	46.93	67.95	91.52	105.31	113.19	115.96	116.60
N_{120}	30.33	48.47	71.02	93.97	107.50	115.21	117.48	118.24
SE(m)±	0.57	0.40	0.72	0.63	0.76	0.80	0.78	0.83
CD(p≤0.05)	**1.64**	**1.16**	**2.10**	**1.82**	**2.02**	**2.12**	**2.03**	**2.41**
S_0	24.42	39.23	58.35	80.32	93.84	101.16	102.38	103.09
S_{15}	26.17	43.67	62.50	85.59	98.49	106.96	108.72	108.80
S_{30}	28.08	45.58	66.95	91.65	103.77	111.89	114.01	115.16
S_{45}	29.67	46.92	68.96	92.57	106.02	114.36	116.01	116.98
SE(m)±	0.57	0.40	0.72	0.63	0.76	0.80	0.78	0.83
CD(p≤0.05)	**1.64**	**1.16**	**2.10**	**1.82**	**2.02**	**2.12**	**2.03**	**2.41**

Table 2. Leaf area index of rice as influenced by different graded levels of nitrogen and sulphur

Treatments	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
N_0	0.13	0.45	1.50	3.83	2.89	2.31
N_{60}	0.16	0.53	1.83	4.01	3.07	2.55
N_{80}	0.21	0.64	2.13	4.39	3.56	3.07
N_{120}	0.23	0.74	2.29	4.57	3.75	3.19
SE(m)±	0.007	0.02	0.09	0.10	0.09	0.08
CD(p≤0.05)	**0.03**	**0.05**	**0.21**	**0.32**	**0.23**	**0.20**
S_0	0.11	0.44	1.51	3.84	2.87	2.32
S_{15}	0.14	0.51	1.80	4.02	3.04	2.52
S_{30}	0.20	0.63	2.14	4.34	3.58	3.09
S_{45}	0.22	0.72	2.25	4.53	3.72	3.17
SE(m)±	0.007	0.02	0.09	0.10	0.09	0.08
CD(p≤0.05)	**0.03**	**0.05**	**0.21**	**0.32**	**0.23**	**0.20**

the higher dose. The overall fact is that increasing levels of N significantly or non-significantly improved all the yield-attributing characters, which might be due to higher growth characters, increased accumulation of photosynthetic products from the source to the sink. Singh and Kumar (2014) and Tiwari et al. (2015) had also reported the response of rice crop to nitrogen in augmenting the yield attributing characters. The results of the present study also revealed that at all the yield attributing characters of the crop which received 45 kg S ha^{-1} recorded highest number of panicles m^{-2}, panicle length, spikelets $panicle^{-1}$, number of filled grains $panicle^{-1}$ and 1000-grain weight as compared to rest of the treatments and was at par with 30 kg S ha^{-1}. This could be attributed to the availability of Sulphur nutrient in soil, which increases these yield-attributing characters. The results are in conformity with the findings of Bhuvaneswari et al*.* (2007), Rahaman et al*.* (2007), Jawahar and Vaiyapuri (2010) and Martin Luther et al*.* (2010).

3.4 Interaction of Nitrogen and Sulphur on Panicle Number m^{-2}

The number of panicles m^{-2} was markedly influenced by the combined application of nitrogen and sulphur. The application rate of 120 kg N + 45 kg S ha^{-1} recorded the maximum number of panicle m^{-2} and was found to be at par with treatment 80 kg N + 30 kg S ha^{-1} (Table 4). This could be due synergistic effect of nitrogen and sulphur on growth and yield attributes (panicles m^{-2}), resulting in greater translocation of photosynthates from source to sink. The same findings were also reported by Ali et al*.* (2013).

3.5 Interaction of Nitrogen and Sulphur on Filled Grains per Panicle

Regarding nitrogen and sulphur level effect, increased rate of nitrogen and sulphur from 0 to 120 kg N ha^{-1} and 0 to 45 kg S ha^{-1} significantly enhanced the number of filled grains per panicle. The combined application rate of 120 kg N + 45 kg S ha^{-1} recorded the maximum number of filled grains per panicle and was found to be at par with treatment 80 kg N + 30 kg S ha^{-1} (Table 5). It is attributed to the greater availability of nitrogen and sulphur to the rice crop. Similar results have been obtained by Elwan et al., (2011) and Nongthombam et al. (2024). This might also be due to the fact that N and S supply was found to increase the photo assimilation of carbon and also promote assimilates to rice panicles. Same findings were also reported by Ahmed & Ahmad (2016), Yoon et al. (2012) and Tanweer et al. (2014).

3.6 Yield

The data presented in Table 6 revealed that N levels and S levels had a significant effect on grain yield, straw yield and biological yield of rice. The grain yield was recorded significantly higher under 120 kg N ha^{-1} as compared to other treatments, while statistically at par with 80 kg N ha^{-1}. This might be due to increased nutrient availability under these treatments, which might have resulted in better growth characters and yield contributing characters. Productivity of a crop is collectively determined by vigour of the vegetative growth, development, as well as yield attributes, which is the result of better translocation of photosynthates from the source to the grains. Similar results have been reported by Rao et al. (2014). The rice grain yield was

Table 3. Yield attributes of Rice as influenced by different graded levels of nitrogen and sulphur

Treatments	Panicle no m^{-2}	Panicle length(cm)	Spikelets / Panicle	Filled Grains / panicle	Sterility Percentage (%)	Test weight (g)
N_0	210.12	17.59	90.12	57.81	35.21	19.63
N_{60}	243.12	18.82	98.47	84.02	15.12	21.87
N_{80}	313.65	21.32	113.57	98.19	13.50	24.22
N_{120}	325.77	23.40	133.58	100.38	24.84	26.33
SE(m)±	2.94	0.71	1.86	1.76	2.51	1.05
CD(p≤0.05)	**8.52**	**2.05**	**5.41**	**5.12**	**7.28**	**3.09**
S_0	211.06	17.96	94.87	70.85	25.30	20.05
S_{15}	243.32	18.53	104.77	79.70	23.91	21.92
S_{30}	316.19	20.63	115.19	93.34	19.26	23.78
S_{45}	322.09	22.70	120.92	96.51	20.20	25.29
SE(m)±	2.94	0.71	1.86	1.76	2.51	1.05
CD(p≤0.05)	**8.52**	**2.05**	**5.41**	**5.12**	**NS**	**3.09**

Table 4. Interaction of nitrogen and sulphur on panicle number m^{-2} as influenced by nitrogen and sulphur

	S_0	S_{15}	S_{30}	S_{45}	Mean
N_0	158.50	181.45	247.71	252.83	210.12
N_{60}	162.70	221.87	289.97	297.92	243.12
N_{80}	258.98	274.66	355.83	365.13	313.65
N_{120}	264.05	295.29	371.26	372.46	325.77
Mean	211.06	243.32	316.19	322.09	

Factors	CD(p≤0.05)	SE(m)
Factor A (Nitrogen)	**8.52**	2.94
Factor B (Sulphur))	**8.52**	2.94
Factor (A X B)	**17.05**	5.88

Table 5. Interaction of nitrogen and sulphur on filled grains per panicle

	S_0	S_{15}	S_{30}	S_{45}	Mean
N_0	53.88	55.36	59.06	62.92	57.81
N_{60}	64.69	74.93	93.63	102.81	84.02
N_{80}	78.01	95.39	111.02	108.34	98.19
N_{120}	86.82	93.12	109.63	111.96	100.38
Mean	70.85	79.70	93.34	96.51	

Factors	CD(p≤0.05)	SE(m)
Factor A (Nitrogen)	**5.12**	1.76
Factor B (Sulphur))	**5.12**	1.76
Factor (A X B)	**10.24**	3.53

significantly influenced by different levels of sulphur. Application of sulphur at 45 kg ha^{-1} produced significantly higher grain yield as compared to other levels and was at par with treatment 30 kg S ha^{-1}. It is attributed to more panicle no, filled grains and the highest 1000 grain weight and these characters are correlated to yield and also increase the grain yield. Similar findings are also reported by Priyanka et al. (2013). Increase in yield due to sulphur fertiliser application could also be attributed to its important role in the synthesis of proteins and S-containing amino acids, as well as enhanced photosynthetic activity of the plant by increased chlorophyll synthesis.

Straw yield and biological yield were influenced significantly by different levels of nitrogen application (Table 6). Maximum straw yield and biological yield were recorded under 120 kg N ha^{-1} and were at par with treatment 80 kg N ha^{-1}. This might be due to higher plant height and hence increased dry matter production. Similar findings were reported by Kumar and Singh (1998). Straw yield and biological yield were influenced significantly by different levels of sulphur application. Maximum straw yield was recorded under 45 kg S ha^{-1} and was at par with treatment 30 kg S ha^{-1}. It is attributed to more plant height and more dry matter being accumulated in these treatments, which increased the straw yield of rice. The same findings were also reported by Kumar et al. (2012) and Priyanka et al. (2013). The biological yield was recorded as highest in treatment 45 kg S ha^{-1} and was at par with treatment 30 kg S ha^{-1}. It is attributed to more grain and straw yield, which ultimately increased the biological yield. These results are in conformity with Priyanka et al. (2013) and Tanweer et al. (2014).

Harvest index was influenced significantly due to different nitrogen levels (Table 6). The higher harvest index was recorded with 80 kg N ha^{-1} (45.06 %), due to a higher grain yield of rice per unit biological yield, which led to a higher harvest index. The results are in conformity with Choubey et al. (2018). The maximum harvest Index was recorded in treatment 45 kg S ha^{-1} and was at par with treatment 30 kg S ha^{-1}. It is attributed to more economic yield was recorded in these treatments; the harvest index shows the physiological efficiency of plants to convert the fraction of photo-assimilation to grain yield. The higher the harvest index is, the greater the grain yield of the crop will be. The same findings were also reported by Ponnamperuma and Deturck (1993).

Table 6. Yield of rice as influenced by different levels of nitrogen and sulphur

Treatments	Grain Yield t/ha	Straw Yield t/ha	Biological Yield t/ha	Harvest Index
N_0	3.35	6.03	9.38	35.81
N_{60}	5.49	7.57	13.07	41.67
N_{80}	7.69	9.11	16.80	45.06
N_{120}	7.86	10.63	18.50	42.77
SE(m)±	0.35	0.51	0.69	1.86
CD(p≤0.05)	**1.02**	**1.48**	**1.99**	**5.39**
S_0	4.46	6.46	10.92	40.34
S_{15}	5.61	8.04	13.65	40.95
S_{30}	6.81	9.26	16.07	41.57
S_{45}	7.52	9.59	17.10	43.14
SE(m)±	0.35	0.51	0.69	1.86
CD(p≤0.05)	**1.02**	**1.48**	**1.99**	**NS**

Table 7. Interaction of nitrogen and sulphur on Grain Yield t ha^{-1}

	S_0	S_{15}	S_{30}	S_{45}	Mean
N_0	3.08	3.11	3.46	3.72	3.34
N_{60}	3.45	4.33	6.54	7.64	5.49
N_{80}	4.74	6.80	8.93	10.30	7.69
N_{120}	6.56	8.20	8.28	8.39	7.86
Mean	4.46	5.61	6.80	7.51	
Factors		**CD(p≤0.05)**		**SE(m)**	
Factor A (Nitrogen)		**1.06**		0.35	
Factor B (Sulphur))		**1.07**		0.35	
Factor (A X B)		**2.03**		0.69	

Table 8. Relative economics of rice as influenced by nitrogen and sulphur

Treatments	COC	Gross	Net Returns	B.C
N_0S_0	44491.0	**56153.7**	11662.70	0.26
N_0S_1	44894.2	59206.3	14312.10	0.32
N_0S_2	45297.5	67231.7	21934.20	0.48
N_0S_3	45700.7	71161.7	25461.00	0.56
N_1S_0	44967.5	64044.3	19076.80	0.42
N_1S_1	45370.7	80312.7	34942.00	0.77
N_1S_2	45773.9	113024.7	67250.80	1.47
N_1S_3	46177.1	128261.0	82083.90	1.78
N_2S_0	45228.3	85939.2	40710.90	0.90
N_2S_1	45631.6	117801.9	72170.30	1.58
N_2S_2	46034.8	148747.9	102713.10	**2.23**
N_2S_3	46438.0	147811.9	101373.90	2.18
N_3S_0	45750.0	111205.7	65455.70	1.43
N_3S_1	46153.3	140753.7	94600.40	**22. 2.05**
N_3S_2	46556.5	147173.3	100616.80	2.16
N_3S_3	46959.7	151910.3	104650.60	2.22

3.7 Interaction of nitrogen and sulphur on grain yield (t/ha)

"Regarding the interaction effect between nitrogen and sulphur on the grain yield of rice. The combined application of N with S increased, on average, the grain yield respectively, compared to the control (N_0S_0). The highest significant grain yield was obtained when nitrogen at 80 kg N ha^{-1} was combined with sulphur at 45 kg ha^{-1} (Table 7). This could be attributed due to the fact that sulphur is reported to enhance the photosynthetic assimilation of N in crop plants" (Anderson, 1990; Ahmad and Abdin, 2000). Hence, the application of N and S fertilisers increases the net photosynthetic rate in crop plants, which in turn increases their dry matter and grain yield, as 90% of the plant's dry weight is considered to be derived from products formed during photosynthesis People et al. (1980).

3.8 Relative Economics

The efficiency of a treatment or a combination of treatments is finally decided in terms of the economics (benefit: cost) of the treatments. The cost of cultivation was registered highest (46959.7 Rs ha^{-1}), respectively, with the application of 120 kg N + 45 kg S ha^{-1} (Table 8). This is attributed to the high dose of fertilisers and labour costs. The net returns and B: C ratio increased with increasing levels of nitrogen and sulphur. The maximum net returns (104650.60 Rs ha^{-1}) were recorded under treatment N_3S_3 (120 kg N + 45 kg S ha^{-1}), and the maximum B: C ratio (2.23) was recorded under treatment N_2S_2 (80 kg N + 30 kg S ha^{-1}) and was statistically at par with treatment N_3S_3. The higher benefit cost ratio in the case of application at 80 kg N +30 kg S ha^{-1} is due to lower cost of cultivation, low cost of fertilisers and also due to higher grain and straw yield in the above treatments. The combined application of nitrogen and sulphur increases the grain yield, straw yield, and quality, which ultimately increases the gross returns and net returns. The results were in line with the results of Jeet et al. (2013).

4. CONCLUSION

The existing recommended dose of nitrogen in rice variety 'Shalimar rice-4' is 120 kg N ha^{-1} in Kashmir valley. From the findings of present study the nitrogen dose can be reduced to 80 kg N ha^{-1} with 30 kg S ha^{-1}, results in 33 percent saving of nitrogen in rice. However, for final recommendation, the experimental findings should be validated on other location of Kashmir valley. The reduced application will reduce losses of different forms of nitrogen to surface water, ground water and to atmosphere.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Ahmed, M., & Ahmad, S. (2016). Climate variability impact on rice production: adaptation and mitigation strategies. In *Quantification of climate variability, adaptation and mitigation for agricultural sustainability* (pp. 91-111). Cham: Springer International Publishing.

Akter, M., Islam, S. M. M., Islam, M. N., Rahman, M. S., Islam, A., Khanam, M., Iqbal, M., & Islam, M. R. (2024). Optimizing rice yield and nutrient uptake: Investigating the interaction between nitrogen and potassium in wet season rice cultivation. *Advances in Agriculture*, Article ID 4984165.

Ali, A., Iqbal, Z., Hassan, S. W., Yasin, M., Khaliq, T., & Ahmad, S. (2013). Effect of nitrogen and sulphur on phenology, growth and yield parameters of maize crop. *Sci. Int*, *25*(2), 363-366.

Balasubramanian, V., & Hill, J. E. (2002). Direct-seeding of rice in Asia: Emerging issues and strategic research needs for 21st century. In *Direct seeding: Research strategies and opportunities* (pp. 38). Proceedings of International Workshop on Direct-seeding in Asia Rice System, 25–28 January 2000, International Rice Research Institute, Los Baños, Philippines.

Balik, J., Kulhanek, M., Cerny, J., Szakova, J., Pavlikova, D., & Cermak, P. (2009). Differences in soil sulphur fractions due to limitation of atmospheric deposition. *Plant, Soil and Environment, 55*, 344–352.

Bhuvaneswari, R., Sriramachandrasekharan, M., & Ravichandran, M. (2007). Integrated use of farmyard manure and sulfur for the growth and yield of rice (*Oryza sativa* L.). *44*(2), 169–171.

Bindra, A. D., Kalia, B. D., & Kumar, S. (2000). Effect of nitrogen levels and dates of transplanting on growth, yield and yield attributes of scented rice. *Advance Agriculture Research, 10*, 45–48.

Bisilki, V., Dzomeku, I. K., Kugbe, J. X., Dogbe, W., Ofori, J. N., & Njomaba, E. (2021). Response of rice to sulfur and zinc applications under fallowed and continuously cropped soils in Northern Ghana. *International Journal of Plant & Soil Science, 33*(3), 1–20.

Choubey, A. K., Sinha, K. K., Pandey, I. B., & Singh, S. K. (2018). Effect of summer legumes on yield and nutrient uptake of succeeding direct-seeded rice (*Oryza sativa* L.) under different nitrogen levels. *Journal of Pharmacognosy and Phytochemistry, 7*(4), 701–703.

Dahipahle, A. V., & Singh, U. P. (2018). Effect of crop establishment, nitrogen levels and time of nitrogen application on growth and yield attributing parameters of direct seeded rice (*Oryza sativa* L.). *International Journal of Chemical Studies, 6*(2), 2889–2893.

Directorate of Economics and Statistics (DES), Ministry of Agriculture. (2018). http://eands.dacnet.nic.in

Djaman, K., Mel, V. C., Ametonou, F. Y., El-Namaky, R., Diallo, M. D., & Koudahe, K. (2018). Effect of nitrogen fertilizer dose and application timing on yield and nitrogen use efficiency of irrigated hybrid rice under semi-arid conditions. *Journal of Agricultural Science and Food Research, 9*(2), 223–231.

Elwan, M. W. M., & Abd El-Hamed, K. E. (2011). Influence of nitrogen form, growing season and sulfur fertilization on yield and the content of nitrate and vitamin C of broccoli. *Scientia Horticulturae*, *127*(3), 181-187.

Fageria, N. K., Soares Filho, W. S., & Gheyi, H. R. (2010). Melodramatic genético vegetable seleção de cultivares tolerantes à salinidade. In *Manejo da salinidade na agricultura: Estudos básicos e aplicados* (pp. 206–218). Fortaleza, INCT Sal.

Food and Agriculture Organization (FAO). (2020). *Food and Agriculture Organization of the United Nations*.

Fukagawa, N. K., & Ziska, L. H. (2019). Rice: Importance for global nutrition. *Journal of Nutritional Science and Vitaminology (Tokyo), 65*(Supplement), S2–S3.

Gupta, R. K., Singh, V., Singh, Y., Singh, B., Thind, H. S., Kumar, A., & Vashistha, M. (2011). Need-based fertilizer nitrogen management using leaf colour chart in hybrid rice (*Oryza sativa* L.). *Indian Journal of Agricultural Sciences, 81*(12), 1153.

Jawahar, S., & Vaiyapuri, V. (2010). Effect of sulphur and silicon fertilizers on growth and yield of rice. *International Journal of Current Research, 9*, 36–38.

Jeet, S., Singh, J. P., Kumar, R., Prasad, R. K., Kumar, P., Kumari, A., & Prakash, P. (2013). Effect of nitrogen and sulphur levels on yield, economics and quality of QPM hybrids under dry land condition of eastern Uttar Pradesh, India. *Indian Journal of Agriculture, 4*(9), 31–38.

Kumar, V. K., Singh, R. P., Sharma, A. K., & Singh, G. (2012). Impact of nitrogen, phosphorus, potash and sulphur on productivity of rice-wheat system in sub-humid region. *Journal of Agricultural Physics, 12*.

Laroo, N., & Shivay, Y. S. (2011). Effect of nitrogen and sulphur levels on growth and productivity of scented rice. *Current Advances in Agriculture Science, 3*(1), 45–48.

Martin, L. M., Narsa Reddy, S., & Veeraraghavaiah. (2010). Response of lowland rice to different sources and levels of sulphur fertilization in Andhra. *Agriculture Journal, 57*(1), 1–3.

Mingotti, G., Topputo, F., & Bernelli-Zazzera, F. (2012). Efficient invariant-manifold, low-thrust planar trajectories to the Moon. *Communications in Nonlinear Science and Numerical Simulation, 17*(2), 817–831.

Nongthombam, J., Gobi, R., Balasubramanian, A., & Sathiyamurthi, S. (2024). Impact of nitrogen, sulphur and silicon application on the growth and yield of lowland rice (*Oryza sativa* L.) in the Cauvery delta zone of Tamil Nadu. *Crop Research*, *59*.

Oko, A. O., Ubi, B. E., Efisue, A. A., & Dambaba, N. (2012). Comparative analysis of the chemical nutrient composition of selected local and newly introduced rice varieties grown in Ebonyi State of Nigeria. *International Journal of Agriculture and Forestry, 2*(2), 16–23.

Ponnamperuma, F. N., & Deturck, P. (1993). A review of fertilization in rice production. *International Rice Commission Newsletter, 42*, 1–12.

Prasad, R. (2004). Current status and strategies for balanced fertilization. *Fertilizer News, 49*(12), 73–80.

Priyanka, Sharma, G. D., Rana, R., & Lal, B. (2013). Effect of integrated nutrient management and spacing on growth parameters, nutrient content and productivity of rice under system of rice intensification. *International Journal of Research in Bio Sciences, 2*. ISSN 2319-2844.

Rahman, M. N., Islam, M. B., Sayem, S. M., Rahman, M. A., & Masud, M. M. (2007). Effect of different rates of sulphur on the yield and yield attributes of rice in old Brahmaputra flood plain soil. *Journal of Soil Nature, 1*(1), 22–26.

Rao, K. T., Rao, A. U., Sekhar, D., Ramu, P. S., & Rao, N. V. (2014). Effect of different doses of nitrogen on performance of promising varieties of rice in high altitude areas of Andhra Pradesh. *International Journal of Farm Sciences, 4*(1), 6–15.

Samonte, S. O. P., Wilson, L. T., Medley, J. C., Pinson, S. R. M., McClung, A. M., & Lales, J. S. (2006). Nitrogen utilization efficiency: Relationships with grain yield, grain protein, and yield-related traits of rice. *Agronomy Journal, 98*, 168–176.

Sen, S., Chakraborty, R., & Kalita, P. (2020). Rice – not just a staple food: A comprehensive review on its phytochemicals and therapeutic potential. *Trends in Food Science & Technology, 97*, 265–285.

Singh, D., & Kumar, A. (2014). Effect of sources of nitrogen on growth, yield and uptake of nutrients in rice. *Annals of Plant and Soil Research, 16*(1), 359–361.

Sumathy, N., Vaiyapuri, V., Srirama Chandra Sekharan, M. V., & Ravichandran, M. (1999). The effect of integrated use of green manure with S sources on the yield of rice (*Oryza sativa* L.). *36*(3), 268–269.

Tanweer Hussain, Malik, S. B., Lal, N. R., Wani, D. A., & Ahmad, W. R. (2014). Effect of different levels of nitrogen on growth and yield attributes of different varieties of Basmati rice (*Oryza sativa* L.). *International Journal of Scientific & Technology Research, 3*(3), 2277–8616.

Tiwari, S., Tiwari, K., Kumar, S., Zaidi, S. F. A., & Prakash, V. (2015). Response of rice to integrated nitrogen management under SRI method of cultivation. *Annals of Plant and Soil Research, 17*(1), 106–108.

Uddin, S., Sarkar, M. A. R., & Rahman, M. M. (2013). Effect of nitrogen and potassium on yield of dry direct seeded rice in aus season. *International Journal of Agronomy and Plant Production, 4*, 69–75.

United States Department of Agriculture (USDA). (2018). *Foreign Agricultural Service*. https://www.fas.usda.gov/data

Walker, T. W., Bond, J. A., Ottis, B. V., Gerard, P. D., & Harrell, D. L. (2008). Hybrid rice response to nitrogen fertilization for mid-southern United States rice production. *Agronomy Journal, 100*(2), 381–386.

Ying-xing, X. Z., Hui, Z., Yun-ji, Z., Li, Y., Jia-heng, C., Fei-na, L., Cao, W., Chen-yang, G., & Tian-cai, G. (2017). Grain yield and water use of winter wheat as affected by water and sulphur supply in the North China Plain. *Journal of Integrative Agriculture, 16*, 614–625.

Yoon, S. J., Yáñez, C., Bruns, M. A., Martínez-Villegas, N., & Martínez, C. E. (2012). Natural zinc enrichment in peatlands: biogeochemistry of ZnS formation. *Geochimica et Cosmochimica Acta*, *84*, 165-176.

Yoshida, H., Horie, T., & Shiraiwa, T. (2006). A model explaining genotypic and environmental variation of rice spikelet number per unit area measured by cross-locational experiments in Asia. *Field Crops Research, 97*(2–3), 337–343.

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