**Response of rice to graded levels of nitrogen and Sulphur in temperate Kashmir**

**Abstract**

Nitrogen is one of the most important plant nutrients and plays a vital role in plant photosynthesis and biomass production. Increasing panicle numbers in per unit area is the main factor of yield increment as a result of nitrogen application. The present study assesses the Response of rice to graded levels of nitrogen and sulphur in temperate Kashmir. A field experiment titled Response of rice to graded levels of nitrogen and sulphur in temperate Kashmir 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 the Kharif 2021 season. The experimental soil was silt clay loam with neutral pH; it was deficient in available nitrogen, medium in phosphorus, potassium, and organic carbon, but sufficient in sulphur. A factorial Randomised Complete Block Design with three replications was used, comprising two factors: nitrogen at 0, 60, 80 and 120 kg ha⁻¹, and sulphur at 0, 15, 30 and 45 kg ha⁻¹. Significant improvements were observed in dry‑matter accumulation, tiller count, nitrogen and sulphur uptake, agronomic efficiency, grain protein content, and protein productivity across treatments. The highest dry‑matter accumulation and tiller count were recorded under 120 kg N ha⁻¹ and 45 kg S ha⁻¹, though responses at 80 kg N ha⁻¹ were statistically similar. A significant interaction between 80 kg N ha⁻¹ and 30 kg S ha⁻¹ enhanced agronomic efficiency. The study concluded that balanced application of nitrogen and sulphur significantly enhanced rice growth, nutrient uptake, agronomic efficiency, and grain protein content.

***Keywords*:** Rice, Dry matter accumulation, tiller count, nitrogen, sulphur, interaction.

**Introduction**

“Nitrogen and Sulphur plays an imperative role in crop production and substantially impacts income and agricultural productivity. It is the most expansively used nutrient in rice crops and is required in greater amounts than other major nutrients” (Jehangir et al., 2022; Krishna et al., 2023). “Rice (*Oryza sativa* L**.)** is one of the important staple food crop for the world population. More than 90% of the world’s rice is produced and consumed in Asia. 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 is grown from immemorial 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). “Global rice crop production is being threatened by a frequent rise in high temperatures and drought. Drought and heat stresses adversely affect the morphological, physiological, and biochemical characteristics of rice, resulting in reduced crop productivity. Heat and drought stresses entail physiological changes in rice plants, such as stomata closure, reduced photosynthesis, loss of turgor adjustment, and reduction in crop productivity. These stresses also cause metabolic changes by increasing the activities of antioxidative enzymes, phytohormones, abscisic acid, reactive oxygen species, and reactive stress metabolites” (Salgotra & Chauhan, 2023).

“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. The per capita food intake in India is 2234 calories per day, of which 30 percent 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 also involves in productivity (Fageria *et al.,* 2010). Sulphur fertilisation improves the nutrient uptake and fertilizer use efficiency of N, P, K and Zn because of the synergistic relationship of sulphur with these nutrients. 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](https://www.tandfonline.com/doi/full/10.1080/24749508.2020.1742509)).

“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 spikelets 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). The present study assesses the response of rice to graded levels of nitrogen and sulphur in temperate Kashmir.

**Materials and methods**

The present investigation was carried out during the Kharif season of 2021 at the Faculty of Agriculture, Wadura (Sopore), Sher e Kashmir University of Agricultural Sciences and Technology of Kashmir. The experimental site is located in the temperate agro-climatic zone of Kashmir, lying at 34°35′ N latitude and 74°40′ E longitude, with an elevation of 1584 metres above mean sea level. The climate of the region is classified as mid-altitude temperate, characterised by hot summers and severe winters. The average annual precipitation is approximately 812 mm, based on 20 years of meteorological data, with the majority of rainfall and snowfall occurring between December and April.The soil of the experimental field was silty clay loam in texture. It tested medium in available phosphorus (P), potassium (K), sulphur (S), and organic carbon, but was low in available nitrogen (N). The soil pH was neutral, indicating a favourable environment for nutrient uptake and crop growth.

Five hills were cut from the base of the middle row randomly from each treatment at 15 days intervals and were sun drying for 3-4 days, the plant samples were then oven dried at 60- 650C for 48 hours to a constant value. The dry weight was recorded in grams and then converted into q ha-1. Tiller count was recorded from 15 DAT till harvest at 15 days intervals from 5 randomly tagged hills of each plot and subsequently the number was transformed to tillers per m-2. For the plant nutrient studies, plant samples collected at harvest were sun-dried and then packed in labelled long paper bags. These samples were put in an electric oven dried for 36 hours at 60-65oC temperature till constant weight was obtained. The oven-dried plant samples were grinded with the help of Yarco grinder. The ground samples were put in labelled bags for chemical analysis. Nitrogen content was estimated by digesting 0.5 g sample with 10 ml concentrated sulphuric acid and the digestion mixture. Total nitrogen was determined by micro Kjeldahls method. N uptake by straw and grain of crop was calculated by multiplying dry matter production with corresponding values of their content and was expressed as kg ha-1. Sulphur content was estimated by turbidimetric method outlined by. S uptake by straw and grain of crop was calculated by multiplying dry matter production with corresponding values of their content and was expressed as kg ha-1. Protein content of grain was calculated by multiplying the nitrogen content of grain with the factor 6.25. It was expressed in terms of percent. Agronomic efficiency was calculated as kg of grain per kg of nutrient applied. Protein productivity was calculated by following formula:

|  |  |
| --- | --- |
| Protein productivity= | Protein content x yield (grams) |
| 100 |

**Results and discussion**

**Dry matter accumulation (q ha-1)**

Dry matter accumulation is an important index to express the growth and metabolic efficiency of plant, which ultimately influences the yield and yield attributes. Periodic dry matter production increased with the increase in crop age. The present data as presented in Table 1 revealed a significant increase in dry matter accumulation with application of higher levels of nitrogen (80 kg N/ha and 120 kg N/ha). At harvest, application of 120 kg ha -1 produced maximum dry matter accumulation in plant, which was at par with 80 kg ha -1. This was due to more assimilation and utilization of available nitrogen by the growing plants during the entire grand growth period. As a result of this more dry matter accumulation in root, stem, leaves and grains which favored to the increase dry weight production. The results are in close conformity to the findings of Pandey *et al*. (2001) and Meena *et al*. (2003).Among different Sulphur (S) levels, significantly higher dry matter production was recorded with application of 45 kg S ha-1 than all other levels of sulphur except with application of 30 kg S ha-1 as it was at par with 45 kg S ha-1. The results are agreement with the findings by Amano *et al.* (1993), Cassman *et al.* (1998) and Jifeng ying *et al.* (1998) who reported that the higher yield of modern rice cultivars was due to higher biomass production.

**Tiller count (m-2)**

The effect of nitrogen on the number of tillers at different crop growth stages was found to be significant (Table 2). Tiller count (m⁻²) increased consistently with nitrogen fertilisation across all observational stages. The highest number of tillers m⁻² was recorded with the application of 120 kg N ha⁻¹, followed closely by 80 kg N ha⁻¹. The lowest tiller count was observed in the control (no nitrogen application). The increase in tillering with higher nitrogen levels can be attributed to the vital role of nitrogen in promoting protoplasmic synthesis, cell division, and elongation, all of which are essential for the formation of new tillers. These findings are in accordance with those reported by Pandey et al. (2001) and Meena et al. (2003). Sulphur application also had a significant influence on tiller production (m⁻²). Application of 45 kg S ha⁻¹ resulted in a significantly higher number of tillers, which was statistically at par with 30 kg S ha⁻¹. This indicates that optimum sulphur availability supports vegetative growth and contributes to enhanced tillering in rice.

**N and S concentration (%) and uptake (kg ha-1) by grain and straw**

N concentration of grain and straw was significantly affected by N levels as well as S levels (Table 3). N concentration in grain and straw was found significantly higher in N120 however, it was at par with N80 while as, N0 recorded the lowest N concentration in grain and straw. Under different Sulphur levels N concentration of grain was recorded significantly higher in S45; however, it was at par with S30 while as it was recorded lowest under S0 treatment. N concentration in straw was found to be higher in S45; however, different S levels were at par with each other (Table 3). The nitrogen levels had a significant effect of N uptake in grain and straw (Table 3). The nitrogen uptake by grain and straw was increased significantly with increasing levels of nitrogen up to 120 kg ha–1. The highest N uptake in grain and straw was recorded in treatment 120 kg ha–1. This was mainly due to a significant increase of nitrogen content in grain and straw as well as their respective yields with increasing levels of nitrogen. The higher uptake of N might also be due to better established roots and better plant growth under increased N level. Similar findings were also reported by Rao *et al.* (2014). S levels had a significant effect on N uptake by grain and straw and the highest N uptake was recorded by application of 45 kg S ha-1 which significantly increased N-uptake by plant. The results conform with the findings of. Significant increase of nitrogen uptake by grain and straw with the application of sulphur might be attributed to the synergistic uptake mechanism of nitrogen and sulphur. The increase could also be attributed to the increase in yield and higher nutrient demand for plant growth. S concentration of grain and straw was significantly affected by N levels as well as S levels (Table 4). S concentration in grain was found significantly higher in N120 while as, N0 recorded the lowest S concentration in grain. S concentration in straw was found significantly higher in N120,however, it was at par with N80, while as, it was recorded lowest in N0 treatment. Among different S levels higher S concentration in grain and straw was found significantly higher in S45 whereas it was recorded lowest in S0 treatment (Table 4). The nitrogen levels had a significant effect on S uptake in grain and straw. The S uptake by grain and straw was increased significantly with increasing levels of nitrogen. Application of 120 kg N ha-1 significantly increased the S uptake however, N120 was at par with N80 with respect to N uptake by grain. Control treatment (N0) recorded lowest S uptake by grain and straw. Among different S levels S uptake by grain and straw was found significantly higher under S45 which was at par with S30, however S0 recorded lowest s uptake by grain and straw. This could be attributed due to better nutrition which resulted in better growth and yield which ultimately lead to higher uptake of Sulphur. The result is in conformity with the findings of Singh and Meena, (2004).

**Protein content of grain and Protein Productivity (g m-2)**

The data presented Table 5 revealed that significantly highest protein content was found in treatment N120 and S45 having a value of 6.71 and 6.28. Similarly in case of protein productivity significantly highest productivity was found in treatment N120 and S45 which is 52.73 g m-2 and 47.83 g m-2 respectively. The treatment N120 and S45 was found to be at par with treatment N80 and S30 in both the cases. Significant increase in protein content of the rice plant with increasing N rates was similarly reported by Mandana *et al*. (2011) and Shiferaw *et al*. (2012). The increase in protein content and protein productivity was attributed to an increase in seed yield.

**Agronomic efficiency (kg of grain/kg of nutrient applied)**

The data presented in Table 6 indicate that the agronomic use efficiency of rice was found superior in treatments N80 and S30, having a value of 53.12. The estimation of nutrient use efficiency (NUE) in crop plants is crucial to assess the fate of applied nutrient and their role in improving maximum economic yield through efficient absorption or utilisation by the plant. The substantial improvement on the NUE components of the rice crop when N is fertilised with S could be due to the synergistic effect of S on N uptake and utilisation that facilitates the biosynthesis of proteins, a vital process that determines yield. The results are in conformity with the findings of Habtegebrial *et al.* (2013).

**Conclusion**

The results of the study indicated that balanced application of nitrogen and sulphur significantly enhanced rice growth, nutrient uptake, agronomic efficiency, and grain protein content. Among the treatments, application of 80 kg N ha⁻¹ in combination with 30 kg S ha⁻¹ was found to be the most effective, resulting in improved productivity and nutrient use efficiency under the temperate agro-climatic conditions of Kashmir.

**Table 1: Dry matter accumulation (q ha-1) as influenced by different graded levels of nitrogen and sulphur**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **15 DAT** | **30 DAT** | **45 DAT** | **60 DAT** | **75 DAT** | **90 DAT** | **105 DAT** | **Harvest** |
| **N0** | 0.95 | 4.88 | 38.24 | 99.29 | 110.83 | 114.67 | 116.15 | 116.47 |
| **N60** | 1.01 | 6.60 | 43.79 | 105.38 | 118.61 | 123.29 | 126.17 | 127.25 |
| **N80** | 1.12 | 7.70 | 52.05 | 113.28 | 128.01 | 138.16 | 141.70 | 142.32 |
| **N120** | 1.16 | 9.14 | 55.59 | 116.90 | 132.47 | 141.90 | 145.44 | 147.49 |
| **SE(m)±** | 0.02 | 0.63 | 1.68 | 2.23 | 2.70 | 3.36 | 2.80 | 3.40 |
| **CD(p≤0.05)** | **0.05** | **1.83** | **4.87** | **6.46** | **8.14** | **9.75** | **8.41** | **9.88** |
| **S0** | 0.95 | 5.31 | 39.91 | 101.98 | 111.97 | 116.73 | 118.02 | 119.18 |
| **S15** | 1.04 | 6.08 | 42.54 | 106.80 | 120.38 | 124.77 | 127.34 | 128.28 |
| **S30** | 1.09 | 7.13 | 50.89 | 111.88 | 126.39 | 134.37 | 138.70 | 140.55 |
| **S45** | 1.13 | 8.11 | 52.43 | 114.18 | 129.19 | 138.16 | 141.41 | 143.71 |
| **SE(m)±** | 0.02 | 0.63 | 1.68 | 2.23 | 2.70 | 3.36 | 2.80 | 3.30 |
| **CD(p≤0.05)** | **0.05** | **1.83** | **4.87** | **6.46** | **8.14** | **9.75** | **8.41** | **9.88** |

**Table 2: Tiller count (m-2) as influenced by different levels of nitrogen and sulphur**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **15 DAT** | **30 DAT** | **45 DAT** | **60 DAT** | **75 DAT** | **90 DAT** | **105 DAT** | **Harvest** |
| **N0** | 230.40 | 250.65 | 272.80 | 319.60 | 301.70 | 278.70 | 250.30 | 236.30 |
| **N60** | 243.70 | 266.60 | 290.30 | 346.20 | 330.50 | 312.80 | 285.20 | 272.70 |
| **N80** | 267.80 | 295.70 | 327.43 | 398.50 | 388.80 | 370.30 | 345.70 | 336.30 |
| **N120** | 280.30 | 308.50 | 342.50 | 416.80 | 409.40 | 389.60 | 358.50 | 350.10 |
| **SE(m)±** | 3.60 | 4.50 | 6.20 | 7.10 | 7.70 | 7.10 | 6.10 | 6.40 |
| **CD(p≤0.05)** | **10.40** | **13.80** | **18.90** | **21.80** | **22.50** | **20.30** | **17.60** | **19.30** |
| **S0** | 228.10 | 247.70 | 270.20 | 316.20 | 299.10 | 277.30 | 248.10 | 231.20 |
| **S15** | 240.20 | 264.80 | 286.20 | 341.20 | 327.40 | 311.20 | 282.60 | 268.40 |
| **S30** | 265.80 | 293.60 | 323.50 | 392.30 | 386.60 | 366.40 | 343.30 | 333.20 |
| **S45** | 272.80 | 300.20 | 336.20 | 409.10 | 401.20 | 379.90 | 351.90 | 341.10 |
| **SE(m)±** | 3.60 | 4.50 | 6.20 | 7.10 | 7.70 | 7.10 | 6.10 | 6.40 |
| **CD(p≤0.05)** | **10.40** | **13.80** | **18.90** | **21.80** | **22.50** | **20.30** | **17.60** | **19.30** |

**Table 3: N content and uptake parameters as influenced by graded levels of nitrogen and sulphur**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **N concentration in grain (%)** | **N concentration in straw (%)** | **N uptake in Grain (kg** **ha-1)** | **N uptake in Straw (kg** **ha-1)** |
| **N0** | 0.90  | 0.42 | 30.28 | 25.62 |
| **N60** | 0.94 | 0.45 | 52.06 | 34.46 |
| **N80** | 0.99 | 0.50 | 76.79 | 46.01 |
| **N120** | 1.07 | 0.52 | 84.37 | 55.88 |
| **SE(m)±** | **0.003** | **0.003** | **3.46** | **2.30** |
| **CD(p≤0.05)** | **0.009** | **0.008** | **10.05** | **6.67** |
| **S0** | 0.95 | 0.46 | 43.64 | 30.35 |
| **S15** | 0.96 | 0.47 | 55.22 | 38.65 |
| **S30** | 0.98 | 0.47 | 68.13 | 45.08 |
| **S45** | 1.00 | 0.49 | 76.51 | 47.90 |
| **SE(m)±** | 0.003 | 0.003 | 3.46 | 0.03 |
| **CD(p≤0.05)** | **0.009** | **0.008** | **10.05** | **6.67** |

**Table 4: S content and uptake parameters as influenced by graded levels of nitrogen and sulphur**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Sulphur concentration in grain (%)** | **Sulphur concentration in straw (%)** | **Sulphur uptake in Grain (kg** **ha-1)** | **Sulphur uptake in Straw (kg** **ha-1)** |
| **N0** | 0.16 | 0.16 | 5.48 | 9.98 |
| **N60** | 0.17 | 0.19 | 10.15 | 14.80 |
| **N80** | 0.22 | 0.22 | 17.65 | 20.35 |
| **N120** | 0.24 | 0.23 | 19.16 | 24.99 |
| **SE(m)±** | 0.00 | 0.00 | 0.76 | 1.01 |
| **CD(p≤0.05)** | **0.01** | **0.01** | **2.20** | **2.92** |
| **S0** | 0.16 | 0.16 | 7.51 | 10.68 |
| **S15** | 0.17 | 0.19 | 10.38 | 16.02 |
| **S30** | 0.21 | 0.20 | 15.38 | 20.92 |
| **S45** | 0.24 | 0.23 | 19.18 | 22.49 |
| **SE(m)±** | 0.00 | 0.00 | 0.76 | 1.01 |
| **CD(p≤0.05)** | **0.01** | **0.01** | **2.20** | **2.92** |

**Table 5: Protein content of grain and Protein Productivity (g m-2) as influenced by different levels of nitrogen and sulphur**

|  |  |  |
| --- | --- | --- |
| **Treatments** | **Protein content** | **Protein productivity (g m-2)** |
| **N0** | 5.64 | 18.93 |
| **N60** | 5.89 | 32.54 |
| **N80** | 6.21 | 47.99 |
| **N120** | 6.71 | 52.73 |
| **SE(m)±** | 0.02 | 2.17 |
| **CD(p≤0.05)** | **0.06** | **6.28** |
| **S0** | 5.99 | 27.28 |
| **S15** | 6.01 | 34.52 |
| **S30** | 6.16 | 42.58 |
| **S45** | 6.28 | 47.83 |
| **SE(m)±** | 0.02 | 2.17 |
| **CD(p≤0.05)** | **0.06** | **6.28** |

**Table 6: Influence of nitrogen and sulphur fertilization on agronomic efficiency (kg of grain/kg of nutrient applied) of rice**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **S0** | **S15** | **S30** | **S45** |
| **N0** | 0 | 1.78 | 12.67 | 14.22 |
| **N60** | 6.11 | 16.67 | 38.44 | 43.37 |
| **N80** | 20.71 | 39.09 | 53.12 | 52.11 |
| **N120** | 29.00 | 37.93 | 34.64 | 32.16 |

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