



Influence of Nitrogen Application Rates and Plant Spacing on Nutrient Uptakes and Yield Curve of Basmati Rice (*Oryza sativa* L.)

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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

Basmati rice is a high-end agricultural product because of its distinctive cooking qualities and exquisite aroma. Basmati rice, also referred to locally as "scented pearls," is native to the Indian subcontinent and has been grown there for more than 250 years. The "Influence of Nitrogen Application Rates and Plant Spacing on nutrient uptakes and yield curve of basmati rice (*Oryza*

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sativa L.)" in the Rabi season crop of 2023–2024 was the subject of a field experiment conducted at Rama University at Mandhana, Kanpur, Uttar Pradesh, India. Nitrogen levels (kg/ha)- N0: 0(kg/ha), N1: 40(kg/ha), N2: 60(kg/ha), N3: 80(kg/ha), N4: 100(kg/ha) and Plant geometry (cm)- G1-20 × 15, G2-15 × 15, G3-20 × 10, G4-15 × 10 were the five treatments with N levels and four treatment with plant geometry that were included in the experiment. Three replications of each treatment were carried out using a Randomised block design (Factorial) Replications. The rice crop was used in the experiment. The experimental soil had a pH between 7.2 and 7.8, medium levels of organic carbon, and medium levels of potassium, phosphorus, and nitrogen. greater nutrient uptake was found to be significantly greater in this pattern, and the results seemed to show that the five treatments with N levels and four treatment with plant geometry N4- 100 (kg/ha) had significant Nitrogen uptake (kg/ha), Nitrogen uptake in grain (kg/ha), Nitrogen uptake in straw (kg/ha), Total Nitrogen uptake (kg/ha), Phosphorus uptake (kg/ha), Phosphorus Uptake by Grain (kg/ha), Phosphorus Uptake by Straw (kg/ha), Total Phosphorus Uptake (kg/ha), Potassium uptake (kg/ha), Potassium Uptake by Grain (kg/ha), Potassium Uptake by Straw (kg/ha), Total Potassium Uptake (kg/ha), Yield Curve, with the different nutrient levels. The farmer's methods produce the lowest grain yield, growth traits, and yield qualities. The decomposition of crop residues and the use of organic manure resulted in an improvement in soil quality at the five treatments with N levels and four treatments with plant geometry. With N4 100 (kg/ha and G3 treatments, the N levels have the highest net return and benefit cost ratio. These findings underscore the importance of balancing nitrogen application and planting density to optimise nutrient uptake and maximise rice yield, with 20 × 10 cm spacing and moderate-to-high nitrogen levels offering the best outcomes.

Keywords: *N levels plant geometry; nitrogen uptake (kg/ha); phosphorus uptake (kg/ha); potassium uptake (kg/ha); yield curve of basmati rice crop cultivation.*

1. INTRODUCTION

As the world's population increased from 3000 to 8000 million between 1960 and 2020, food and nutritional insecurity are significant global challenges for more than 3000 people in developing and underdeveloped countries. From 1990 (598.67 million tonnes of rice production) to 2020 (756.74 million tonnes of rice), the use of high-yielding rice varieties, management of nutrients and soil, improved efficiency of water use in significant global pest management (including weed management) increased global rice yield by 26.4% (Sadhukhan et al., 2023). When it comes to rice cultivation, basmati holds a unique position. It is a type of aromatic rice with long, thin grains. Basmati rice is farmed in a limited number of Indian states, specifically in the foothills of the Himalayas. These states, which include Punjab, Haryana, Himachal Pradesh, Uttarakhand, Western Uttar Pradesh, Delhi, and Bihar, are found in the northern regions of our nation. The length of Basmati rice doubles after cooking, which is one of the characteristics that sets it apart from other fragrant rice (Shehzad et al., 2012). Other qualities include a delightful and fluffy texture, a unique flavour, and a great perfume. Basmati rice contains 0.09 parts per million of 2-acetyl-1-pyrroline, the chemical component that gives rice its scent, which is about twelve times greater than in non-Basmati

rice. Thus, among other aromatic long-grained rice, Basmati rice is distinct. A crop of global importance, rice (*Oryza sativa* L.) belongs to the Poaceae family. Numerous studies have been carried out to increase rice yield in both normal and stressful conditions because of the importance of rice grain production in breeding programs (Elkhoby et al., 2013; El-Hity et al., 2020; Hafez et al., 2020; Mohamed et al., 2021).

In agricultural markets around the world, aromatic rice (*Oryza sativa* L.) varieties—especially the Basmati and Jasmine varieties—command premium prices (Shehzad et al., 2012a). Despite its low volume, Basmati Rice fetches a higher price than non-Basmati Rice, making it an important export commodity (Tiwari et al., 2025). Basmati rice is a high-end agricultural product because of its distinctive cooking qualities and exquisite aroma. Basmati rice, also referred to locally as "scented pearls," is native to the Indian subcontinent and has been grown there for more than 250 years (Nene, 1998; Singh and Singh, 2009; Siddiq et al., 2012). Since basmati rice is the most popular speciality rice grown in the Indian subcontinent. It is a key product in the international market, praised for its distinct and pleasant aroma, fluffy texture, palatability, simple digestion, extended shelf life, and volume expansion while cooking. Iron absorption is aided by the metallothionein-

like protein 160 found in basmati rice, which is made up of the sulfur-containing amino acid cysteine (Chaudhary and Tran, 2001; Salgotra et al., 2015). The Indian states of Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Delhi, and Western Uttar Pradesh have been cultivating basmati rice for generations (Singh and Singh, 2009). According to Ashfaq et al. (2015), Basmati rice is also crucial to the life of people in Punjab, Pakistan.

Only if rice's quality and quantity are increased will its role in the future be more favourable and noticeable. Today, a variety of methods, such as pre-sowing seed or post-emergence treatment, are used to boost crop yields in response to rising consumption (Perveen et al. 2011; Haq et al. 2012; Iqbal et al. 2012; Jamil et al. 2012;). To draw in customers and satisfy both domestic and international standards for high-quality rice, the quality of the kernels can be further enhanced. Pakistan's rice industry has been transformed by the introduction of high-yielding International Rice Research Institute (IRRI) rice varieties, but, in terms of quality, those kinds cannot compete with our traditional fine rice varieties, especially Basmati. The two most common ways to plant rice are transplanting and direct seeding, with transplanting being the most popular (Verma et al., 2002). When there is good control over the water supply, direct planting is used. Better stand establishment, increased tillering, and occasionally higher grain yield are benefits of direct seeding over transplanting. Better pest control, less risk of drought and flooding damage, consistent growth and decreased lodging, and low requirements for improved water management methods are further benefits. On the other hand, direct seeding is less costly, time-consuming, and labour-intensive than transplanting. This is due to labour shortages, high labour costs, and challenges in nurturing seedlings (Pandey et al. 2002).

Indian In addition to being a significant agricultural export item that is gaining popularity on the international market and generating bigger profits, basmati rice production has been steadily increasing over the past few years. Since there is a growing demand for basmati rice in the home market due to its health benefits and to meet the ongoing supply in the worldwide market, great preference should be given to improving production and productivity levels. Furthermore, the demand for high-quality rice like basmati in India has surged due to the rise of a sizable

middle-class population and a noticeable shift in their eating habits. It is anticipated that basmati rice would adapt to plant spacing and nutrients in order to overcome the poor productivity barrier. Research shows that the growth and production of basmati rice are significantly influenced by seedling age, spacing, and nutrient management techniques. To get a high grain yield, the aforementioned productivity variables must be optimised using various rice varieties, particularly basmati rice, within various agro-climatic zones (Panigrahi et al., 2014).

Growing hybrid rice would be greatly aided by a planting density that can reduce the amount of seed needed without compromising yield. Due to a decrease in plant population, the hybrid rice may yield more if it is tillered extensively. Plant kind, season, fertility level, seedling age, and transplanting date are some of the variables that affect the ideal plant geometry. System of Rice Intensification (SRI) is a paradoxical cropping strategy where more is produced with lessening of external inputs. Even labour inputs, although initially higher during the learning phase, can usually be cut back because of the reduction in plant populations. Although SRI was originally developed for irrigated rice cultivation, once farmers understood its logic, they adapted the changes in management practices to growing unirrigated (upland) rice as well. An unexpected bonus has been that SRI's agroecological methods, with appropriate adaptations, improve the production of other crops, such as wheat, sugarcane, finger millet, pulses, and vegetables (Uphoff, 2024).

To get the best plant stand in the field and increase yields, the ideal plant geometry must be used. The main reason for the underutilization of the yield potential is the insufficient number of plants. Since plant geometry is thought to have a significant impact on light tailoring, interception, and utilisation, it is possible to increase productivity by changing it. Plant density and shape have a significant impact on yield qualities, which in turn affect grain production. Increasing the amount of sunlight that crops use for photosynthesis helps to maximise production. Therefore, altering the geometry of the plant seems to have a promising chance of raising the yield. Because more plants and leaf area were exposed to sunlight during the growth period, which improved photosynthesis and increased production, a closer spacing of 15 cm by 15 cm produced a higher yield than a wider spacing of 20 cm by 20 cm.

The last ten years have seen the majority of research on chemicals that reduce or impede transpiration. Early research focused on using film-forming compounds to keep plants from drying out during transpiration. These materials function by physically blocking the flow of water vapour away from plant leaves, which lowers transpiration. A substance of this kind ought to be non-toxic, weatherproof, and impermeable to water vapours yet permeable to CO₂ and O₂.

In order to produce rice, a significant amount of nitrogen is needed. When used as an inorganic source in a puddle field, it has significant system losses and is one of the most significant limiting nutrients in rice production. The generation of efficient tillers per plant, yield, and yield characteristics is all positively impacted by nitrogen. Finding the right amount of nitrogen is essential for effective management and

increased rice output. For increased yield, the right planting geometry and nitrogen dosage are required. Because of the agroclimatic circumstances in Eastern Uttar Pradesh, the work on the aforementioned aspects is limited.

2. MATERIALS AND METHODS

2.1 Nutrient Uptake Studies

2.1.1 Nitrogen content and uptake

The processed straw and grain samples were digested with concentrated H₂SO₄ in the presence of a catalyst mixture, using a modified Kjeldahl method as outlined by Jackson (1973) to measure nitrogen content in both straw and grain. The nitrogen percentage was then multiplied by the grain and straw yields to calculate the nitrogen uptake in the seeds and straw, respectively.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in grain (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

2.1.2 Phosphorus content and uptake

The ground grain and plant samples were digested using a di-acid mixture of nitric and perchloric acid, and the phosphorus content was determined by the vanadomolybdo phosphoric yellow colour method as described by Jackson (1973). The percentage of phosphorus was then multiplied by the grain and plant yields to calculate the phosphorus uptake in the grain and straw, respectively.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in grain (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

2.1.3 Potassium content and uptake

The plant samples were digested with a di-acid mixture and analysed separately using a flame photometer, following the method described by Jackson (1973). The percentage of potassium content was then multiplied by the grain and straw yields to determine the potassium uptake in the grain and straw, respectively.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in grain (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

2.1.4 Nitrogen use efficiency (kg kg⁻¹)

Field trials are carried out to evaluate Nitrogen Use Efficiency (NUE) in rice crops under varying nitrogen application rates, schedules, and management techniques. Nitrogen absorption, usage, and losses are measured using isotopic tracing, nutrient assessments, and environmental observations. Soil testing is conducted to study soil nitrogen dynamics and their connection to NUE. Statistical modelling may be applied to pinpoint the primary factors affecting NUE variations.

2.1.5 Apparent N recovery (%)

Field trials are undertaken to assess apparent nitrogen recovery in rice crops under different nitrogen application rates, timings, and management strategies. Nitrogen absorption, utilisation, and losses are evaluated using isotopic tracing, nutrient assessments, and environmental monitoring methods. Soil testing is conducted to examine soil nitrogen dynamics and their influence on nitrogen recovery. Statistical models may be used to determine the main factors contributing to variability in nitrogen recovery.

2.2 Quality Parameters

2.2.1 N, P and K content (%) in grain and straw

Determination of Nitrogen (N) Content: The nitrogen content in the digested samples was quantified using the Kjeldahl method (Goyal et al., 2022). The digested sample was subjected to distillation in the presence of 40% sodium hydroxide (NaOH) to liberate ammonia (NH₃). The liberated ammonia was trapped in a 4% boric acid (H₃BO₃) solution containing a mixed indicator (bromocresol green and methyl red). The trapped ammonia was then titrated against a standardised 0.01 N hydrochloric acid (HCl) solution until the endpoint was reached, indicated by a colour change from green to pink. The nitrogen content (%) was calculated using the following formula:

$$N(\%) = \frac{(V_s - V_b) \times N_{HCl} \times 14.01 \times 100}{W \times 1000}$$

Where:

- V_s = Volume of HCl used for sample titration (mL)

- V_b = Volume of HCl used for blank titration (mL)
- N_{HCl} = Normality of HCl (0.01 N)
- 14.01 = Atomic weight of nitrogen
- W = Weight of the sample (g)

Determination of Phosphorus (P) Content:

The phosphorus content was determined calorimetrically using the vanadomolybdate method. An aliquot of the digested sample (5 mL) was taken and mixed with vanadomolybdate reagent, which forms a yellow-colored phosphovanadomolybdate complex in the presence of phosphorus. The reaction mixture was allowed to stand for 10 minutes to ensure complete colour development. The absorbance of the solution was measured at 420 nm using a UV-Vis spectrophotometer. A standard curve was prepared using known concentrations of phosphorus (KH₂PO₄), and the phosphorus content in the samples was estimated by comparing the absorbance values against the standard curve. The P content (%) was calculated as:

$$P(\%) = \frac{C \times V \times 100}{W \times 1000}$$

Where:

- C = Concentration of P obtained from the standard curve (mg/L)
- V = Total volume of the digest (mL)
- W = Weight of the sample (g)

Determination of Potassium (K) Content: The potassium content was analysed using flame photometry (Chavan et al., 2024). An aliquot of the digested sample was aspirated into the flame photometer, calibrated with standard potassium solutions (prepared from KCl) ranging from 0 to 100 ppm. The emission intensity of potassium at 766.5 nm was recorded, and the concentration of K in the sample was determined by comparing it with the standard curve. The K content (%) was calculated using the formula:

$$K(\%) = \frac{C \times V \times 100}{W \times 1000}$$

Where:

- C = Concentration of K obtained from the standard curve (mg/L)
- V = Total volume of the digest (mL)
- W = Weight of the sample (g)

2.2.2 Yield curve

The yield data were compiled and organised based on the corresponding nitrogen application

rates. To smooth random variations and derive a continuous relationship, the yield response to nitrogen was modelled using a quadratic function, commonly employed in agronomic studies to describe crop yield curves. The general form of the equation used was:

$$Y = a + bN + cN^2$$

Where:

- Y = Grain yield (kg ha⁻¹)
- N = Nitrogen application rate (kg ha⁻¹)
- a = Yield at zero nitrogen (intercept)
- b = Linear coefficient (initial yield response)
- c = Quadratic coefficient (rate of yield curvature)

3. RESULTS AND DISCUSSION

3.1 Nitrogen Uptake (kg/ha)

3.1.1 Nitrogen uptake in grain (kg/ha)

Data on nitrogen uptake in grain as impacted by nitrogen levels and planting geometry are shown in Table 1. Different nitrogen levels had a substantial impact on the grain's nitrogen uptake during the course of the two-year trial. The data unequivocally demonstrate that higher N levels increased grain's absorption of N. Applying N₄ 100 kilogram N/ha resulted in higher N uptake in grain; this was comparable to applying N₃₈₀ kg N/ha and significantly superior to the other two nitrogen levels in both research years.

Grain's capacity to absorb nitrogen was significantly impacted by varying planting geometry and nitrogen levels throughout the course of the two study years, as the table makes evident. The data clearly show that a 20x10 cm plant spacing led to a higher nitrogen uptake in grain during both research years. This was significantly above the other two planting geometries and comparable to a 15x15 cm spacing.

3.1.2 Nitrogen uptake in straw (kg/ha)

The effects of planting geometry and nitrogen levels on the uptake of nitrogen in straw are shown in Table 1. Different nitrogen levels had a significant impact on the nitrogen uptake in straw over the course of the two-year trial. The statistics unequivocally demonstrate that as the N level increased, so did the amount of N absorbed by the straw. The N uptake in straw was higher after applying N₄ 100 kg N/ha of nitrogen, which was similar to N₃₈₀ kg N/ha but much higher than the other two nitrogen levels during the two study years.

It is evident from the table that variations in planting geometry and nitrogen levels significantly affected the uptake of nitrogen in straw during the two study years. The results unequivocally demonstrate that, in both research years, a 20x10 cm plant spacing led to a higher nitrogen uptake in the straw. This was significant over the other two planting patterns but comparable to a 15x15 cm spacing.

Table 1. Influence of nitrogen levels and planting geometry on nitrogen uptake by grain, nitrogen uptake by straw and Total N uptake of rice

Treatments	Nitrogen uptake by grain(kg/ha)		Nitrogen uptake by straw(kg/ha)		Total N uptake(kg/ha)	
	2022	2023	2022	2023	2022	2023
Nitrogen levels (kg/ha)						
N ₀	38.5	40.7	16.2	17.2	54.7	57.9
N ₁	75.3	78.8	22.3	23.3	97.6	102.1
N ₂	85.3	89.3	33.4	35.2	118.7	124.5
N ₃	87.9	92.8	33.9	36.3	121.8	129.1
N ₄	88.5	93.6	34.6	37.1	123.1	130.7
SEm±	1.89	1.85	0.44	0.85	2.33	2.7
C.D (0.05)	5.52	5.41	1.30	2.48	6.82	7.89
Planting Geometry						
G1 (20 × 15)	61.7	64.7	24.0	21.6	85.7	86.3
G2 (15 × 15)	66.7	70.9	26.0	27.7	92.7	98.6
G3 (20 × 10)	75.2	78.9	29.5	31.4	104.7	110.3
G4 (15 × 10)	64.3	67.2	25.3	25.2	89.6	92.4
SEm±	2.28	2.23	0.55	1.05	2.83	3.28
C.D. (0.05)	7.89	7.72	1.90	3.66	9.79	11.38

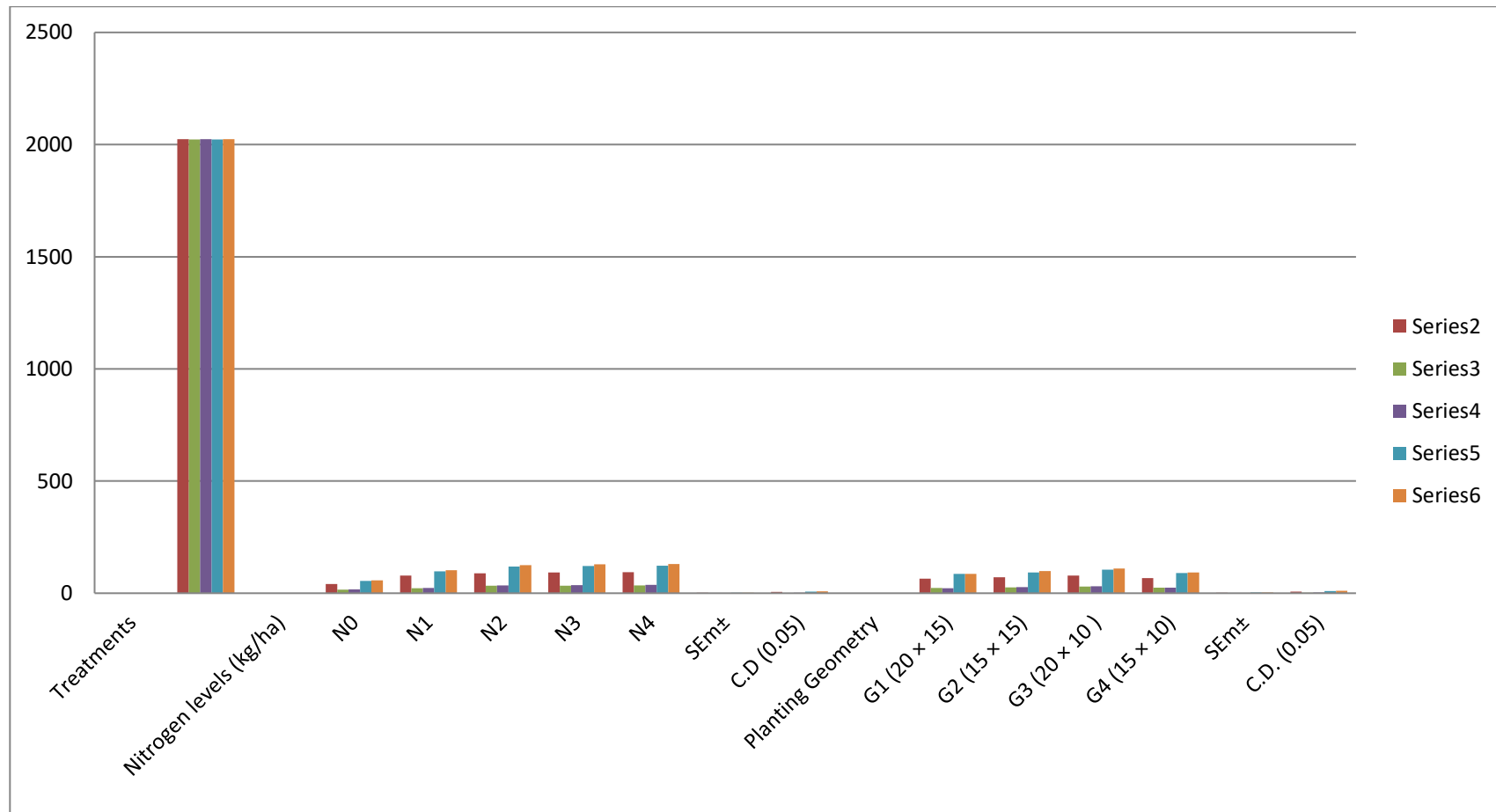


Fig. 1. Influence of nitrogen levels and planting geometry on nitrogen uptake by grain, nitrogen uptake by straw and Total N uptake of rice

3.1.3 Total Nitrogen uptake (kg/ha)

Data on total N uptake as impacted by planting geometry and nitrogen levels are shown in Table 1. The total amount of nitrogen absorbed was significantly impacted by changes in nitrogen levels throughout the course of the two research years. The results unequivocally demonstrate that a rise in N level caused a rise in total N uptake. Throughout the two experimental years, N4 100 kg N/ha nitrogen delivery resulted in higher total N uptake, which was comparable to N3 80 kg N/ha but significantly superior to the other two nitrogen levels.

The overall amount of N absorbed during the two study years was significantly impacted by varying planting geometry and nitrogen levels, as the table makes evident. According to the data, a plant spacing of 20 × 10 cm recorded a higher value of total nitrogen uptake during both research years. This value was comparable to a spacing of 15 × 15 cm and significantly higher than the other two planting geometries.

3.2 Phosphorus Uptake (kg/ha)

The study evaluated how nitrogen levels and planting geometry affected rice's phosphorus uptake by grain, straw, and total phosphorus over the 2022 and 2023 cropping seasons.

3.2.1 Phosphorus uptake by grain (kg/ha)

As nitrogen levels increased in 2022, grain's phosphorus intake increased significantly, from 17.44 kg/ha at N0 to 32.34 kg/ha at N4. Similar trends were observed in 2023, with values ranging from 18.10 kg/ha at N0 to 32.51 kg/ha at N4. Phosphorus uptake increased noticeably at N2 and N4 compared to N0. In the presence of Planting Geometry Grain's 2022 phosphorus absorption ranged from 22.17 kg/ha at G1 (20 × 15 cm) to 28.31 kg/ha at G2 (15 × 15m). Similar trends were seen in 2023, when G2 showed the highest absorption at 29.31 kg/ha. There was no discernible difference in grain phosphorus uptake between planting geometries.

3.2.2 Phosphorus uptake by straw (kg/ha)

In 2022, the amount of phosphorus absorbed by straw ranged from 13.63 kg/ha at N0 to 30.28 kg/ha at N4. With phosphorus uptake ranging from 12.64 kg/ha at N0 to 29.57 kg/ha at N4, the trend continued in 2023, showing a consistent increase with greater nitrogen application. G2

exhibited the highest phosphorus uptake by straw under planting geometry when compared to other planting geometries (26.43 kg/ha in 2022 and 25.87 kg/ha in 2023). In 2022 and 2023, G1 had the lowest uptake (18.99 kg/ha and 18.25 kg/ha, respectively). In 2022 and 2023, notable differences in the uptake of phosphorus from straw were noted.

3.2.3 Total phosphorus uptake (kg/ha)

Total phosphorus intake increased with higher nitrogen levels. The values ranged from 31.07 kg/ha at N0 to 62.62 kg/ha at N4, and from 30.74 kg/ha at N0 to 62.08 kg/ha at N4 between 2022 and 2023. The phosphorus intake was highest in N4 and lowest in N0. Similar trends were seen in the total phosphorus intake under Planting Geometry, with G2 registering the highest uptake (54.74 kg/ha in 2022 and 55.18 kg/ha in 2023). G1 had the lowest total phosphorus uptake, with 41.16 kg/ha in 2022 and 40.96 kg/ha in 2023. The total phosphorus intake varied significantly among planting geometries.

These findings showed that both nitrogen levels and planting geometry had a significant impact on rice's phosphorus uptake, with higher nitrogen levels and closer planting geometries leading to higher phosphorus uptake, especially in the grain and straw.

3.3 Potassium Uptake (kg/ha)

The study assessed the impact of nitrogen levels and planting geometry on potassium uptake by grain, straw, and total potassium uptake in rice during the 2022 and 2023 cropping seasons.

3.3.1 Potassium uptake by grain (kg/ha)

In 2022, the amount of potassium absorbed by grain ranged from 7.47 kg/ha at N0 to 12.21 kg/ha at N4. Potassium uptake in 2023 followed a similar pattern, ranging from 8.31 kg/ha at N0 to 13.26 kg/ha at N4. Uptake increased significantly with higher nitrogen levels, with N2 and N4 exhibiting the highest values. Under Planting Geometry, the amount of potassium consumed by grain in 2022 ranged from 8.74 kg/ha at G3 (20 × 10 cm) to 11.24 kg/ha at G4 (15 × 10 cm). In 2023, the uptake ranged from 9.11 kg/ha at G3 to 11.87 kg/ha at G4. G4 exhibited the highest grain potassium uptake in both years.

Table 2. Influence of planting geometry and nitrogen levels on Phosphorus uptake by grain, Phosphorus uptake by straw and Total Phosphorus uptake of rice

Treatments	Phosphorus uptake by grain(kg/ha)		Phosphorus uptake by straw(kg/ha)		Total Phosphorus uptake (kg/ha)	
	2022	2023	2022	2023	2022	2023
Nitrogen levels (kg/ha)						
N ₀	17.44	18.10	13.63	12.64	31.07	30.74
N ₁	21.78	21.87	18.46	17.78	40.24	39.65
N ₂	31.21	31.95	28.83	28.13	60.04	60.08
N ₃	25.70	27.71	26.89	25.98	52.59	53.69
N ₄	32.34	32.51	30.28	29.57	62.62	62.08
SEm±	1.87	1.86	2.48	2.47	4.35	4.33
C.D (0.05)	5.50	5.51	7.29	7.26	12.79	12.77
Planting Geometry						
G1 (20 × 15)	22.17	22.71	18.99	18.25	41.16	40.96
G2 (15 × 15)	28.31	29.31	26.43	25.87	54.74	55.18
G3 (20 × 10)	21.18	22.65	18.92	18.21	40.1	40.86
G4 (15 × 10)	22.87	23.94	21.45	20.67	44.32	44.61
SEm±	1.62	1.71	2.15	2.14	3.77	3.85
C.D. (0.05)	NS	NS	6.32	6.26	6.32	6.26

Table 3. Influence of planting geometry and nitrogen levels on Potassium uptake by grain, Potassium uptake by straw and Total Potassium uptake of rice

Treatments	Potassium uptake by grain(kg/ha)		Potassium uptake by straw(kg/ha)		Total Potassium uptake(kg/ha)	
	2022	2023	2022	2023	2022	2023
Nitrogen levels (kg/ha)						
N ₀	7.47	8.31	60.23	58.24	67.7	66.55
N ₁	9.13	9.83	66.75	64.12	75.88	73.95
N ₂	11.54	12.11	83.78	82.76	95.32	94.87
N ₃	9.55	10.51	79.61	79.52	89.16	90.03
N ₄	12.21	13.26	82.72	81.93	94.93	95.19
SEm±	0.54	0.55	3.36	3.38	3.9	3.93
C.D (0.05)	1.59	1.6	9.85	9.84	11.44	11.44
Planting Geometry						
G1 (20 × 15)	9.09	9.91	68.67	66.84	77.76	76.75
G2 (15 × 15)	10.22	11.21	77.22	75.39	87.44	86.6
G3 (20 × 10)	8.74	9.11	69.05	68.53	77.79	77.64
G4 (15 × 10)	11.24	11.87	71.21	70.11	82.45	81.98
SEm±	0.47	0.48	2.91	2.89	3.38	3.37
C.D. (0.05)	1.38	1.39	8.53	8.5	9.91	9.89

3.3.2 Potassium uptake by straw (kg/ha)

In 2022, the potassium intake of straw ranged from 60.23 kg/ha at N₀ to 82.72 kg/ha at N₄. The uptake was higher in 2023, with values ranging from 58.24 kg/ha at N₀ to 81.93 kg/ha at N₄. Higher uptake was consistently linked to higher nitrogen levels, particularly at N₂ and N₄. Under Planting Geometry, G₄'s straw had the highest potassium uptake in 2022 (71.21 kg/ha), followed by G₂ (77.22 kg/ha). With a 69.05 kg/ha uptake, G₃ had the lowest. Similar trends were observed in 2023, where G₄ showed

the highest uptake (70.11 kg/ha), followed by G₂ (75.39 kg/ha).

3.3.3 Total potassium uptake (kg/ha)

The overall potassium uptake trend was comparable. In 2022, it ranged from 67.7 kg/ha at N₀ to 94.93 kg/ha at N₄. In 2023, the values ranged from 66.55 kg/ha at N₀ to 95.19 kg/ha at N₄. The potassium uptake at N₂ and N₄ was significantly higher than that at N₀, leading to the maximum total uptake. Under Planting Geometry, G₂ had the greatest overall potassium

uptake in both years. In 2022, G2 had the highest total absorption at 87.44 kg/ha, followed by G4 at 82.45 kg/ha. At 77.79 kg/ha, G3 had the lowest overall uptake in 2022. After G2 (86.6 kg/ha), G4 had the second-highest absorption in 2023 (81.98 kg/ha).

These findings suggest that both nitrogen levels and planting geometry had a significant influence on rice's potassium uptake, with tighter planting geometries and greater nitrogen levels leading to higher potassium uptake, especially in the grain and straw.

According to these results, rice's potassium uptake was significantly influenced by both nitrogen levels and planting geometry, with tighter planting geometries and higher nitrogen levels resulting in higher potassium uptake, particularly in the grain and straw.

3.4 Yield Curve

The Yield Curve figures for 2022 and 2023 illustrate the relationship between grain yield and various nitrogen concentrations and planting configurations. The yield curve displays the percentage change in grain yield for each treatment in comparison to the previous treatment. This information helps to understand the efficacy of different nitrogen levels and planting geometries over a two-year period.

A significant initial rise in yield after nitrogen application is depicted in the yield curve for nitrogen levels in 2022. The N1 treatment (33.5%) showed a significant increase in yield when compared to N0; however, the pace of growth progressively decreased as nitrogen levels increased. While yield gains for N3 and N4 were somewhat smaller, at 1.4% and 2.4%, respectively, N2 produced an 8.8% increase.

The trend of declining returns as nitrogen levels rose was maintained into 2023. N1 showed a gain of 28.2% over N0, which was higher than the 2022 boost. The increases for N2, N3, and N4 were slightly smaller at 8.2%, 1.1%, and 3.5%, respectively. Despite the fact that raising nitrogen levels eventually loses their effectiveness, this indicates that nitrogen will still boost output in 2023.

The planting geography yield curve indicates that in 2022, denser planting patterns yielded higher yields. Compared to G1 (20 × 15 cm), the yields of G2 (15 × 15 cm) and G3 (20 × 10 cm) were 5.3% higher. However, G4 (15 × 10 cm) produced a -6.2% lower yield than G1, suggesting that excessively dense planting may restrict yield potential.

In 2023, the trend of planting geometry influencing yield became more apparent. Denser planting arrangements were nevertheless beneficial, as seen by the yields of G2 (15 × 15 cm) and G3 (20 × 10 cm), which were 25.0% and 41.0% greater, respectively, than G1 and G3. However, the yield of G4 (15 × 10 cm) dropped by -13.2%, confirming the idea that planting too densely could negatively impact output, particularly in 2023.

According to an analysis of the production curves for 2022 and 2023, nitrogen fertiliser boosts yield, but the benefits decrease as nitrogen levels grow. With denser arrangements generally yielding higher yields, the 20 × 10 cm spacing (G3) is the most productive planting geometry in 2023. However, overly thick planting (such as G4) typically produces poorer yields, suggesting that the ideal plant density is crucial for maximum output. These findings highlight the necessity of carefully controlling nitrogen application and planting geometry in order to optimise rice output all through the growing season.

Table 4. Effect of different nitrogen levels and spacing yield curve of basmati rice

Treatments	Yield Curve	
	2022	2023
Nitrogen levels (kg/ha)		
N ₀	-	-
N ₁	33.5%	28.2%
N ₂	8.8%	8.2%
N ₃	1.4%	1.1%
N ₄	2.4%	3.5%
Planting Geometry		
G ₁ (20 × 15)	-	-
G ₂ (15 × 15)	5.3%	25.0%
G ₃ (20 × 10)	5.3%	41.0%
G ₄ (15 × 10)	-6.2%	-13.2%

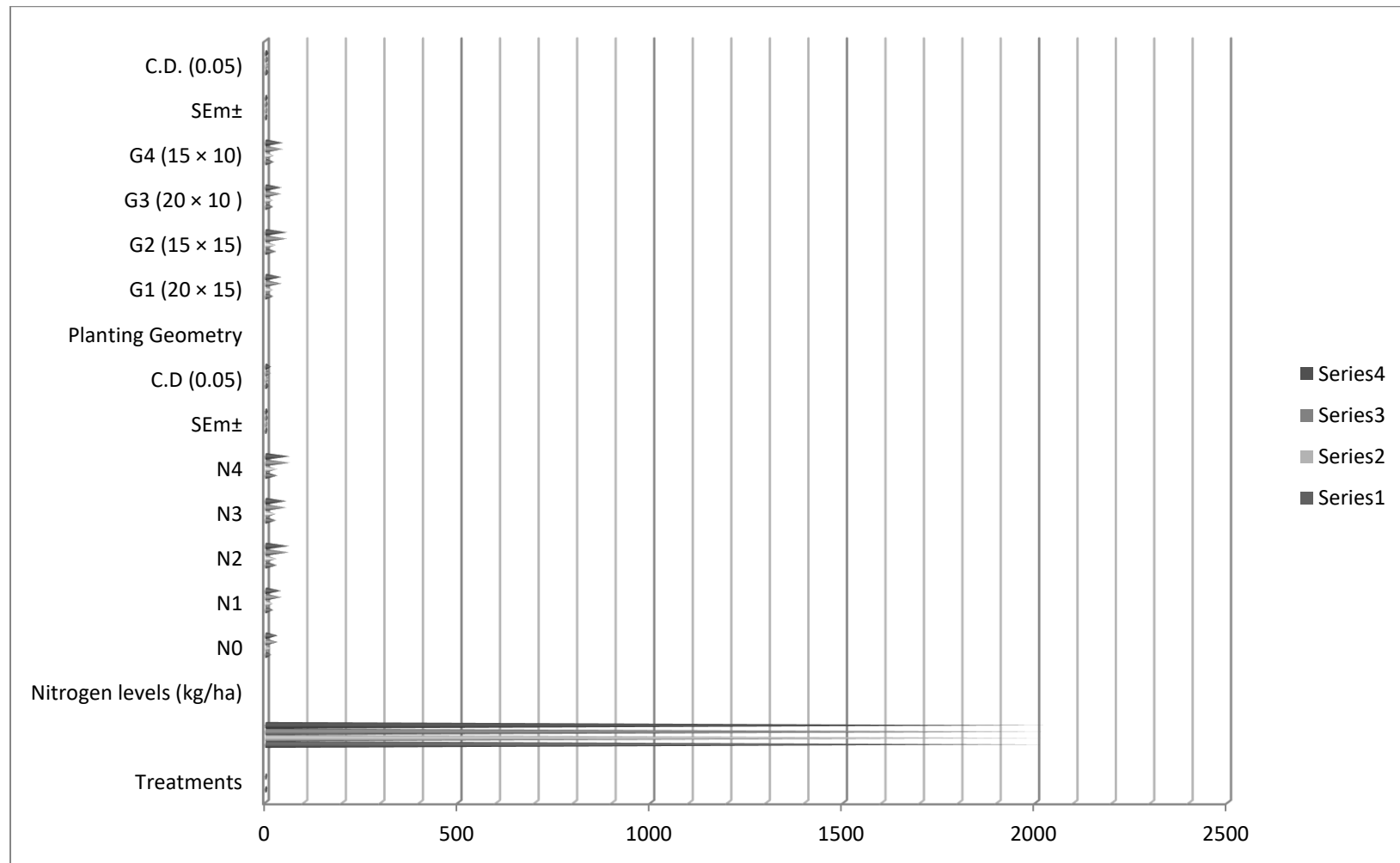


Fig. 2. Influence of planting geometry and nitrogen levels on Phosphorus uptake by grain, Phosphorus uptake by straw and Total Phosphorus uptake of rice

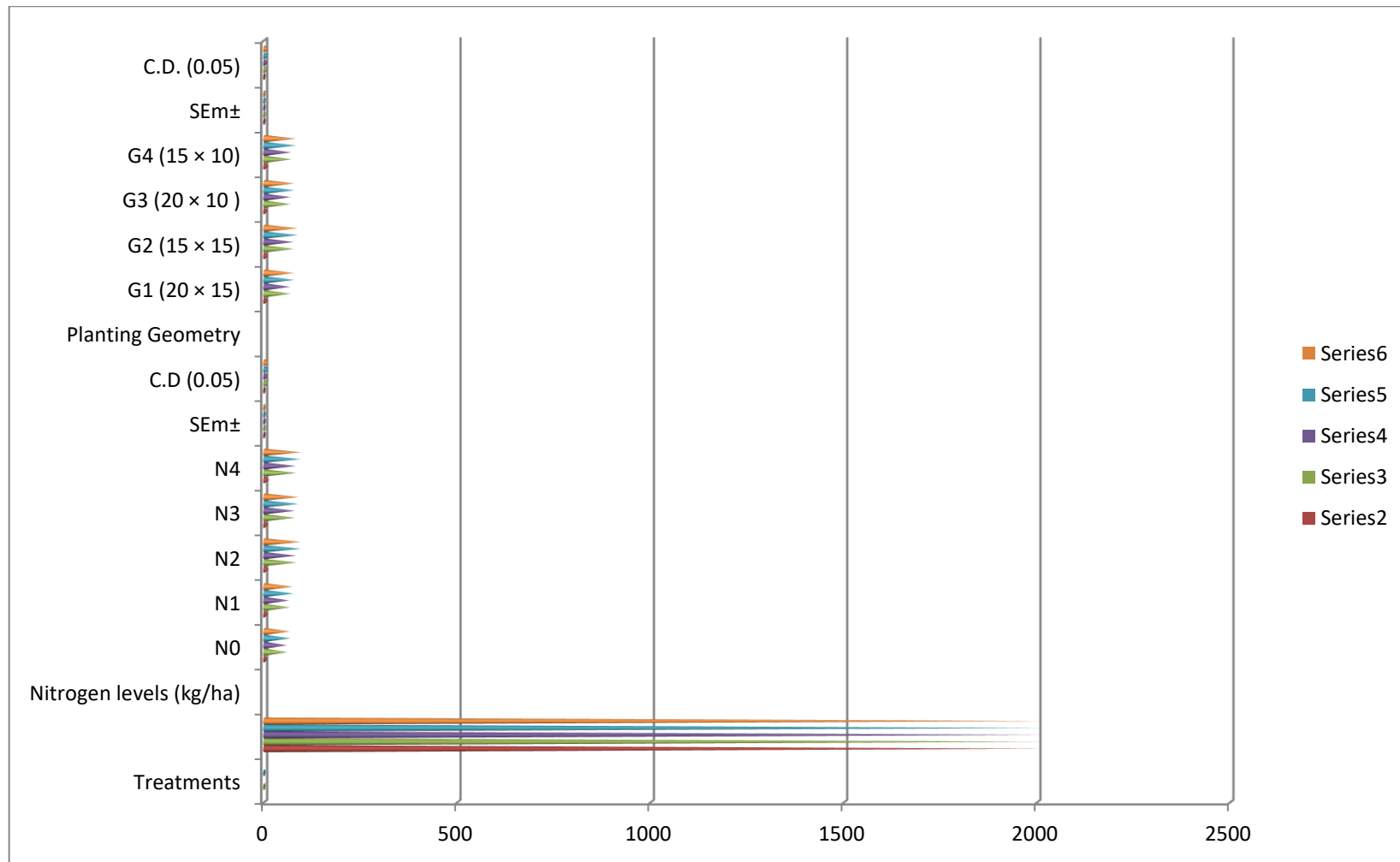


Fig. 3. Influence of planting geometry and nitrogen levels on potassium uptake by grain, potassium uptake by straw and total potassium uptake of rice

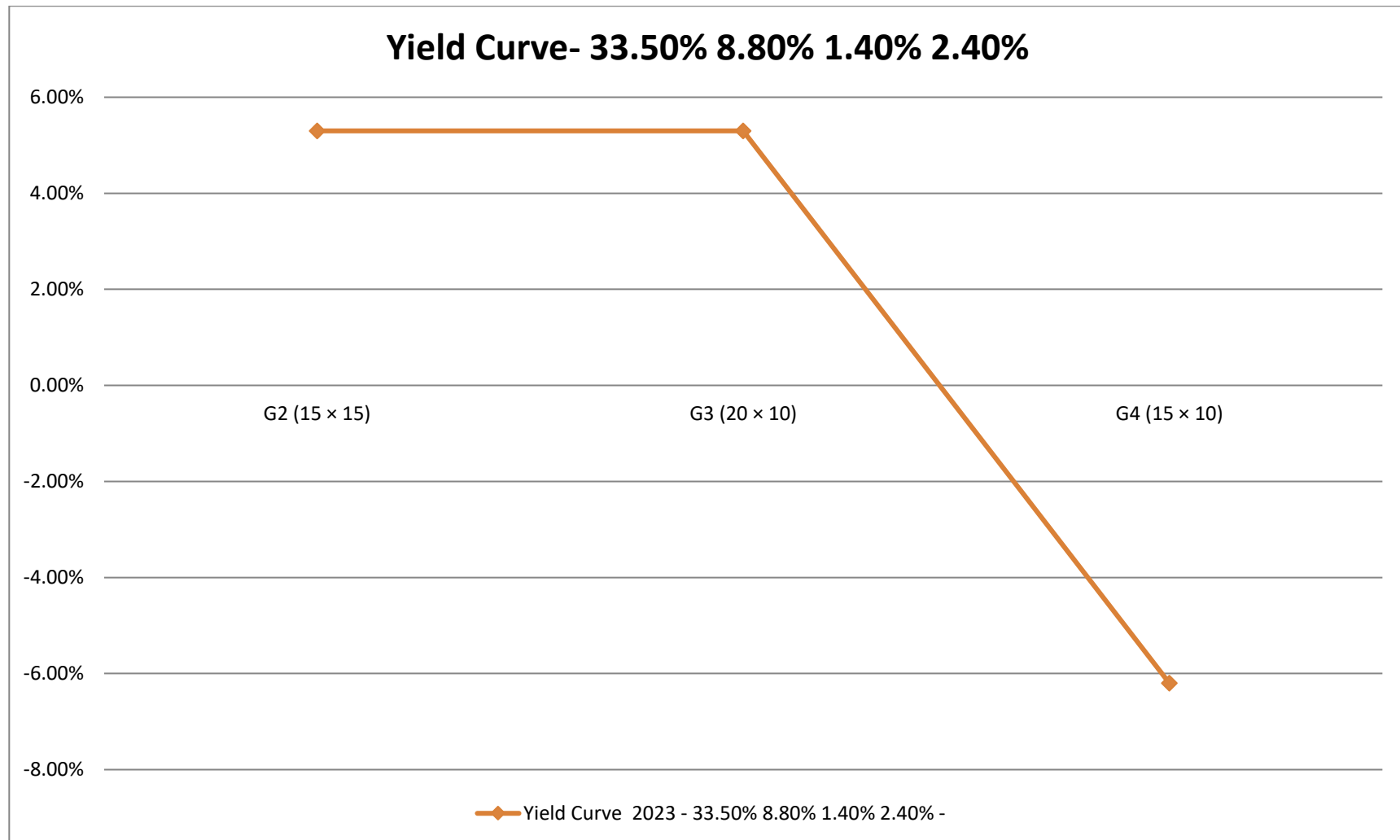


Fig. 4. Effect of different nitrogen levels and spacing yield curve of basmati rice

4. CONCLUSION

The two-year study (2022–2023) demonstrated that nitrogen levels and planting geometry significantly influenced nitrogen, phosphorus, and potassium uptake, as well as grain yield in rice. Higher nitrogen applications, particularly at 100 kg N/ha (N4), consistently enhanced nutrient uptake across grain, straw, and total uptake for all three nutrients, with results comparable to 80 kg N/ha (N3) but significantly superior to lower levels. The 20 × 10 cm planting geometry (G3) generally maximised nutrient uptake and grain yield, closely followed by 15 × 15 cm (G2), while overly dense spacing (15 × 10 cm, G4) often reduced yields, indicating an optimal density threshold. Yield curves revealed diminishing returns with increasing nitrogen, with the most significant yield boost at lower nitrogen levels (N1), and denser planting geometries like G3 outperforming others, especially in 2023. These findings underscore the importance of balancing nitrogen application and planting density to optimise nutrient uptake and maximise rice yield, with 20 × 10 cm spacing and moderate-to-high nitrogen levels offering the best outcomes.

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.

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