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Effect of Planting Geometry and Inorganic Fertilizers with Nano Urea Quality and Nutrient Uptake of Rice Crop (*Oryza sativa* L.)

Manju Singh [a++*], A.K. Singh [a#], Kamaran Azam [a++], Vikash Singh [a++], Mohammad Nabi Marufi [a++] and Alok Kumar Pandey [b†]

[a] *Department of Agronomy, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, Uttar Pradesh- 224229, India.*
[b] *Department of Soil Science and Agricultural Chemistry, Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, Uttar Pradesh- 224229, India.*

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

The present investigation entitled "Influence of planting geometry and inorganic fertilizers with nano urea on productivity of rice crop (*Oryza sativa* L.)." was conducted at Agronomy Research Farm of Narendra Deva University of Agriculture and Technology, Narendra Nagar (Kumarganj), Faizabad-

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++ *Research Scholar;*
# *Professor;*
† *Assistant Professor;*
**Corresponding author: E-mail: anilkumarsinghmausam@nduat.org;*

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224229 (U.P.) during *Kharif* seasons of 2022 and 2023. Fifteen treatment combinations comprised of three planting geometry C_1 (20 cm × 10 cm), C_2 (20 cm × 15 cm) and C_3 (20 cm × 20 cm) in main plot with five fertility levels F_1 - 100% RDF (150:60:40), F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1}(Tillering and Panicle initiation stage)], F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1}(Tillering and Panicle initiation stage)], F_4 [50% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1}(Tillering and Panicle initiation stage)] and F_5 - Control [no fertilizers] were executed in split plot design keeping fertility levels in sub plot with three replications. The soil of experimental plot was silty loam in texture with low in orgainic carbon and nitrogen médium in phosphorus and high in potassium. The treatment combination C_1 (20 cm × 10 cm) along with F_2 [100% RDF + two foliar applications of nano urea at 3000 ml ha^{-1} (during Tillering and Panicle initiation stages)] demonstrated significantly elevated levels of quality and nutrient uptake, including protein content (%), yield (kg ha^{-1}), NPK content (%), and NPK uptake (kg ha^{-1}). This performance was comparable to the combination of C_1 (20 cm × 10 cm) with F_3 [75% RDF + two foliar applications of nano urea at 3000 ml ha^{-1} (during Tillering and Panicle initiation stages)], and notably surpassed other treatments. In summary, the utilization of C_1 (20 cm × 10 cm) coupled with F_2 [100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (during Tillering and Panicle initiation stages)] exhibited superior outcomes across all parameters of quality and nutrient absorption, leading to increased rice crop yield and profitability over both study years.

Keywords: Protein yield, nano urea and NPK uptake.

1. INTRODUCTION

"Rice (*Oryza sativa* L.) of Family Poaceae is a prominent staple food for a large part of the world. In India, rice cultivation spans over 450.57 lakh hectares, yielding around 122.27 million tons annually, with an average productivity of 2713 kg per hectare" [1]. Uttar Pradesh ranks as the second-largest rice-growing state after West Bengal, though its productivity remains comparatively low. With approximately 59.70 lakh hectares dedicated to rice cultivation, Uttar Pradesh yielded about 159.68 lakh metric tons, with a productivity of 26.75 quintals per hectare [2]. Rice cultivation occurs in various soil and climatic conditions, yet productivity levels in India lag behind those of many other countries. Thus, there exists significant potential for enhancing rice productivity within the country through the adoption of improved technologies and various interventions.

"Planting geometry of a crop affects the interception of solar radiation, crop canopy coverage, dry matter accumulation and crop growth rate" [3]. The integration of planting geometry and inorganic fertilizer with nano urea fertilizer management presents an opportunity to enhance resource use efficiency, maximize yield potential, and mitigate environmental risks in rice cultivation.

2. MATERIALS AND METHODS

The geographical location of the experimental site falls within the sub-tropical climate of the Indo-Gangetic plains (IGP), characterized by alluvial calcareous soil. The experiment was conducted during the *Kharif* seasons of 2022 and 2023 at the Agronomy Research Farm of Acharya Narendra Deva University of Agriculture and Technology in Kumarganj, Ayodhya (U.P.). The soil in the experimental field was classified as "silty loam," with low organic carbon and available nitrogen, medium phosphorus, and rich potassium levels. A Split Plot Design with three replications was employed for the experiment. The rice variety Sarjoo-52 was manually transplanted during the *Kharif* seasons of both years, on July 2, 2022, and July 13, 2023, respectively. The main plot consisted of three planting geometries: C_1 (20 cm × 10 cm), C_2 (20 cm × 15 cm), and C_3 (20 cm × 20 cm). The sub-plot treatments included five fertilizer levels: F_1 [100% RDF (150:60:40)], F_2 [100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (during Tillering and Panicle Initiation stages)], F_3 [75% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (during Tillering and Panicle Initiation stages)], F_4 [50% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (during Tillering and Panicle Initiation stages)], and F_5 [Control (no fertilizers)].

2.1 Nano Urea

The nano urea, sourced from the Indian Farmers Fertilizer Cooperative Limited (IFFCO), was administered at a rate of 3000 ml per hectare, equivalent to 4 ml per liter, in two separate applications during the Tillering and Panicle Initiation stages.

2.2 NPK Content in Grain and Straw

Nitrogen content in grain and straw was analyzed by modified micro-Kjeldahl method [4] by digesting samples in sulphuric acid in a micro-Kjeldhal flask (digestion tube) on a hot plate. The distillation process was carried out using Nitrogen Analyzer (Gerhart) and titration was carried out using digital burette.

Phosphorus content in grain and straw was estimated by Vanadomolybdo phosphoric acid yellow colour method [4] and the intensity of yellow colour was read with Spectro-photometer at 420 nm and the contents were expressed in terms of percentage phosphorus.

Estimation of potassium content in grain and straw by flame emission photometry method [4,5,6] was used in di-acid digested samples and reported as per cent potassium.

2.3 NPK Uptake

“The nitrogen content in plants was determined by Kjeldahl's method. The grain straw was separated and then grinded. The grinded material was digested in concentrated sulphuric acid using copper sulphate and potassium sulphate mixture as catalyst. The digested material was then distilled with 40 per cent sodium hydroxide and distillate was collected in boric acid containing the mixed indicator. The content was estimated by titrating the distillate against N/20 sulphuric acid. The nitrogen uptake was calculated by multiplying the dry weight with nitrogen content. To get total uptake of nitrogen, the uptake values for grain and straw were added together”.

“Phosphorus uptake was determined in the extract by Vando molybdate yellow color method. The optical density (OD) was measured with photoelectric colorimeter at 470nm. The content was estimated with calibration curve. The phosphorous uptake by grain and straw per hectare was calculated with the help of per cent value of phosphorus and yield of grain and straw. To get uptake of phosphorous, the uptake value for grain and straw were added together plot wise” [7].

The potassium content was determined with the help of flame photometer [8,9,4] and was estimated with calibration curve. The uptake of potassium by rice grain and straw was calculated by multiplying their relative contents with yield and values were added to know the uptake of potassium in kgha^{-1}.

Grain uptake (kgha^{-1}) = Grain yield (qha^{-1}) × Nutrient content (%) in grain

Straw uptake (kgha^{-1}) = Straw yield (qha^{-1}) × Nutrient content (%) in straw

2.4 Protein Content in Grain (%)

Protein content in rice grains was estimated separately by multiplying the nitrogen content of grain ‘6.25’ as determined by modified Nessler’s reagent method. The nitrogen content was multiplied by a factor of 6.25 [10].

2.5 Protein Yield (Kg ha^{-1})

The protein yield of rice was calculated by multiplying the respective grain yield (kg/ha) with their protein content in grains divided by 100.

3. RESULTS AND DISCUSSION

3.1 Nitrogen Content in Grain and Straw of Rice (%)

The data related to Nitrogen content in grain and straw of rice presented in Table 1, clearly indicates that planting geometry has non-significant effect on nitrogen content in grain and straw in rice during both the years of experiment. However, maximum nitrogen content 1.35 % and 1.40 % in grain and 0.48 % and 0.50 % in straw was recorded under treatment C_1 (20 cm × 10 cm) during both the year 2022 and 2023. On the other hand, the minimum nitrogen content 1.20 % and 1.23% in grain and 0.40 % and 0.42 % in straw was recorded under treatment C_3 (20 cm × 20 cm) during both year 2022 and 2023. This could be attributed to increased N supply as well as better availability and activity of nutrients. Nitrogen content of rice was significantly affected by successive stages of plant growth. Similar findings were also found by Gunari et al. (2004) and Pal et al. [11].

Among fertilizer levels, application of F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1}(Tillering and PI stage)] recorded significantly maximum nitrogen content in grain and straw i.e. 1.36 % and 1.41% and 0.49 % and 0.52% during 2022 and 2023 respectively which was at par with application of F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)]. This might be due to N uptake with increasing supply of nitrogen and escalation in growth as reflected in grain yields. Similar findings were also found by Anwar et al. [12].

3.2 Nitrogen Uptake by Grain and Straw of Rice (kg ha^{-1})

The data related to nitrogen uptake by grain and straw (kg ha^{-1}) is summarized in Table 1. Data further revealed that maximum nitrogen uptake by grain and straw (65.21 kg ha^{-1} and 70.56 kg ha^{-1}) and straw (33.27 kg ha^{-1} and 35.81 kg ha^{-1}) during 2022 and 2023 respectively, was recorded under treatment C_1 (20 cm × 10 cm) which was at par with treatment C_2 (20 cm × 15 cm) and was significantly higher than rest of the treatments. This might be because dry matter increased in terms of grain and straw yields. Similar findings were also found by Gunari et al. (2004) and Pal et al. [11].

Among fertilizer levels, treatment F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] recorded significantly maximum nitrogen uptake in grain and straw i.e., 72.90 kg ha^{-1} and 78.11 kg ha^{-1} and, 35.82 kg ha^{-1} and 39.20 kg ha^{-1} during both the year 2022 and 2023 respectively which was at par with application of F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] and F_1 (100% RDF; 150:60:400 and significantly higher than the rest of the fertilizer levels during both years. This might be due to the increased application of nitrogen in split doses accelerates its availability for crop uptake. This could be attributed to factors such as larger surface area and nano-scale particle size in nano-fertilizers, along with a higher number of particles per unit area. These characteristics may enhance the efficiency of nutrient uptake by facilitating entry through stomatal openings in leaves. These findings echo similar conclusions drawn by Yadav et al. [13], Rizwan et al. [14], and Sahu et al. [15].

3.3 Phosphorus Content in Grain and Straw of Rice (%)

The data related to phosphorus content in grain and straw (%) presented in Table 2, clearly indicates that the phosphorus content in grain and straw was non-significantly influenced by planting geometry during both the years. Maximum phosphorus content 0.36 % and 0.40 % in grain and 0.19 % and 0.21 % in straw during both the year 2022 and 2023 respectively, was recorded under treatment C_1 (20 cm × 10 cm). This might be because dry matter increased in terms of grain and straw yields. Similar findings were also found by Gunari et al. (2004) and Pal et al. [11].

Table 1. Nitrogen content (%) and Nitrogen uptake (kg/ha) of rice as influenced by different planting geometry and inorganic fertilizers with nano urea

Treatments	Nitrogen content (%)				Nitrogen uptake (kg ha^{-1})			
	Grains		Straw		Grains		Straw	
	2022	2023	2022	2023	2022	2023	2022	2023
(A) Planting geometry`								
C_1 - 20 cm×10 cm	1.35	1.40	0.48	0.50	65.21	70.56	33.27	35.81
C_2 - 20 cm×15 cm	1.24	1.29	0.44	0.46	57.29	61.40	29.92	31.96
C_3 - 20 cm×20 cm	1.20	1.23	0.40	0.42	51.73	55.75	25.75	28.95
SEm±	0.004	0.004	0.001	0.002	2.86	3.12	1.24	1.34
C.D. (P=0.05)	NS	NS	NS	NS	8.54	9.31	3.70	3.97
(B) Fertilizers levels								
F_1 - 100% RDF (150:60:40)	1.28	1.33	0.45	0.47	63.23	68.36	31.83	34.72
F_2 -100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	1.36	1.41	0.49	0.52	72.90	78.11	35.82	39.20
F_3 - 75% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	1.35	1.39	0.48	0.53	69.43	75.07	34.19	36.92
F_4- 50% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	1.26	1.30	0.44	0.46	59.60	63.96	28.82	31.55
F_5 - Control (no fertilizers)	1.21	1.22	0.40	0.42	40.32	43.52	22.78	25.24
SEm±	0.006	0.006	0.003	0.003	3.32	3.46	1.62	1.78
C.D. (P=0.05)	0.018	0.019	0.009	0.009	9.92	10.34	4.82	5.31

Table 2. Phosphorus content (%) and Phosphorus uptake (kg/ha) of rice as influenced by different planting geometry and inorganic fertilizers with nano urea

Treatments	Phosphorus content (%)				Phosphorus uptake (kg ha^{-1})			
	Grains		Straw		Grains		Straw	
	2022	2023	2022	2023	2022	2023	2022	2023
(A) Planting geometry								
C_1 - 20 cm×10 cm	0.36	0.40	0.19	0.21	17.39	20.16	13.17	15.04
C_2 - 20 cm×15 cm	0.32	0.35	0.16	0.18	14.78	16.66	10.88	12.51
C_3 - 20 cm×20 cm	0.30	0.34	0.15	0.17	12.72	15.16	9.20	11.18
SEm±	0.002	0.002	0.003	0.003	0.97	1.21	0.94	1.02
C.D. (P=0.05)	NS	NS	NS	NS	2.90	3.61	2.80	3.02
(B) Fertilizers levels								
F_1 - 100% RDF (150:60:40)	0.34	0.36	0.17	0.19	16.80	18.50	12.03	14.04
F_2 -100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	0.37	0.39	0.20	0.23	19.83	21.61	14.62	17.34
F_3 - 75% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	0.35	0.38	0.19	0.21	18.27	20.67	13.53	15.51
F_4- 50% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	0.33	0.36	0.16	0.18	15.61	17.71	10.48	12.34
F_5 - Control (no fertilizers)	0.30	0.32	0.14	0.16	10.08	11.23	7.78	9.39
SEm±	0.003	0.003	0.003	0.003	1.12	1.20	1.08	1.16
C.D. (P=0.05)	NS	NS	NS	NS	3.32	3.57	3.20	3.45

The data further revealed that the fertilizer levels had non-significant effect on phosphorus content in grain and straw. However, maximum phosphorus content 0.37 % and 0.39 % in grain, and 0.20 % and 0.23 % in straw was recorded in treatment F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] during both the year 2022 and 2023 respectively [16,17]. Minimum phosphorus content, 0.30 and 0.32 % in grain, 0.14 and 0.16 % in straw was recorded in treatment F_5 (Control; no fertilizers) during both years respectively. Higher uptake was mainly due to synergistic effect of nitrogen levels and potassium at that combination. Nishanth and Biswas [18] also reported similar types of responses.

3.4 Phosphorus Uptake by Grain and Straw of Rice (kg ha^{-1})

The data related to phosphorus uptake by grain and straw (kg ha^{-1}) is presented in Table 2. revealed that maximum phosphorus uptake by grain (17.39 kg ha^{-1} and 20.16 kg ha^{-1}) and straw (13.17 kg ha^{-1} and 15.04 kg ha^{-1}) during 2022 and 2023 respectively was recorded under treatment C_1 (20 cm × 10 cm) which was at par with treatment C_2 (20 cm × 15 cm) and was also significantly higher than rest of the treatments. This might be because dry matter increased in terms of grain and straw yields. Similar findings were also found by Gunari et al. (2004) and Pal et al. [11].

Among fertilizer levels, application of F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1}(Tillering and PI stage)] recorded significantly maximum phosphorus uptake in grain and straw i.e., 19.83 kg ha^{-1} and 21.61 kg ha^{-1} in grain, 14.62 kg ha^{-1} and 17.34 kg ha^{-1} in straw during both the year 2022 and 2023 respectively which was at par with application of F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] and F_1 (100% RDF; 150:60:40). The effect of F_2 was significantly higher than the rest of the fertilizer levels during both years. The uptake of phosphorus may have been notably influenced by varying levels of nitrogen application. Higher phosphorus uptake could be attributed to the higher availability of phosphorus in soil. These results were in conformity with the findings of Nishanth and Biswas [18].

3.5 Potassium Content in Grain and Straw of Rice (%)

The data related to potassium content in grain and straw (%) presented in Table 3, clearly indicates that the potassium content in grain and straw in rice non-significantly influenced by planting geometry during both the years. However, the maximum Potassium content 0.47 % and 0.50 % in grain and 1.33 % and 1.36 % in straw during both the year 2022 and 2023 respectively was recorded under treatment C_1 (20 cm × 10 cm). This might be because dry matter increased in terms of grain and straw yields. Similar findings were also found by Gunari et al. (2004) and Pal et al. [11].

The data further revealed that the fertilizer levels had non-significant effect on Potassium content in grain and straw. However, the maximum Potassium content 0.49 % and 0.53 % in grain, and 1.36 % and 1.39 % in straw was recorded with the application of F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] during both the year 2022 and 2023 respectively. Minimum Potassium content 0.42 and 0.45 % in grain, 1.24 and 1.27 % in straw, was recorded under treatment F_5 (Control; no fertilizers) during both years respectively. This can be attributed to the fact that specific effect of potassium is observed through the increased nitrogen utilization efficiency. The results are in conformity with work done by Thakuria and Choudary [19].

3.6 Potassium Uptake by Grain and Straw of Rice (kg ha^{-1})

The data related to potassium uptake by grain and straw (kg ha^{-1}) is presented in Table 3. revealed that maximum potassium uptake by grain and straw, 22.70 and 25.20 kg ha^{-1} by grain and 92.18 and 97.39 kg ha^{-1} by straw during 2022 and 2023 respectively was recorded under treatment C_1 (20 cm × 10 cm) which was at par with treatment C_2 (20 cm × 15 cm) and was significantly higher than rest of the treatments. This might be because dry matter increased in terms of grain and straw yields. Similar findings were also found by Gunari et al. (2004) and Pal et al. [11].

Table 3. Potassium content (%) and Potassium uptake (kg/ha) of rice as influenced by different planting geometry and inorganic fertilizers with nano urea

Treatments	Potassium content (%)				Potassium uptake (kg ha^{-1})			
	Grains		Straw		Grains		Straw	
	2022	2023	2022	2023	2022	2023	2022	2023
(A) Planting geometry								
C_1 - 20 cm×10 cm	0.47	0.50	1.33	1.36	22.70	25.20	92.18	97.39
C_2 - 20 cm×15 cm	0.44	0.47	1.28	1.31	20.33	22.37	87.03	91.02
C_3 - 20 cm×20 cm	0.42	0.45	1.25	1.28	17.81	20.07	76.63	84.21
SEm±	0.003	0.003	0.004	0.004	0.90	0.98	1.86	2.24
C.D. (P=0.05)	NS	NS	NS	NS	2.72	2.97	5.65	6.70
(B) Fertilizers levels								
F_1 - 100% RDF (150:60:40)	0.46	0.49	1.31	1.34	22.72	25.19	92.67	99.00
F_2 -100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	0.49	0.53	1.36	1.39	26.26	29.36	99.43	104.79
F_3 - 75% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	0.48	0.51	1.33	1.36	25.06	27.74	94.74	100.42
F_4- 50% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	0.45	0.48	1.29	1.32	21.29	23.62	84.51	90.53
F_5 - Control (no fertilizers)	0.42	0.45	1.24	1.27	14.11	15.80	68.89	74.54
SEm±	0.004	0.004	0.005	0.005	1.24	1.42	2.32	2.47
C.D. (P=0.05)	NS	NS	NS	NS	3.70	4.24	6.94	7.38

Among fertilizer levels, application of F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] recorded significantly maximum potassium uptake in grain and straw i.e., 26.26 kg ha^{-1} and 29.36 kg ha^{-1} in grain, 99.43 kg ha^{-1} and 104.79 kg ha^{-1} in straw during both the year 2022 and 2023 respectively which was at par with application of F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] and F_1 (100% RDF; 150:60:40) and significantly higher than the rest of the fertilizer levels during both years. This can be attributed to the fact that specific effect of potassium is observed through the increased nitrogen utilization efficiency. The results are in conformity with work done by Thakuria and Choudary [19].

3.7 Protein Content in Grain (%)

The data related to protein content in grain (%) presented in Table 4, indicates that planting geometry had non-significant effect on protein content (%) in grain during both the years of experiment. However, maximum protein content 8.44 % and 8.75 % in grain was recorded under treatment C_1 (20 cm × 10 cm) during both the year 2022 and 2023. The minimum protein content 7.50 % and 7.69 % in grain was recorded under treatment C_3 (20 cm × 20 cm) during both the year 2022 and 2023. Similar findings were also found by Singh and Verma [20], Dewedi et al. [21].

Among fertilizer levels, application of F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] recorded significantly maximum protein content in grain i.e., 8.50 and 8.81 %, in both the year 2022 and 2023 respectively which was at par with application of F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] and F_1 (100% RDF; 150:60:40) and significantly higher than the rest of the fertilizer levels during both years. This increment in protein content might be due to increment in nitrogen content in grain and straw, as nitrogen (N) in vegetative organs (tillers and leaves). Similar findings were also found by Havlin et al. [22], and Khanday et al. [23].

3.8 Protein Yield (Kg/ha)

The data related to protein yield (kg ha^{-1}) presented in Table:4, clearly indicates that planting geometry had significant effect on protein yield (Kg/ha) during both the experimental. Maximum protein yield (407.65 kg ha^{-1} % and 441.00 kg ha^{-1}) recorded under treatment C_1 (20 cm × 10 cm) was at par with that of C_2 (20 cm × 15 cm), during both year 2022 and 2023 and was significantly higher than rest

Table 4. Protein content in grain (%) and Protein yield (Kg/ha) of rice as influenced by different planting geometry and inorganic fertilizers with nano urea

Treatments	Protein content in grain (%)		Protein yield (Kg/ha)	
	2022	2023	2022	2023
(A) Planting geometry				
C_1 - 20 cm×10 cm	8.44	8.75	407.65	441.00
C_2 - 20 cm×15 cm	7.75	8.06	358.05	383.66
C_3 - 20 cm×20 cm	7.50	7.69	318.00	342.97
SEm±	0.11	0.15	13.70	15.01
C.D. (P=0.05)	NS	NS	55.23	60.53
(B) Fertilizers levels				
F_1 - 100% RDF (150:60:40)	8.00	8.31	395.20	427.97
F_2 -100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	8.50	8.81	455.60	488.07
F_3 - 75% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	8.31	8.63	433.78	469.47
F_4- 50% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)	7.88	8.13	372.72	400.00
F_5 - Control (no fertilizers)	7.56	7.63	254.02	267.81
SEm±	0.17	0.21	20.90	22.33
C.D. (P=0.05)	0.51	0.62	61.26	65.21

of the treatments. Similar findings were also found by Singh and Verma [20], Dewedi et al. [21].

Among fertilizer levels, application of F_2 [100% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] recorded significantly maximum protein yield i.e., 455.60 kg ha^{-1} and 488.07 kg ha^{-1} in both the year 2022 and 2023 respectively which was at par with application F_3 [75% RDF + Two foliar spray of nano urea @ 3000 ml ha^{-1} (Tillering and PI stage)] and F_1 (100% RDF; 150:60:40) and significantly higher than the rest of the fertilizer levels during both years [24,25]. This increment in protein content (%) might be due to increment in nitrogen content in grain and straw, as nitrogen (N) in vegetative organs (tillers and leaves) resulted in higher protein yield. Similar findings were also found by Havlin et al. [22], and Khanday et al. [23].

4. CONCLUSION

Based on the above findings, it is evident that treatment C_1 (20 cm × 10 cm) coupled with the application of F_2 [100% RDF + foliar spray of nano urea @ 3000 ml ha^{-1} (during Tillering and PI stages)] exhibited superior quality and growth indices in terms of protein content (%), yield (kg ha^{-1}), as well as NPK content (%) and uptake (kg ha^{-1}) across both 2022 and 2023.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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