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Relative influence of nitrogen induced crop parameters on grain yield of rice using principal component analysis model

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Abstract

Nitrogen (N) plays a crucial role in the metabolic and physiological processes of rice. This caused variation in growth parameters, yield attributes and yield of rice. Growth parameters were recorded at different times and yield attributes were used to work out the relationship of each parameter with grain yield. Such statistical analysis may not yield a concrete result. However, Principal Component Analysis (PCA) helps in identifying the principal components among the observed parameters and their relative influence on yield. A field study was carried out to assess the performance of different crop parameters and yield of *kharif* rice under seven nitrogen levels. The crop was exposed to 0, 20, 40, 60, 80, 100 and 120 kg N ha^{-1}. An increase in the N level increases the magnitude of all growth parameters, yield attributes, grain and straw yield. The increment significantly differed among the treatments when the N level difference was 40 kg N ha^{-1}. Principal component analysis (PCA biplot) established that rice performed strongly under N$_{80}$ (which is the recommended dose of rice in this region), followed by N$_{60}$, N$_{100}$, N$_{40}$, N$_{120}$ and so on. Panicle bearing tiller is the well-representative parameter in the PCA space, followed by percent filled grain and plant height. The present study identified the relative influence of growth parameters at different growth stages and yield attributes on grain yield. The output of this study helped the breeders to put emphasis on particular traits in relation to their contribution towards yield for their future research plan.

Keywords

filled grains; leaf area index; nutrient management; productive tillers; yield

Introduction

Before 3000 BC, the domestication of rice started in South and Southeast Asia. Southern Odisha, where the present study was carried out, has been identified as a place in India where the rice cultivation originated during that period (1). Globally, rice (*Oryza sativa* L.) is a principal crop that feeds around 50 % of the global population and supplies 35 to 60 % of calory to them (2). The global demand for rice increased from 437.179 million tons (Mt) to 520.437 Mt during 2008-09 to 2022-23 (3). The projected demands by 2035 and 2050 are respectively, 553 and 623 Mt (4). The demand for rice for the current Indian population is 116.5 Mt. It will be 125.5 and 137.4Mt to feed the projected Indian population of 1619 and 1824 million by the years 2035 and 2050 (5). Currently, in India, rice occupies an area of 43.9 million ha with an annual production of 130.94 Mt and a productivity of 3427 kg ha^{-1}. The rice area in Odisha is 3.8 million ha, with a total production of 6.6 million tons and a productivity level of 1739 kg ha^{-1} (6). By another 11 years, India will have produced an additional amount of 7.56 Mt rice per year, which is over the current status. To achieve the target, various factors need to be explored and nitrogen management is one of them.

Nitrogen (N) is the most critical limiting factor, which influences yield parameters as well as grain yield (7). Nitrogen influences various metabolic and physiological processes within rice plants to the maximum possible extent (8). Canopy structure, the main output of photosynthesis, is regulated by N availability in the root rhizosphere. The status of the leaf area index is very much related to the N application rate. Tillering is a crucial parameter that influences the yield of rice (9). Nitrogen plays a crucial role in the enhancement of cytokinin content within tiller nodes, which boosts the germination of the tiller primordium (10). This way, N plays a significant role in the promotion of tiller development (11). The yield of rice is regulated by indirect traits like the height of the plant, tillering ability and duration of the growing period (12, 13). Besides, direct traits like the number of panicles bearing tillers per unit area, number of filled grains per panicle, length of panicle and spikelet per panicle are also influenced by the magnitude of the yield (14, 15). An increase in N level and enhanced the translocation of carbon and nitrogen during the grain filling stage resulted in more spikelet numbers per panicle and grain filling %, thus resulting in a higher yield. An increase in N dose from 120 to 190 kg ha^{-1} significantly escalates the status of plant height, panicle length, number of filled grains /panicle and grain yield (16, 17).

It has already been discussed that yield is dependent on a good number of indirect (growth parameters) and direct (yield attributes) traits. Indirect traits were recorded on multiple dates during the crop-growing period. As a result, huge amount of data is generated to correlate them to the yield component. To overcome such a difficult task, a statistical technique can be adopted to transform the huge number of variables into a set of new orthogonal variables called principal components (18, 19). Principal component analysis (PCA) reveals the patterns and eliminates the redundancy in datasets, as variation occurs commonly in plants for yield and yield-related traits (20, 21).

In the present study, efforts have been made to determine how N levels influenced the status of both the traits as well as the grain and straw yield. Additionally, principal component analysis was done to reveal the level of influence opted by both traits on grain yield. So that higher contributing traits can be paid special attention to by the breeders in future breeding programs. The purpose of the present study was to address 2 objectives: How a wide range of nitrogen levels influences the status of an individual trait and the ranking of an individual trait in terms of its contribution towards grain yield.

Materials and Methods

Experimental area

A field study was carried out during the *Kharif* season of 2023 at the research farm of Centurion University of Technology and Management, Bagusala, India (18.80°N latitude, 84.17°E longitude), at an elevation of 86 m above sea level. During the cropping period, maximum and minimum temperatures ranged between 31.2 °C to 35 °C and 22.5 °C to 26.5 °C respectively. The crop received a total rainfall of 457.5 mm. Maximum and minimum relative humidity in the study area ranged between 83.6 % to 89.7 % and 60.4 % to 80.4 % respectively. The average bright sunshine hours during the crop growing period varied between 5.1 h day^{-1} to 11 h day^{-1}. The experimental soil was sandy loam in texture. The soil organic carbon content was 0.38 %. The initial available soil N: P: K status was 253:11.8:123 kg ha^{-1} respectively. The experiment was conducted by using a randomized block design (RBD) with 7 treatments replicated thrice. The experimental treatments were N_0 (Control, 0 kg N ha^{-1}), N_{20} (20 kg N ha^{-1}), N_{40} (40 kg N ha^{-1}), N_{60} (60 kg N ha^{-1}), N_{80} (Recommended one for the local area, 80 kg N ha^{-1}), N_{100} (100 kg N ha^{-1}) and N_{120} (120 kg N ha^{-1}). The phosphorus and potassium doses were fixed as 40 kg P_2O_5 and 40 kg K_2O ha^{-1}. Rice was taken as a test crop with the genotype Shatabdi. Twentynine days old seedlings were transplanted. The experimental data were analysed using standard procedures for analysis of variance (22). the standard error of means and least significant difference at the 5 % level of significance for the interpretation of multiple comparison tests were calculated using R Studio version 4.3.1, R Foundation for Statistical Computing, Vienna, Austria. Principal Component Analysis: The data obtained for different treatments imposed were subjected to statistical analyses using software packages of MS Excel, SPSS 23.0 and Origin Pro 2021 version.

Results

Plant height

30 days after transplanting (DAT), application of 20 (N_{20}) and 120 (N_{120}) kg N ha^{-1} increased the value of plant height respectively by 12 and 84 % over the controlled (N_0, no nitrogen was applied) condition. The said increment was noted in the range of 9 and 66 %, 11 and 58 % and 9 and 51 % respectively, during 50, 70 and 90 DAT (Table 1). In general, the application of an additional dose of N at ≥40 kg N ha^{-1} resulted in a significant increase in plant height. However, on 70 DAT, even an increment of 20 kg N ha^{-1} from N_{80} to N_{120} level resulted in a significant increase (15.62 %) in plant height value. The % at which the plant height increased with the increase in nitrogen level followed a decreasing trend. This was more prominent on 30 DAT and narrowed down with the advancement of the crop growing period from 30 to 90 DAT.

Total tiller number

In the present study, it has been recorded that, irrespective of observation dates, an increment of 40 kg N ha^{-1},

Table 1. Impact of nitrogen levels on temporal changes in plant height

Nitrogen levels	Plant height (cm)			
	30 DAT	50 DAT	70 DAT	90 DAT (Harvest)
N_0	31.2	68.2	74.8	85.2
N_{20}	34.9	74.1	82.7	92.8
N_{40}	38.5	78.7	85.6	95.5
N_{60}	42.5	83.3	90.4	100.4
N_{80}	46.7	90.2	96.6	106.6
N_{100}	52.2	104.1	111.6	120.5
N_{120}	57.5	113.2	118.4	128.4
SEm±	2.25	4.38	4.54	4.70
LSD* (p =0.05)	6.82	13.29	13.78	14.27
CV %	9.40	8.97	8.60	8.03

resulted in a significant increase in values of total tiller number per m^2. However, in some cases, the same has been achieved by an additional 20 kg N ha^{-1}. At the initial crop growth stage (30 DAT), the total tiller number increased by 19 to 98 % respectively, under N_{20} and N_{120} nitrogen levels over the controlled condition. Subsequently, at 50, 70 and 90 DAT, the same increased by 25 to 123 %, 8 to 123 % and 8 to 123 % respectively. Irrespective of nitrogen levels, a sharp increase (62 to 91 %) in total tiller number was noted between 30 and 50 DAT. After attaining its maximum value on 50 DAT, the same decreased marginally till the harvest. This was because, as rice plants entered the reproductive stage, all metabolic energy resources were allocated towards the development of grains rather than producing new tillers. (Table 2)

Table 2. Impact of nitrogen levels on temporal changes in total tiller number

Nitrogen levels	Total tiller number (m^{-2})			
	30 DAT	50 DAT	70 DAT	90 DAT
N_0	98	158	142	134
N_{20}	117	197	153	151
N_{40}	128	222	198	172
N_{60}	138	262	236	188
N_{80}	163	303	266	203
N_{100}	182	324	297	208
N_{120}	194	348	316	219
SEm±	8.19	7.31	6.23	5.68
LSD* (p =0.05)	24.83	22.16	18.89	17.22
CV %	10.26	6.65	5.33	5.06

Leaf Area Index

Leaf area index (LAI) is one of the important growth parameters and is used as an input variable in many crop growth simulation models to predict grain yield. The present study shows that, in general, on 30 and 50 DAT, an increase in N level to the tune of 40 kg ha^{-1} only made a significant increment in the magnitude of LAI between the two treatments. At later growth stages (70 and 90 DAT), in some cases, the significant increase was noted only when the nitrogen level differed by 60 kg ha^{-1}. Irrespective of observation dates, an increase in N levels from 20 to 120 kg ha^{-1} recorded a continuously increasing trend on LAI. In comparison to the controlled condition (N_0), the rate of increase in the magnitude of LAI under N_{20} to N_{120} were 9 to 91, 22 to 65, 2 to 79 and 23 to 100 % higher respectively on 30, 50, 70 and 90 DAT. A massive (114 to 176 %) increase in the temporal changes in LAI was noted between 30 to 50 DAT. A maximum increase (176 %) was observed under N_{20} level and continuously decreased to 114 % till it reached to N_{120} level. An amount of 24 to 41 % decrease in magnitude of LAI was recorded from 50 to 70 DAT. After attaining the maximum (41 %) decrease under N_{20} level, the same narrowed down continuously to 24 % under N_{120} level. From 70 to 90 DAT magnitude of LAI lowered down by 16 to 33 % without any specific trend. (Table 3)

Table 3. Impact of nitrogen levels on temporal changes in leaf area index

Nitrogen levels	Leaf area index			
	30 DAT	50 DAT	70 DAT	90 DAT (Harvest)
N_0	1.17	2.9	2.04	1.42
N_{20}	1.28	3.53	2.08	1.74
N_{40}	1.53	3.64	2.41	2.03
N_{60}	1.64	3.84	2.64	2.23
N_{80}	1.81	4.16	2.89	2.32
N_{100}	1.96	4.53	3.31	2.67
N_{120}	2.24	4.79	3.65	2.84
SEm±	0.09	0.21	0.16	0.13
LSD* (p =0.05)	0.29	0.65	0.49	0.41
CV %	10.22	9.85	10.55	11.23

Yield attributing parameters

The present study shows that with an increase in nitrogen doses, in general, a difference of 60 kg N ha^{-1} only resulted in a significant difference in panicle-bearing tillers (PBT) numbers per m^{-2}. Data showed that an increase in nitrogen level from N_0 to N_{120} resulted in the continuously increasing trend of PBT from 5 to 36 %. Comparison between 2 adjacent N levels showed the maximum (10 %) increase in PBT recorded between N_{40} and N_{60} N levels. In contrast, the minimum (2 %) was between N_{100} and N_{120} levels.

Application of each additional 20 kg N ha^{-1} resulted in a 2 to 27 % increase in the magnitude of spikelet number per panicle (SNPP) under N_{20} to N_{120} nitrogen levels over the controlled (N_0) condition The difference in SNPP values was found significant only when the difference in nitrogen doses was 40 kg ha^{-1} or more in between two treatments. The increase in SNPP between N_{60} and N_{80}, as well as N_{100} and N $_{120}$ levels, is 9 and 6 % respectively. In other cases, it is 3 %.

An increase in nitrogen doses from N_0 to N_{120} resulted in a continuous increase in % filled grain values by 2 to 7 %. Unlike other parameters, a difference of a minimum of 100 kg nitrogen per ha is needed toward significant variance in values of % filled grains.

Variation in panicle length among different nitrogen levels was much wider than that of percent-filled grains. In comparison to N_0, under N_{20} to N_{120} nitrogen levels, the magnitude of panicle length increased by 10 to 50 %. A minimum difference of 40 kg N ha^{-1} made a significant increase in values of panicle length among the treatments. At lower levels (N_0 to N_{60}), the increment of panicle length value was around 10 %. At a higher level till N_{100}, the same was only 3 %. In comparison to N_{100}, the increment was 9 % under the N_{120} level. (Table 4)

Table 4. Impact of nitrogen levels on temporal changes on yield attributes

Nitrogen levels	Panicle bearing tiller number (m^{-2})	Spikelet number per panicle	Percent filled grains	Panicle length (cm)
N_0	157	118	87.93	16.83
N_{20}	165	120	90.11	18.53
N_{40}	171	123	91.29	19.57
N_{60}	188	127	92.03	21.67
N_{80}	195	138	92.85	22.23
N_{100}	208	142	93.44	23.13
N_{120}	213	150	93.76	25.27
SEm±	8.92	7.21	2.22	0.98
LSD* (p=0.05)	27.06	21.86	6.74	2.98
CV %	8.64	9.75	4.25	8.37

Grain Yield

The data on the grain yield revealed that an increase in nitrogen doses from N_0 to N_{120} levels resulted in 22 to 99 % increase in grain yield. Subsequent increment of 20 kg N ha^{-1} increased the yield by 15 %, 13 %, 11 %, 7 % and 6 % respectively under N_{40}, N_{60}, N_{80}, N_{100} and N_{120} nitrogen levels. It has been found that the magnitude of grain yield increment continuously decreased under each additional application of 20 kg N ha^{-1}. This yield trend is in line with that reported in the Lower Gangetic Plain (22).

Straw yield

The increase in straw yield due to an increase in nitrogen application rate followed a similar trend to that of grain yield. However, a comparison of data presented in Table 5 shows that under N_0 to N_{120} range, straw yield increased by 6 (N_{20}) to 63 % (N_{120}). However, the same was statistically significant only when the difference in nitrogen doses was 40 kg N ha^{-1}. Though the increment rate was low over grain (22 to 99 %) irrespective of nitrogen levels, straw yield was 26 to 57 % higher than that of grain yield. The differences were maximum (54 %) under controlled conditions (N_0) and minimum (26 %) under the N_{120} level. The enhancement rate of straw yield in between 2 consecutive nitrogen levels was maximum (15 %) under N_{60} over N_{40} and the same was minimum (3 %) in between N_{100} to N_{120} N levels (23).

Table 5. Impact of nitrogen levels on temporal changes on grain yield

Nitrogen levels	Yield (Mg ha^{-1})	
	Grain yield	Straw yield
N_0	2.72	4.19
N_{20}	3.32	4.45
N_{40}	3.83	5.10
N_{60}	4.31	5.63
N_{80}	4.77	6.10
N_{100}	5.12	6.63
N_{120}	5.42	6.85
SEm±	0.19	0.19
LSD* (p =0.05)	0.59	0.56
CV %	8.54	6.03

Principal component analysis

Principal component analysis (PCA) has been done to statistically compute the relative contribution of plant growth parameters as well as yield attributes on grain yield. The eigen values, % of variance and cumulative % of variance for grain yield are presented in Table 6. In the case of PC1, the Eigenvalue was 14.51 and the same reduced drastically in PC2 and thereafter marginally till PC7. As per Kaiser report (24), eigenvalues greater than 1.0 must be considered in PCA analysis to ensure diversity among the potential input sources.

Table 6. Eigen values and contribution of variability for the principal component axis for grain yield

Principal Component	Eigenvalue	Percentage of variance	Cumulative % of variance
PC1	14.5101	90.6881	90.7
PC2	0.8110	5.0688	95.8
PC3	0.4055	2.5342	98.3
PC4	0.1645	1.0280	99.3
PC5	0.0633	0.3958	99.7
PC6	0.0338	0.2113	99.9
PC7	0.0118	0.0738	100.0

In all of the scatter plot diagrams, treatment numbers associated with the highest grain yield, along with the higher value of the desired plant parametric traits, have been identified. They are plant height, total tillers and LAI at 50 DAT and the panicle bearing tillers, spikelet per panicle, % filled grain and panicle length at 90 DAT. The extraction value of these seven variables explains the relative importance of each variable. Maximum vector length was found for % filled grain, followed by the panicle bearing tiller number per m^2 on 90 DAT. However, as panicle bearing tillers on 90 DAT are close to the vector of grain yield with slightly less vector length, it is considered as the most influencing parameter to regulate grain yield status (Fig. 1). This figure also gives an idea about how the 7 variables interact with each other in PC1 and PC2 to perform variable biplot analysis. Principal component analysis (PCA biplot) established that the strong performance of rice was recorded under the application of 80 kg N ha^{-1} (N_{80}). This is the recommended dose of rice in this region. The performance of other nitrogen levels was in the order of N_{60}, N_{100}, N_{40}, N_{120} and so on (Table 7).

Discussion

Table 7. Communalities of initial and extraction values of variables.

Variables	Initial	Extraction
P height 50 DAT	1.000	0.995
Total tillers 50 DAT	1.000	0.994
LAI 50 DAT	1.000	0.981
Panicle bearing tiller at 90 DAT	1.000	0.999
Spikelet per panicle	1.000	0.988
Percent filled grains	1.000	0.997
Panicle length	1.000	0.995
Straw Yield	1.000	0.992

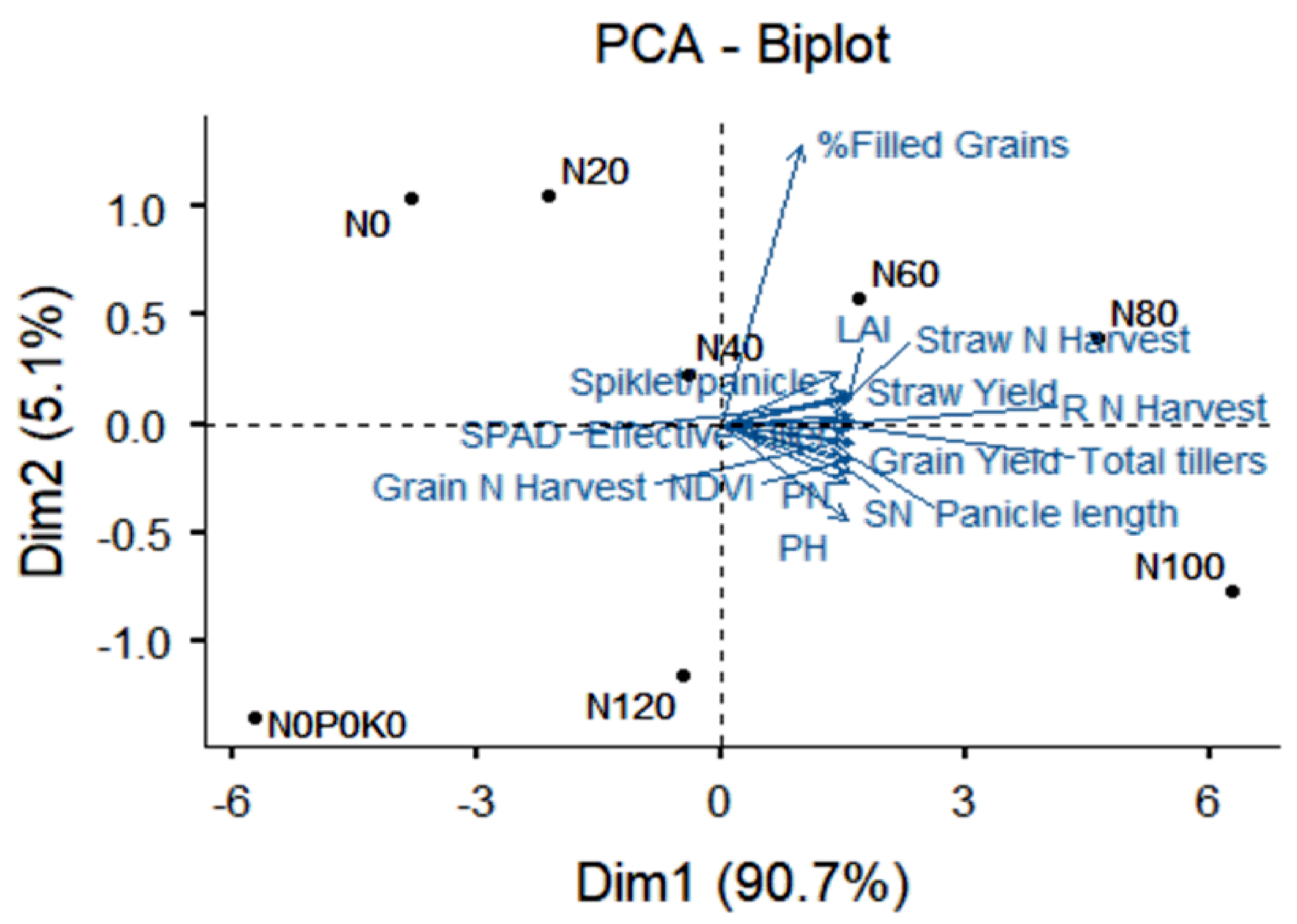

Fig. 1. Biplot of seven grain yield related variables across the first two principal components.

Nitrogen is one of the main nutrient inputs for crop production. Thus, there is a need to assess how the status of various traits (growth parameters and yield attributes) is influenced by nitrogen availability in sol and thereafter rank each trait as per its monitoring capacity on grain yield. Nitrogen plays a crucial role in the enhancement of the size and number of meristematic cells (25). This helps in an increase in plant height (26) with an increase in N doses. Adequate N supply during the tillering stage shall escalate the mineralization process, which helps in producing more tillers and to ensure higher grain yield (27). Though late-emerging tillers have a lower influence on yield due to the totipotency of rice coleoptile tissue, these tillers play a notable role in higher crop yield (28, 29). For this reason, researchers consider this growth parameter to be important. The reason for a significant increase in tiller number with different levels of N application can be attributed to Soil N availability, which regulates the cytokinin content within tiller nodes and further increases the germination of the tiller primordium (11). Nitrogen plays a crucial role in the metabolic activities of rice and the accumulation of higher photosynthates is reflected in LAI status, as observed in this study. During the vegetative stage, rice needs N to promote tillering, which regulates the number of panicles per unit area as well as the accumulation of carbohydrates in culms and leaf sheaths during the pre-heading stage. The accumulated carbohydrate also promotes the bearing of panicles (30). Nitrogen regulates yield attributes like the number of panicles m^{-2}, the number of spikelets per panicle, grain filling rate and grain weight, which in turn is reflected in grain yield (31). The PCA analysis also supports this hypothesis by identifying panicle-bearing tillers m^{-2} as the most influencing trait.

Nitrogen influences the process of starch biosynthesis process (32), causing variation in the hierarchical structure and physicochemical properties of starch (33, 34) and thus regulates the duration of the grain filling period and ultimately influences grain yield. Nitrogen is a component of amino acids and chlorophyll, thus regulating the protein metabolic process and photosynthesis rate (35), which in turn is reflected in grain yield. Many researchers have reported that the grain yield of rice increases with an increase in nitrogen level. However, the rate of increase decreases at higher N levels and beyond a point, total yield decreases with a further increase in N level (18). In fact, reduction in physiological processes beyond a critical dose of N is the reason for yield reduction. The experimental soil was coarse-textured lateritic soil with low initial available N (253 kg ha^{-1}) and organic carbon (0.42 %) content. These made the soil highly responsive to applied nitrogen. Secondly, the crop was exposed to favourable weather conditions during the majority of the growing period. Higher bright sunshine hours clubbed with lower relative humidity with a favourable soil moisture environment helps the crop to have a higher transpiration rate. A higher transpiration rate means a higher rate of photosynthesis (36). These are the reasons for the relatively higher grain yield in the present study. The correlation coefficient between 2 vectors representing variables in a biplot analysis is given by the cosine of the angle between the 2 vectors. Any angle between a vector representing a variable and an axis representing a principal component also gives an indication of the correlation between 2 variables (37). The vector length of each variable in the biplot signifies its overall contribution to the divergence. The longer vector length means greater contribution (38).

Conclusion

Different levels of nitrogen application have been found to have a significant influence on growth, yield attributes, and yield of rice. The increased level of nitrogen from 0 kg ha^{-1} to 120 kg ha^{-1} has resulted in a proportionate increase in growth parameters, yield attributes, and yield of rice. From the study, it can be concluded that the application of 120 kg N ha^{-1} dose of nitrogen along with 40 kg $^{-1}$ P_2O_5 and 40 kg $^{-1}$ K_2O can be the best nutrient management practice for a low fertile coarse-textured soil. Besides, the principal Component Biplot Technique can identify the particular growth parameter at any specific growth stage as well as yield attributes having a major influence on the grain yield of rice. The output of this study will assist the breeders in future breeding research to prioritize traits in relation to grain yield.

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Authors' contributions

Conceptualization, SS, TS and SR; Methodology, SR, CVR; Validation; SR, SS, TS; Analysis, SR, PKP, TB, CVR; Data curation, SR, SS, TB; Writing- original draft paper, SR; Writing - review and editing, SR, SS, TS, PKP; Supervision, SS, TS. All authors have read and agreed to the published version of manuscript.

Compliance with ethical standards

Conflict of interest: The authors of this paper declare that they have no conflicts of interests associated with this paper.

Ethical issues: None

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