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EVALUATING AGRONOMIC PRACTICES AND RADIATION USE EFFICIENCY IN PROMISING RICE GENOTYPES UNDER DIFFERENT NITROGEN LEVELS

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Abstract

Despite the critical role of rice in global food security, rice cultivation in Pakistan faces significant challenges due to climatic variability, inefficient nitrogen utilization, and a limited understanding of genotype-specific responses to various agronomic practices. Improved nitrogen management and a deeper understanding of rice genotypes are crucial for enhancing productivity and ensuring food security. This study aims to evaluate agronomic practices and radiation use efficiency in promising rice genotypes under different nitrogen levels. The field experiment was conducted in Agronomic Research Area of the University of Agriculture Faisalabad, Punjab, Pakistan. The treatments included four rice cultivars (Super Gold, Super Basmati, Chanab Basmati, and Punjab Basmati) and five nitrogen levels (Control, 50 kg ha^{-1}, 100 kg ha^{-1}, 150 kg ha^{-1}, and 200 kg ha^{-1}). The experiment used a randomized complete block design with a factorial layout having three replications. The results indicated that 2020 showed superior performance in several aspects: Leaf area index (LAI) was higher in 2020 (3.04) compared to 2019 (2.87); Total dry matter (TDM) was greater in 2019 (10898 kg ha^{-1}) than in 2020 (10476 kg ha^{-1}). Super Basmati had the highest 1000-grain weight (22.49 g). The highest RUE for TDM (1.77 g MJ^{-1}) was observed at the 150 and 200 kg ha^{-1} nitrogen levels. Among the genotypes, Super Basmati exhibited the highest grain yield (3199 kg ha^{-1}), while Super Gold had the lowest (3101 kg ha^{-1}). Nitrogen treatments of 150 kg ha^{-1} and 200 kg ha^{-1} significantly enhanced growth and yield parameters, whereas the control (0 kg N ha^{-1}) lagged behind, underscoring the essential role of nitrogen in rice cultivation. These findings highlight the importance of optimizing nitrogen levels and genotype selection to improve rice productivity and resource efficiency in Pakistan.

Keywords: Leaf Area Index, Total Dry Matter, Nitrogen, Cultivars, Radiation Use Efficiency, Grain Yield.

1. INTRODUCTION

Rice is a staple food crop that plays a pivotal role in global food security. However, rice cultivation in Pakistan faces significant challenges due to climatic variability, inefficient nitrogen utilization, and a limited understanding of genotype-specific responses to various

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agronomic practices. Patterns of rainfall and temperature fluctuations have greatly influenced rice production. Insufficient rainfall leads to reduced water availability, hindering the creation of the semi-aquatic conditions essential for rice cultivation, thereby widening the supply and demand gap. Similarly, global warming and rising temperatures negatively impact rice yields, with studies indicating that a 1ºC increase in minimum temperature can reduce rice production by up to 10% (Abbas and Dastgeer, 2021).

Traditional rice transplanting methods, which favor standing water, are major sources of methane emissions, posing significant health risks and environmental concerns. These methods also increase soil bulk density and reduce porosity (Nawaz et al., 2017). The shrinking water resources and other drawbacks of conventional rice cultivation methods threaten future rice production, exacerbating the supply-demand gap and increasing the risk of starvation. To mitigate these issues, water-saving techniques such as Direct Seeded Rice (DSR) have been adopted (Feng et al., 2007; Saleem et al., 2020).

Direct seeded rice (DSR), a technique under resource conservation technologies (RCTs), offers an eco-friendly alternative that sustains productivity and soil properties while reducing greenhouse gas emissions (Hobbs et al., 2008). This method, which does not require puddled or saturated soil conditions, is used to produce one-third of the world's rice (Bouman, 2007; Nadeem and Farooq, 2019; Nawaz et al., 2019). DSR is cost-effective, reducing both labor and water consumption, and it allows for earlier crop maturation compared to transplanted rice (Balasubramanian and Hill, 2002; Dawe, 2005; Bhushan et al., 2007; Farooq et al., 2011). Studies in India, China, and the USA have shown that DSR can increase grain yield with minimal water usage (Pathak et al., 2011; Liu et al., 2015). Additionally, DSR provides efficient weed control and better water management strategies (Gill et al., 2011; Liu et al., 2015; Tao et al., 2016).

Effective nitrogen management is crucial for optimizing rice production. Improper fertilizer application, whether excessive or insufficient, can significantly impact rice yield. Overuse of nitrogen can lead to pest attacks, lodging, and delayed crop maturity, while underuse results in reduced yields (Sidhu et al., 2004; Maheswari et al., 2007; Farooq et al., 2011). Therefore, a balanced nitrogen application strategy is essential for enhancing crop yield and quality (Manzoor et al., 2006). Nitrogen is a vital nutrient for plant growth, especially for paddy, which requires higher nitrogen levels than other crops (Djaman et al., 2018). Advanced nitrogen management techniques are being applied in Asia to ensure the precise delivery of this nutrient (Ali, 2020).

Nitrogen fertilization constitutes 37% of the total fertilization of the rice crop worldwide, with approximately 60% of nitrogen fertility applications dedicated solely to rice (Zheng et al., 2020). The efficiency of nitrogen application depends on soil characteristics and the cultivars used, as environmental and soil organism effects can lead to significant nitrogen losses (Walker, 2006; Zhang et al., 2020). Adoption of high-yielding, low-fertility, short-stature, and water-efficient rice varieties, along with improved mechanization and reduced labor requirements, encourages farmers to shift towards DSR (Joshi et al., 2013). Thus, knowing the importance of nitrogen in soil of Pakistan, this trial was directed to evaluate

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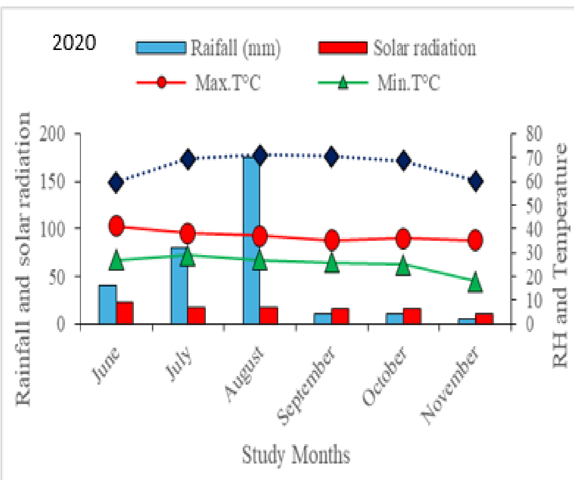
agronomic practices and radiation use efficiency in promising rice genotypes under different nitrogen levels.

2. MATERIAL AND METHODS

An experiment was conducted at the University of Agriculture Faisalabad, to optimize nitrogen fertilizer for rice crops. The study employed a Randomized Complete Block Design (RCBD) with a factorial arrangement and three replications. A two-year trial comprised of 4 rice genotypes Super and 5 nitrogen levels on June 25, 2020, at a seeding rate of 24 kg ha^{-1}. The treatments included varying nitrogen levels: control (0 kg ha^{-1}, 50 kg ha^{-1}, 100 kg ha^{-1}, 150 kg ha^{-1}, and 200 kg ha^{-1}. All agronomic practices, aside from the variables under investigation, followed the recommended guidelines. Additionally, soil profile and weather attributes of the experimental site were recorded (refer to Table 1 and Figure 1). Data on growth, phenology and agronomic traits were recorded in this study which given as under.



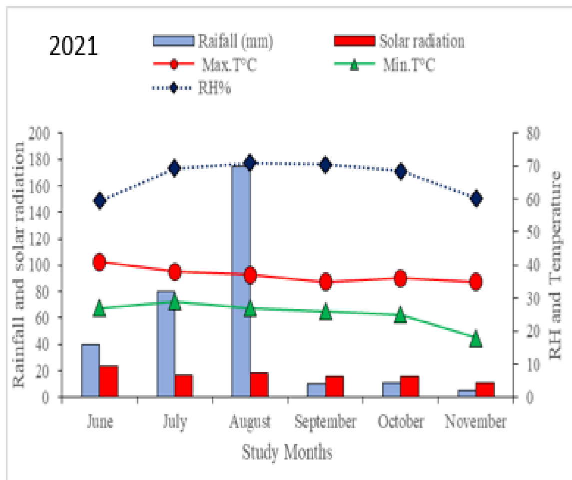


Figure 1: Summary of weather at experimental site during 2020 and 2021

Table 1: Soil physicochemical characterization

Parameter	Unit	2019-20	2020-21
Textural Class	-	sandy clay Loam	sandy clay Loam
Sand	%	40.70	40.62
Silt	%	37	37
Clay	%	22	21.5
pH	-	7.54	7.44
EC	dS m^{-1}	1.5	1.55
Total soluble salts (TSS)	%	12.29	12.39
Organic matter	%	0.85	0.98
Nitrogen (N)	%	0.64	0.70
Potassium (K)	ppm	19.4	24.40
Phosphorus (P_2O_5)	ppm	10.5	11

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Phenological observations: In the context of this study, detailed phenological observations (days taken to anthesis and maturity) were meticulously documented. A trio of plants within each experimental plot was carefully selected, marked, and monitored throughout the growth period daily.

Total dry matter-TDM (gm^{-2}): It is obtained after sun-drying and oven drying the harvest material at a specific temperature. Fresh weight taken after harvest is subjected to oven drying for the calculation of total dry matter in gm^{-2}.

$$\text{TDM} = \frac{W_d}{W_f} \times Wt$$

Where total fresh matter of crop is denoted by the term W_d, Fresh sub-sample when weighed before oven drying is W_f, and after oven drying the sub-samples, the material thus obtained is denoted as W_t.

Leaf area index (LAI): For the measurement of leaf area, a leaf area meter (Model CL-203, CID, Inc.) was utilized. An appropriate sub-sample, comprising 5 grams of green leaf lamina, was carefully collected from each plot. Using this meter, the total leaf area of the sub-sample was accurately determined. The Leaf Area Index (LAI) was then calculated following the method described by Watson (1952). This index is essential for understanding the canopy structure and photosynthetic potential of the crops under study.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground Surface Cover}}$$

Radiation use efficiency (RUE) in g MJ^{-1}: Total Dry Matter (TDM) for each treatment was correlated with the accumulated intercepted PAR (∑Sa) using the least square method. The slope of the regression line indicates the efficiency of radiation use. RUE was calculated separately for Total Dry Matter (TDM) and Grain Yield (GY) per plot as:

$$RUE_{TDM} = \text{TDM} / \sum Sa \; (gMJ^{-1})$$

$$RUE_{GY} = \text{Grain yield} / \sum Sa \; (gMJ^{-1})$$

Plant height (cm): For this measurement, ten plants were randomly selected from each plot. The height of each plant was measured using a meter rod. These measurements were then averaged to calculate the average plant height.

Number of plants per m^2: In each plot, the number of plants within a 1 m^2 area was counted.

Number of spikelets per panicle: This involved examining ten panicles and counting the spikelets in each independently. The average number of spikelets per panicle was then determined.

1000-grain weight (g): An electronic balance was utilized to weigh 1000 grains from each plot. The grains were dried 24 hours prior to weighing.

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Grain yield (kg ha^{-1}): A random 1m² patch was harvested from each plot, taking care to avoid border effects. The grain yields were recorded after the sun-dried rice had been threshed. Yields were reported in kilograms per hectare.

Statistical analysis: Fisher's Analysis of Variance technique was employed for data analysis. Treatment means were differentiated using Tukey's Honest Significance Difference (HSD) test at a P ≤ 0.05 probability level (Steel et al., 1960).

3. RESULTS

Plant height (cm):

The annual variation in plant height was not statistically significant (Table 2). Among the genotypes, Super Basmati (G_2) recorded the highest plant height of 100.40 cm, while Super Gold (G_1) had the lowest at 96.38 cm. Regarding nitrogen doses, the plant height increased with higher nitrogen levels, with the tallest plants (104.42 cm) observed at 200 kg ha^{-1} (N_4).

Days taken to anthesis:

The number of days to anthesis was significantly different between the years, with 2020 showing a higher average of 84 days compared to 79 days in 2019 (Table 2). No significant difference was observed among the genotypes. For nitrogen doses, there was no significant difference, although the highest average was at 150 kg ha^{-1} (N_2) with 83 days.

Days taken to maturity:

The days to maturity showed a significant difference between years and genotypes (Table 2). The average maturity days were higher in 2020 (112 days) than in 2019 (109 days). Among the genotypes, Punjab Basmati (G_4) matured the earliest with 109 days, while Super Gold (G_1), Super basmati (G_2) and Chanab Basmati (G_3) took the longest with 111 days. Nitrogen doses did not show a significant effect on maturity days.

Leaf area index (LAI):

Significant differences were observed in LAI between years, genotypes, and nitrogen doses (Table 2). The LAI was higher in 2020 (3.04) compared to 2019 (2.87). Among the genotypes, Super Basmati (G_2) recorded the highest LAI of 3.11, while Super Gold (G_1) had the lowest at 2.81. The LAI increased with higher nitrogen levels, reaching 3.66 at 150 and 200 kg ha^{-1} (N_4 and N_5).

The data obtained from the 2020 and 2021 growing seasons elucidate the impact of rice genotypes and nitrogen (N) fertilization rates on leaf area index (LAI). Over the course of both seasons, a congruent trend in LAI progression was observed, with values ascending post-sowing, peaking between 60 and 80 days, and then diminishing (Figure 2).

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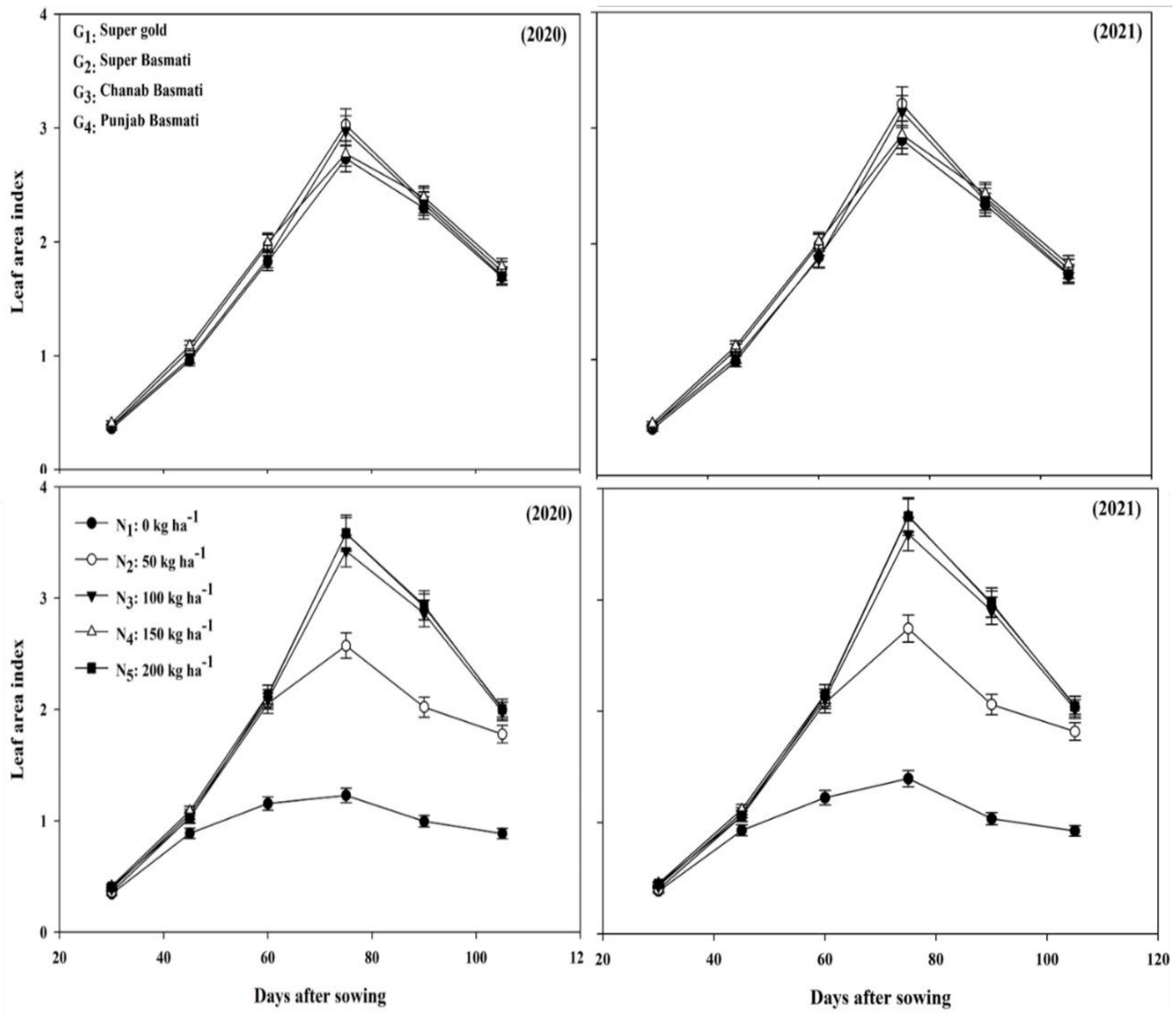

Figure 2: Changes in leaf area index with time as affected by rice genotypes and nitrogen levels during 2020 and 2021

Total dry matter (kg ha^{-1}):

TDM was significantly affected by year, genotype, and nitrogen dose (Table 2). The TDM was higher in 2019 (10898 kg ha^{-1}) compared to 2020 (10476 kg ha^{-1}). Among the genotypes, Super Basmati (G_2) had the highest TDM of 11021 kg ha^{-1}, while Super Gold (G_1) had the lowest at 10395 kg ha^{-1}.

The highest TDM (11981 kg ha^{-1}) was observed with the application of 200 kg ha^{-1} (N_4). Analyzing data from the 2020 and 2021 growing seasons, a significant interaction between rice genotypes and nitrogen (N) fertilization levels on the accumulation of total dry matter (TDM) is evident.

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The genotypes included G_1 (Super gold), G_2 (Super Basmati), G_3 (Chenab Basmati), and G_4 (Punjab Basmati). Throughout both growth periods, a robust increase in TDM is observable, with all genotypes exhibiting a similar upward trajectory, reaching peak values toward the end of the measurement period (Figure 3).

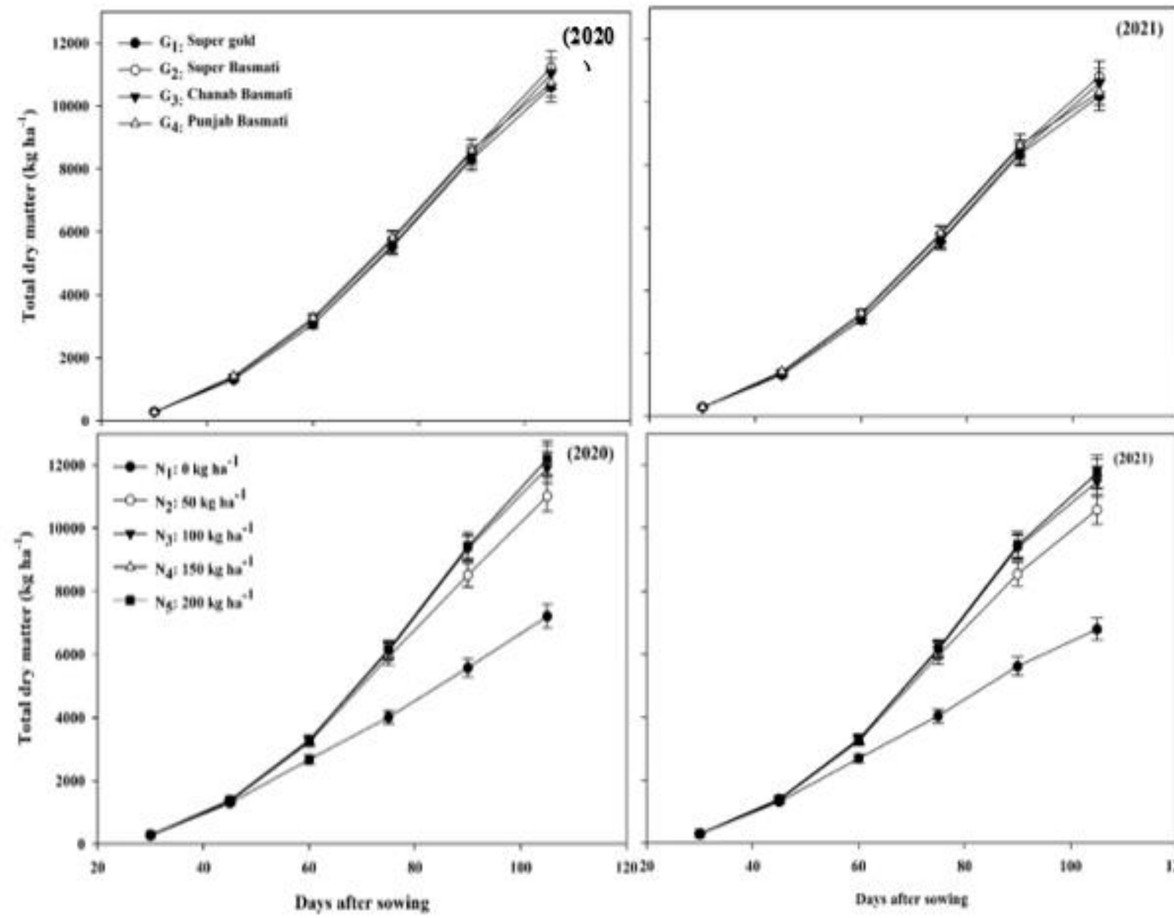

Figure 3: Changes in total dry matter with time as affected by rice genotypes and nitrogen levels during 2020 and 2021

1000-grain weight (g):

The weight of 1000 grains was significantly different between years, with 2020 showing a higher average of 22.42 g compared to 2019 (20.99 g).

Among the genotypes, Super Basmati (G_2) had the highest 1000-grain weight of 22.42 g. The application of nitrogen did not significantly affect the 1000-grain weight.

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Number of Panicles per Meter (NPPM):

Significant differences were observed in NPPM between years and nitrogen doses (Table 2). The NPPM was higher in 2020 (46) compared to 2019 (44).

Among the genotypes, Super Basmati (G_2) had the highest NPPM of 48, while Super Gold (G_1) had the lowest at 43. Nitrogen application at 150 kg ha^{-1} (N_4) resulted in the highest NPPM of 51.

Number of spikelets per panicle (NSPP):

Significant differences were observed in NSPP among the years, genotypes and nitrogen doses (Table). Maximum NSPP was recorded in 2nd year with 11.05 NSPP. The highest NSPP was recorded for Super Basmati (G_2) with 11.43. Nitrogen application at 150 kg ha^{-1} (N_4) resulted in the highest NSPP of 12.58.

Radiation use efficiency (RUE_{TDM} and RUE_{GY}) (g MJ^{-1}):

RUE_{TDM} showed significant differences among the years and nitrogen doses (Table 2). The RUE_{TDM} was higher in 2020 (1.78 g MJ^{-1}) compared to 2019 (1.70 g MJ^{-1}). Among the genotypes, Super Basmati (G_2) and Chanab Basmati (G_3) had the highest RUE_{TDM} (1.74 g MJ^{-1}), while Super Gold (G_1) and Punjab Basmati (G_4) had the lowest at 1.73 g MJ^{-1}. The highest RUE_{TDM} (1.77 g MJ^{-1}) was observed with the application of 150 and 200 kg ha^{-1} (N_4, N_5).

RUE_{GY} showed significant differences among the years and nitrogen doses (Table 2). The RUE_{GY} was higher in 2020 (0.66 g MJ^{-1}) compared to 2019 (0.60 g MJ^{-1}). Among the genotypes, Super Basmati (G_2) had the highest RUE_{GY} (0.64 g MJ^{-1}), while Punjab Basmati (G_4) had the lowest at 0.61 g MJ^{-1}. The highest RUE_{GY} (0.67 g MJ^{-1}) was observed with the application of 150 kg ha^{-1} (N_4,).

Grain yield (kg ha^{-1}):

Grain yield was significantly influenced by the year, genotype, and nitrogen dose (Table 2). The yield was higher in 2019 (3228 kg ha^{-1}) compared to 2020 (3068 kg ha^{-1}). Among the genotypes, Super Basmati (G_2) recorded the highest yield of 3199 kg ha^{-1}, followed by Chanab Basmati (G_3) with 3157 kg ha^{-1}.

The lowest yield was observed in Chanab Basmati (G_3) (2881 kg ha^{-1}). The highest grain yield (3553 kg ha^{-1}) was achieved with the application of 150 kg ha^{-1} (N_4), while the lowest yield was obtained from the control (2221 kg ha^{-1}).

Table 2: Effect of genotypes and nitrogen levels on growth, yield, and radiation use efficiency of rice crop

Treatment	PH	AD	MD	LAI	TDM (kg ha^{-1})	1000-grain weight (g)	NPPM	NSPP	RUE_{TDM} (g MJ^{-1})	RUEgy (g MJ^{-1})	Grain Yield (kg ha^{-1})
A. **Year**											
2019	96.80 a	79 b	109 b	2.87 b	10898 a	20.99 b	44.45 b	10.70 b	1.70 b	0.60 b	3228 a
2020	99.20 a	84 a	112 a	3.04 a	10476 b	22.42 a	46.66 a	11.05 a	1.78 a	0.66 a	3068 b
HSD 5%	2.69	2.32	2.82	0.07	295.96	0.56	1.23	0.29	0.04	0.01	92.15
Significance	ns	**	*	**	**	**	**	**	**	**	**
B. **Genotypes**											
G_1: Super Gold	96.38 b	82 a	111 a	2.81 b	10395 b	21.14 b	43.93 c	10.43 b	1.73 a	0.62 ab	3101 a
G_2: Super Basmati	100.40 a	82 a	111 a	3.11 a	11021 a	22.42 a	48.13 a	11.43 a	1.74 a	0.64 a	3199 a
G_3: Chanab Basmati	98.58 ab	82 a	111 a	3.05 a	10806 ab	21.80 ab	45.83 b	11.06 a	1.74 a	0.63 ab	3157 a
G_4: Punjab Basmati	96.65 ab	81 a	109 a	2.85 b	10524 b	21.43 b	44.33 bc	10.56 b	1.73 a	0.61 b	3133 a
HSD 5%	3.81	3.29	4	0.10	418.55	0.80	1.74	0.41	0.06	0.02	130.83
Significance	ns	ns	ns	**	**	*	**	**	ns	ns	ns
C. **Nitrogen Doses**											
N_1: control	81.81 d	81 a	110 a	1.31 d	6998 c	17.17 d	35.83 d	7.33 d	1.65 b	0.59 c	2221 d
N_2: 50 kg ha^{-1}	96.76 c	81 a	110 a	2.65 c	10800 b	21.47 c	43.62 c	10.66 c	1.74 a	0.60 bc	3119 c
N_3: 100 kg ha^{-1}	100.67 bc	81 a	111 a	3.50 b	11690 a	22.77 b	47.25 b	11.50 b	1.76 a	0.62 b	3361 b
N_4: 150 kg ha^{-1}	106.34 a	83 a	111 a	3.66 a	11963 a	23.82 a	51.25 a	12.58 a	1.77 a	0.67 a	3533 a
N_5: 200 kg ha^{-1}	104.42 ab	82 a	111 a	3.66 a	11981 a	23.38 ab	49.83 a	12.29 a	1.77 a	0.66 a	3504 ab
HSD 5%	4.26	3.68	4.47	0.12	467.96	0.89	1.95	0.46	0.06	0.02	146.28
Significance	**	ns	ns	**	**	**	**	**	**	**	**
Linear	**	ns	ns	**	**	**	**	**	**	**	**
Quadratic	**	ns	ns	**	**	**	**	**	*	ns	**
Cubic	ns	ns	ns	**	**	ns	ns	*	ns	*	**
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

PH: plant height, AD: Days to anthesis, MD: Days to maturity, LAI: leaf area index, TDM: Total dry matter, NSPP: Number of spikelets per spike, RUE_{TDM}: radiation use efficiency for total dry matter, RUEgy: radiation use efficiency for grain yield.

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Correlation patterns of rice agronomic traits

Figure 4. Presents correlation matrices for the rice crop years of 2020 and 2021, offering a detailed look at the interrelations between key agronomic traits. In both years, there is a strong positive correlation among various indicators, notably between the leaf area index (LAI), total dry matter (TDM), and radiation use efficiency for total dry matter (RUET). These correlations, with coefficients close to the maximum of 1.00, suggest a direct relationship where an increase in LAI may correspond to greater biomass production and more efficient conversion of radiation to dry matter. Additionally, grain yield (GY) shows a positive correlation with 1000 grain weight (TGW) and the number of spikes per panicle (NSPP), proposing that both the weight of grains and the density of reproductive units contribute significantly to overall yield. While the 2020 matrix indicates a slight reduction in the strength of these correlations, the fundamental patterns of trait interdependence remain evident. The perfect correlation scores along the diagonal validate the data's consistency. By illustrating these complex trait interconnections, the figure underscores the myriads of factors that affect rice yield and points to potential agronomic traits for enhancement and yield optimization in rice cultivation.

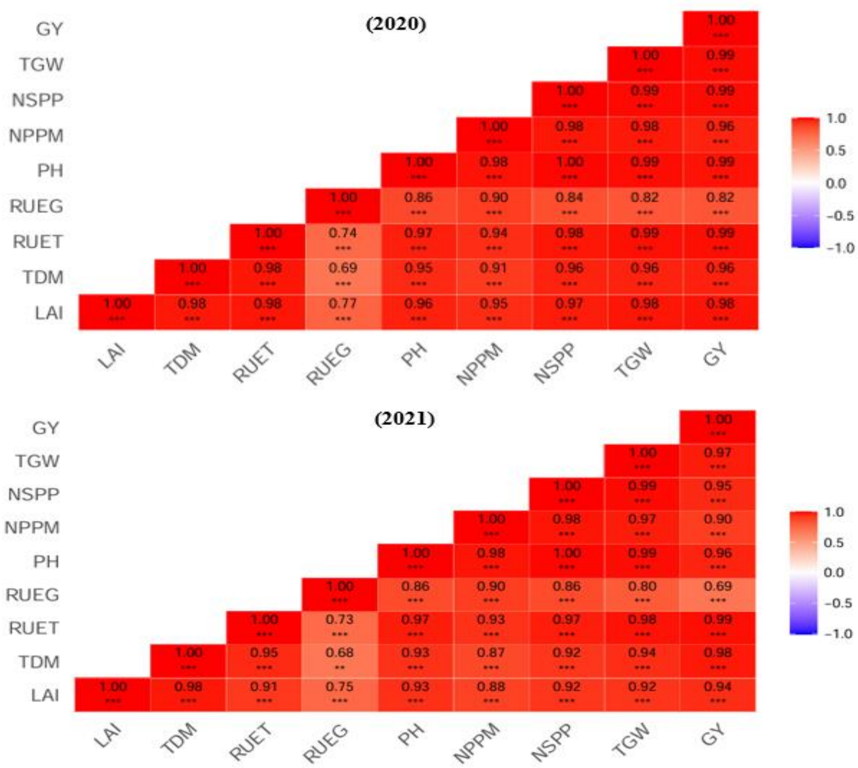

Figure 4: Correlation patterns of rice agronomic traits: A two-year (2019-20 and 2020-21) analysis

* for $p \leq 0.05$, ** for $p \leq 0.01$, and *** for $p \leq 0.001$, r value ranges from -1 to 1 indicating strength LAI: Leaf area index, TDM: Total dry matter, RUET: Radiation use efficiency for

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total dry matter, RUEG: Radiation use efficiency for grain yield, PH: Plant height, NPPM: Number of plants per m^{-2}, NSPP: Number of spikelets per panicle, TGW: 1000 grain weight, GY: Grain yield.

4. DISCUSSION

The significant variability in LAI among rice genotypes, particularly the higher LAI in Super Basmati (G_2), highlights the crucial role of genotype in leaf development, a key factor for photosynthesis and crop yield Sing et al. (2014). This genotype dependency of LAI aligns with the findings of Zou et al. (2023), who observed similar trends in rice. Furthermore, the positive response of LAI to increased nitrogen levels, as noted in our study and supported by Sharma et al. (2018) and Zou et al. (2019), emphasizes the importance of nitrogen management in enhancing leaf growth, thereby potentially improving overall crop productivity in rice cultivation. The analysis of rice's TDM accumulation over the 2020 and 2021 growing seasons revealed a pronounced interaction between genotypes and nitrogen fertilization levels. All genotypes, including Super Gold (G_1) and Punjab Basmati (G_4), exhibited a consistent increase in TDM, reflecting a robust genotypic response to nitrogen application, a finding corroborated by Gawdiya et al. (2023) and Kaysar et al. (2022). The positive yet diminishing returns of TDM with increased nitrogen levels, particularly beyond the N_4 (150 kg ha^{-1}) level, suggest a threshold for nitrogen efficiency in rice, echoing observations by Zou et al. (2023). The investigation into RUE_{TDM} in rice, across various genotypes and nitrogen levels, revealed uniform efficiency across genotypes and a negligible impact of nitrogen. This consistency in RUE_{TDM} among genotypes like Super Gold (G_1) and Chanab Basmati (G_3), as seen in both 2019 and 2020, suggests that radiation use efficiency in rice is largely genotype-independent, a finding echoed by research from Sharma et al. (2018). The lack of significant change in RUETDM with varying nitrogen levels challenges the conventional understanding of nitrogen's role in enhancing photosynthetic efficiency, as discussed by Zou et al. (2023). The importance of RUE related to nitrogen in rice cultivars is significant for optimizing yield, improving nitrogen utilization, and understanding the genetic and environmental factors that influence radiation use efficiency and grain production Deng et al. (2023). The findings on rice's RUE_{GY} over two years, focusing on different genotypes and nitrogen levels, showed consistent RUEGY across genotypes and a positive response to nitrogen application. In both 2020 and 2021, genotypes like Super Gold (G_1) and Super Basmati (G_2) demonstrated similar RUE_{GY} values, suggesting a genotype-independent efficiency in converting radiation into grain yield, a concept supported by findings from Kar and Kumar (2016). The increase in RUEGY with elevated nitrogen levels aligns with research (Deng et al., 2023; Zheng et al., 2022), indicating that nitrogen availability can enhance the efficiency of radiation use in grain production. The analysis of rice plant height across different genotypes and nitrogen levels over two years demonstrated minimal genotype-based differences but a clear response to nitrogen application. In both 2020 and 2021, genotypes such as Super Gold (G_1) and Super Basmati (G_2) showed similar heights, indicating that plant height in rice is not significantly influenced by genetic variation, a

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finding consistent with research by Zhang et al. (2020). However, the significant increase in plant height with higher nitrogen levels, particularly at the highest application rates, underscores nitrogen's role in promoting vertical growth in rice, as discussed by Wu et al. (2022) and Gawdiya et al. (2023). Plant density in rice cultivation, a critical factor influencing overall crop yield, showed minimal genotype-dependent variation but a significant response to nitrogen application. In the study, while genotypes like Super Gold (G_1) and Super Basmati (G_2) exhibited similar plant densities, a notable increase in density with elevated nitrogen levels was observed, aligning with findings by Zou et al. (2019). This trend suggests that nitrogen management is pivotal in optimizing plant density, a key determinant of yield potential. The significant interaction between genotype and nitrogen in 2020, as opposed to 2019, underscores year-to-year variability and the importance of adapting nitrogen strategies to specific genotypic needs in different environmental conditions, as discussed by Sharma et al. (2018). The findings indicate that while the number of spikelets per panicle in rice varied slightly among genotypes in 2020, by 2021, Super Basmati (G_2) emerged as the most prolific. This suggests a variable genotypic influence on spikelet production, potentially influenced by annual environmental conditions. Notably, a consistent increase in spikelet numbers with higher nitrogen levels was observed, aligning with Zou et al. (2023) findings on nitrogen's enhancing effect. The year-specific genotype-nitrogen interactions highlight the dynamic nature of rice's response to nitrogen, necessitating flexible fertilization strategies, as emphasized by Ullah et al. (2016). The rate and degree of grain filling in rice spikelets differ largely depending on their positions on a panicle (Zhang et al., 2010). The investigation on1000-kernel weight revealed that Super Basmati (G_2) consistently had the highest weight, suggesting a genetic predisposition for larger kernels. A notable increase in kernel weight with increased nitrogen levels was observed, echoing Xu et al. (2023) research on nitrogen's influence on grain development. The findings show that both genotype and nitrogen independently affect kernel weight, with a clear trend of weight gain with higher nitrogen levels, highlighting effective nitrogen management as a key factor in optimizing rice yield, as supported by Sharma et al. (2018). The study on rice paddy yield across different genotypes and nitrogen levels showed uniform yields among genotypes like Super Gold (G_1) and Super Basmati (G_2), with a slight edge for Super Basmati. A significant yield increase with higher nitrogen applications, as seen in both years, underscores nitrogen's role in boosting yields, resonating with Wang *et al.* (2022) and Kaysar et al. (2022) findings. The consistent response of all genotypes to nitrogen, without significant genotype-nitrogen interactions, highlights nitrogen management as a crucial factor in enhancing rice yield, a concept echoed by Gawdiya et al. (2023).

5. CONCLUSION

The study concluded that the year, genotype, and nitrogen levels significantly impacted the growth, yield, and radiation use efficiency of rice crops. Grain yield was higher in 2019 compared to 2020, attributed to favorable climatic conditions. Among the genotypes, Super Basmati (G_2) achieved the highest yield, while Super Gold (G_1) had the lowest.

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Increasing nitrogen levels consistently improved growth parameters and yield, with the highest grain yield observed at 150 kg ha^{-1} (N_4). These findings underscore the importance of optimizing genotype selection and nitrogen application to enhance rice productivity.

Conflict of Interest

The authors declare that there is no conflict of interest.

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