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Influence of nitrogen levels on chlorophyll content and nitrogen uptake in paddy (*Oryza sativa* L.)

Trilok Nath Rai[1], Kedar Nath Rai[2], Sanjeev Kumar Rai[3], Rajeev Kumar Rai[4], Mohit Singh[5]
[1] Department of Soil Science & Agricultural Chemistry, Krishi Vigyan Kendra (ICAR-CSSRI), Dhikunni, Sandila, Hardoi, Uttar Pradesh, India
[2] Associate Professor and Head, Department of Soil Science & Agricultural Chemistry, Kamla Nehru Institute of Physical and Social Sciences, Sultanpur, Uttar Pradesh, India
[3] Department of Soil Science & Agricultural Chemistry, Kamla Nehru Institute of Physical and Social Sciences, Sultanpur, Uttar Pradesh, India
[4] Department of Nursing, Institue of Nursing & Paramedical Sciences Sultanpur, Uttar Pradesh, India
[5] Agriculture Extension, Krishi Vigyan Kendra (ICAR-CSSRI), Dhikunni, Sandila, Hardoi, Uttar Pradesh, India

Abstract
A field experiment was conducted during 2023 and 2024 to evaluate the effect of different crop establishment methods and nitrogen levels on chlorophyll content and nitrogen uptake of rice at various growth stages. The study assessed chlorophyll content at 30, 60 and 90 days after sowing (DAS) and measured nitrogen uptake at harvest. The results revealed that chlorophyll content of rice leaves increased from 30 DAS to 60 DAS and then slightly declined at 90 DAS during both years, indicating maximum photosynthetic activity at the mid-growth stage. Among the crop establishment methods, M_3 consistently recorded the highest chlorophyll content at all growth stages during both years. In 2023, chlorophyll content under M_3 reached 33.656, 40.178 and 36.078 SPAD units at 30, 60 and 90 DAS, respectively, while similar higher values were also observed during 2024. In contrast, the lowest chlorophyll content was generally recorded under M_1. Nitrogen levels significantly influenced chlorophyll content, where the highest nitrogen level (N_3) resulted in maximum chlorophyll values at all growth stages in both years, whereas the lowest values were observed under N_1. The interaction effect also showed that the combination of M_3N_3 produced the highest chlorophyll content across all growth stages during both years, indicating improved physiological efficiency and leaf greenness under this treatment combination. Nitrogen uptake by rice was also significantly affected by crop establishment methods and nitrogen levels. The highest nitrogen uptake was recorded under M_3 (70.26 kg ha^{-1} in 2023 and 72.40 kg ha^{-1} in 2024), while the lowest uptake was observed under M_1. Similarly, nitrogen uptake increased with increasing nitrogen levels, with N_3 recording the highest uptake (78.11 kg ha^{-1} in 2023 and 81.88 kg ha^{-1} in 2024). The interaction effect revealed that the combination M_3N_3 resulted in the maximum nitrogen uptake (80.83 kg ha^{-1} in 2023 and 86.00 kg ha^{-1} in 2024), whereas the lowest uptake was recorded under M_1N_1. Overall, the results indicate that improved crop establishment methods combined with higher nitrogen levels significantly enhanced chlorophyll content and nitrogen uptake in rice. The combination of M_3 establishment method with N_3 nitrogen level proved most effective in improving physiological efficiency and nutrient absorption, which may ultimately contribute to better crop growth and productivity.

Keywords: Nitrogen levels, chlorophyll content, nitrogen uptake, *Oryza sativa L,* crop establishment methods

Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and serves as a staple food for more than half of the global population, particularly in Asian countries where it constitutes the primary dietary energy source. Globally, rice contributes significantly to food security and agricultural sustainability. In India, rice occupies a substantial share of the total cultivated area and plays a vital role in ensuring national food security, rural employment and economic stability of farming communities. According to recent agricultural reports, India is among the leading producers and consumers of rice, highlighting the importance of improving its productivity through advanced agronomic practices (FAO, 2021; Singh *et al*., 2022) [14]. Improving rice productivity requires efficient crop management practices, particularly proper crop establishment methods and balanced nutrient management. Crop establishment methods influence plant growth and development by modifying soil physical conditions such as aeration, moisture retention and soil structure, which in turn affect root proliferation, nutrient uptake and overall crop performance. Different establishment techniques such as conventional transplanting, direct seeded rice and improved establishment practices can significantly influence plant growth, physiological efficiency and yield attributes (Kumar *et al*., 2018; Chauhan *et al*., 2019) [1, 6]. Studies have shown that appropriate crop establishment techniques improve soil–plant interactions and create favorable micro-environmental conditions for crop growth, thereby enhancing productivity (Sharma *et al*., 2020; Yadav *et al*., 2021) [13, 16]. Nitrogen is considered the most important macronutrient required for rice growth and development. It plays a critical role in various physiological and biochemical processes in plants. Nitrogen is a key component of chlorophyll, amino acids, proteins, nucleic acids and enzymes that regulate metabolic activities within the plant system. Adequate nitrogen supply promotes vigorous vegetative growth, enhances leaf area development and improves overall plant vigor. Moreover, nitrogen application has been reported to significantly influence chlorophyll synthesis and photosynthetic efficiency in rice plants (Zhang *et al*., 2017; Liu *et al*., 2019) [9, 17]. Higher nitrogen availability generally results in increased chlorophyll concentration in leaves, which enhances the capacity of plants to capture light energy and convert it into chemical energy through photosynthesis (Wang *et al*., 2020) [15].

Chlorophyll content is widely considered an important physiological indicator of plant health and productivity. It reflects the photosynthetic capacity of the crop and is closely associated with biomass accumulation and yield potential. Higher chlorophyll content improves light interception and photosynthetic activity, thereby promoting better plant growth and productivity. Several studies have reported that proper nitrogen management significantly increases chlorophyll content and improves the physiological efficiency of rice plants (Prasad *et al*., 2018; Li *et al*., 2021) [8, 11]. Therefore, chlorophyll content is often used as an important parameter to evaluate the nutritional status and growth performance of crops under different management practices (Haque *et al*., 2022) [4].

Nitrogen uptake by plants is another crucial parameter that indicates the efficiency of nutrient utilization and overall crop performance. Efficient nitrogen uptake depends on several factors such as root growth, soil nutrient availability, moisture status and crop management practices. Improved crop establishment methods can enhance nitrogen uptake by promoting better root development, increasing soil microbial activity and improving nutrient availability in the rhizosphere. Enhanced root proliferation under favorable establishment methods allows plants to absorb nutrients more effectively from the soil (Gupta *et al*., 2019; Patel *et al*., 2020) [3, 10]. In addition, higher nitrogen application rates generally increase nutrient availability in the soil, which contributes to greater nitrogen uptake and improved plant growth (Islam *et al*., 2023) [5]. Furthermore, the interaction between crop establishment methods and nitrogen management plays an important role in determining nutrient use efficiency and crop productivity. Studies have indicated that appropriate crop establishment techniques combined with optimal nitrogen levels significantly improve nutrient uptake, physiological efficiency and yield of rice crops (Kumar *et al*., 2021; Rahman *et al*., 2024) [7, 12]. Such integrated management practices not only enhance plant growth but also improve resource use efficiency and sustainability of rice production systems.

Therefore, understanding the combined influence of crop establishment methods and nitrogen levels on chlorophyll content and nitrogen uptake is essential for improving the physiological efficiency and productivity of rice crops. Keeping these aspects in view, the present study was conducted to evaluate the effect of different crop establishment methods and nitrogen levels on chlorophyll content and nitrogen uptake of rice under field conditions.

Materials and Methods

Experimental Site

The field experiment was conducted during the kharif seasons of 2023 and 2024 at the experimental farm under irrigated conditions. The experiment was carried out at the farmers fields in the district Sultanpur, U.P. with KVK, Experts. The present investigation was conducted at Sultanpur district U.P., India in the supervision of KVK, SMS, Soil Science. The climate of this district is characterized by a hot summer and a pleasant cold season. The climate is semi-arid with very hot summer and equally cold winter season. During the summer months i.e. May-June, the maximum temperature goes beyond 44 degree Celsius and in winter months of December & January, it is around 3-4 degree Celsius. Winds are generally light to moderate with some strengthening during later part of the summer and monsoon season. Winds are mostly from the east or south-east during the period from May to September. The average annual rainfall is about 900 to 1000 mm and confined mainly during July to September. The rainfall in general increases from the south-west towards the north-east and about 80-85 per cent of the annual rainfall is received during the south-west monsoon months June to September, July being the rainiest month. Hail and Dust Storms are observed only during March to June.

Soil: Alluvial soils generally cover the major portion of the district. They have developed an alluvium deposited by the Gomti and its tributaries. The soils are neutral to moderately alkaline and calcareous and have sometimes, well developed clay accumulation in the sub-soils. The large areas of barren waste are striking characteristics of the district. Tahsil Sultanpur has the greatest area of such land. Most of this area is of a very unproductive nature and consists of wide usar plains, which are specially noticeable in the south and the east of district. Nothing grows on such land, not even grass. Most of the land affected by soil erosion in the district lies in the water sheds of the rivers Gomti, Mangar, Majhai and Sai. The mainstay of the population is still agriculture and more than 90 percent of families have excess number of persons engaging themselves in agricultural related activities. Out of the total geographical area, about 67% is devoted to Agriculture. The culturable and non-culturable waste land contributes 14.85 % and 18.21 % respectively. The main occupation of the people is agriculture, the crop pattern was all alike on the usual pattern of harvesting two crops rabi and kharif. But zaid crop are also found in this district.

Agro-Ecological Situations

As per the survey of the district, it has been observed that agro-ecological situations are directly correlated with physiographic situations, land quality and availability of irrigation facilities of the area. Broadly, the farming situations have been divided into four i.e. productive plain, sodic, ravenous and waterlogged conditions. The first three conditions, are further divided into two i.e. irrigated and rain fed. The waterlogged areas are temporarily or permanently submerged in nature. Bore well is the major source of irrigation (48.5%) followed by canal (38.65%) and public tube wells (9.17%).The soil of the experimental field was sandy loam to clay loam soil.

Land Preparation

The field was prepared by ploughing by harrow and cultivaters up to a depth of 35 cm using a tractor-drawn plough, followed by harrowing with a tractor-drawn disc harrow. The land was then puddled using a wooden plank to obtain a fine tilth suitable for transplanting of paddy of crop.

Experimental Design and Treatments

The field experiment was conducted using a split plot design with three replications to evaluate the effect of crop establishment methods and nitrogen levels on the growth and yield of rice. The treatments consisted of two factors, namely crop establishment methods and nitrogen levels. Crop establishment methods were assigned to the main plots, while nitrogen levels were allocated to the sub plots within each main plot. The main plot factor included four crop establishment methods, *viz*., M_1, M_2, M_3, and M_4, representing different techniques of rice establishment. The sub plot factor consisted of three nitrogen levels, *viz*., N_1, N_2, and N_3, representing different rates of nitrogen application. Thus, a total of twelve treatment combinations were formed through the interaction of crop establishment methods and nitrogen levels, namely M_1N_1, M_1N_2, M_1N_3, M_2N_1, M_2N_2, M_2N_3, M_3N_1, M_3N_2, M_3N_3, M_4N_1, M_4N_2, and M_4N_3. These treatment combinations were randomly allocated within each replication following the principles of split plot design.

Observations Recorded

Chlorophyll Content

Chlorophyll content of rice leaves was measured using a SPAD chlorophyll meter at different growth stages, namely 30, 60 and 90 days after sowing (DAS). Readings were taken from fully expanded upper leaves of randomly selected plants in each plot and expressed as SPAD units. The average of several readings per plot was used for statistical analysis.

Nitrogen Uptake

Nitrogen uptake by rice plants was determined at harvest. Plant samples were collected from each plot, oven-dried at 65–70°C until constant weight and ground for chemical analysis. Nitrogen content in plant samples was estimated using the Kjeldahl digestion method.

Statistical Analysis

The experimental data were analyzed using analysis of variance (ANOVA) appropriate for a factorial randomized block design. The significance of treatment effects was tested using the F-test at the 5% level of significance. When the treatment effects were found significant, the critical difference (CD) values were calculated to compare the treatment means.

Result and Discussion

The data presented in Table 1 and Fig. 1 reveal that chlorophyll content of rice leaves was significantly influenced by different crop establishment methods and nitrogen levels at successive growth stages (30, 60 and 90 DAS) during both the years of experimentation (2023 and 2024). In general, chlorophyll content increased from 30 DAS to 60 DAS and thereafter declined slightly at 90 DAS, indicating maximum leaf greenness and photosynthetic activity at the mid-growth stage.

Table 1: chlorophyll content at successive growth stages of rice as affected by crop establishment methods and nitrogen levels both years

Treatment	2023			2024		
	30 DAS	**60DAS**	**90DAS**	**30 DAS**	**60DAS**	**90DAS**
M1	31.667	38.089	34.511	32.056	38.611	35.233
M2	32.744	39.256	35.100	32.978	39.400	35.867
M3	33.656	40.178	36.078	34.011	40.467	36.533
M4	32.556	38.956	34.900	32.689	39.100	35.633
S Em (±)	0.103	0.034	0.467	0.049	0.020	0.027
C.D at 5%	0.356	0.117	1.614	0.168	0.069	0.094
N1	30.942	36.858	33.258	31.117	37.067	33.950
N2	32.675	39.200	35.150	33.050	39.350	35.775
N3	34.350	41.300	37.033	34.633	41.767	37.725
S Em (±)	0.060	0.041	0.108	0.067	0.015	0.008
C.D at 5%	0.178	0.123	0.323	0.200	0.046	0.025
Interaction	**Interaction (M*N) 2023**			**Interaction (M*N) 2023**		
	30 DAS	**60DAS**	**90DAS**	**30 DAS**	**60DAS**	**90DAS**
M1N1	30.23	35.90	32.80	30.67	36.5	33.5
M1N2	31.63	38.23	34.53	32.00	38.5	35.2
M1N3	33.13	40.13	36.20	33.50	40.8	37.0
M2N1	31.00	37.00	33.20	31.00	37.0	34.0
M2N2	32.73	39.27	35.13	33.17	39.4	35.8
M2N3	34.50	41.50	36.97	34.77	41.8	37.8
M3N1	31.77	37.77	34.03	32.00	38.0	34.5
M3N2	33.70	40.27	35.97	34.27	40.5	36.5
M3N3	35.50	42.50	38.23	35.77	42.9	38.6
M4N1	30.77	36.77	33.00	30.80	36.8	33.8
M4N2	32.63	39.03	34.97	32.77	39.0	35.6
M4N3	34.27	41.07	36.73	34.50	41.5	37.5
S Em (±)	0.14	0.08	0.50	0.12	0.032	0.030
C.D at 5%	0.42	0.23	1.49	0.36	0.096	0.091

Among the crop establishment methods, chlorophyll content differed significantly at all growth stages during both the years. During 2023, the chlorophyll content at 30 DAS ranged from 31.667 to 33.656 SPAD units. The maximum chlorophyll content (33.656) was recorded under M3, which was statistically superior to the other treatments, while the minimum value (31.667) was observed under M1. The differences among treatments were significant as the variation exceeded the critical difference (CD = 0.356). At 60 DAS, chlorophyll content ranged from 38.089 to 40.178 SPAD units. Again, M3 recorded the highest chlorophyll content (40.178) followed by M2 (39.256) and M4 (38.956), whereas M1 registered the lowest value (38.089). The differences among treatments were statistically significant (CD = 0.117). At 90 DAS, chlorophyll content ranged between 34.511 and 36.078 SPAD units. The maximum value (36.078) was recorded with M3, whereas the minimum value (34.511) was observed under M1. However, the variation among establishment methods was comparatively smaller at this stage though still within the limits of statistical significance (CD = 1.614).

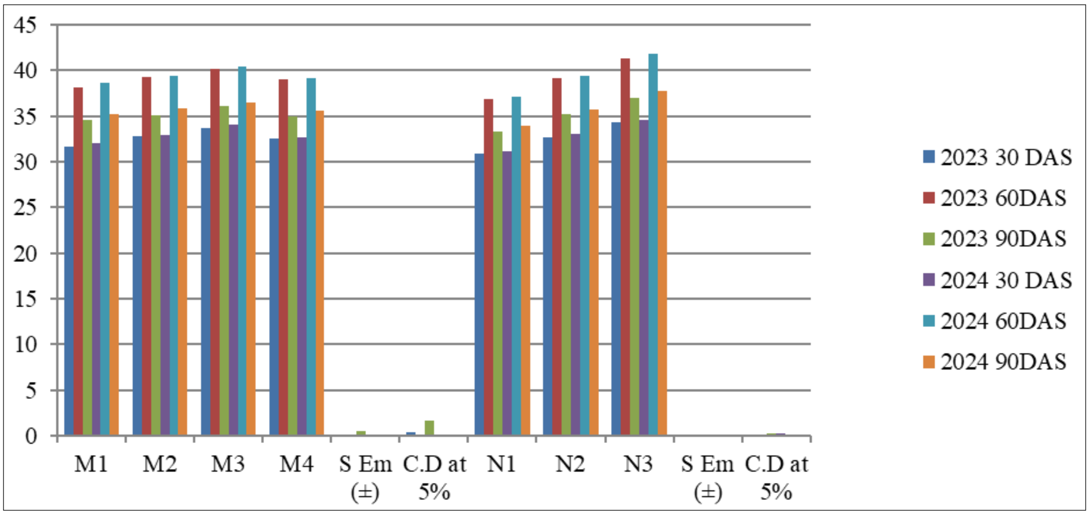

Fig 1: chlorophyll content at successive growth stages of rice as affected by crop establishment methods and nitrogen levels both years

A similar trend was observed during 2024. At 30 DAS, chlorophyll content varied from 32.056 to 34.011 SPAD units, with M3 recording the highest value (34.011) and M1 the lowest (32.056). At 60 DAS, chlorophyll content ranged between 38.611 and 40.467 SPAD units, where again M3 (40.467) showed significantly higher chlorophyll content compared with other methods. At 90 DAS, values ranged from 35.233 to 36.533 SPAD units, with M3 recording the maximum (36.533) and M1 the minimum (35.233). Overall, the results clearly indicated that M3 consistently produced higher chlorophyll content at all growth stages in both years, suggesting that this establishment method provided better crop growth conditions, resulting in higher leaf greenness and photosynthetic efficiency.

Nitrogen levels significantly influenced chlorophyll content at all stages of crop growth during both years. In 2023, chlorophyll content at 30 DAS ranged from 30.942 to 34.350 SPAD units. The highest chlorophyll content (34.350) was recorded with N3, which was significantly superior to N2 (32.675) and N1 (30.942). The lowest value was observed under N1, indicating that reduced nitrogen supply limited chlorophyll synthesis. At 60 DAS, chlorophyll content varied from 36.858 to 41.300 SPAD units. The maximum value (41.300) was recorded with N3, followed by N2 (39.200), while N1 recorded the minimum value (36.858). The differences among nitrogen levels were statistically significant (CD = 0.123). At 90 DAS, chlorophyll content ranged between 33.258 and 37.033 SPAD units, where again N3 recorded the highest value (37.033) and N1 the lowest (33.258).

A similar pattern was observed during 2024. At 30 DAS, chlorophyll content ranged from 31.117 to 34.633 SPAD units, with N3 showing the maximum value (34.633) and N1 the minimum (31.117). At 60 DAS, values varied from 37.067 to 41.767 SPAD units, and the highest chlorophyll content was again recorded under N3, which was significantly superior to N2 and N1. At 90 DAS, chlorophyll content ranged from 33.950 to 37.725 SPAD units, with N3 recording the maximum value (37.725) and N1 the minimum. The consistent increase in chlorophyll content with higher nitrogen levels indicates the vital role of nitrogen in chlorophyll synthesis, leaf development and maintenance of photosynthetic activity.

Interaction effect (Crop establishment methods × Nitrogen levels)

The interaction between crop establishment methods and nitrogen levels also showed significant variation in chlorophyll content at different growth stages given in table 1 and Fig. 2. During 2023, the chlorophyll content at 30 DAS varied from 30.23 to 35.50 SPAD units across treatment combinations. The highest chlorophyll content (35.50) was recorded with the combination M3N3, while the lowest value (30.23) was observed under M1N1. At 60 DAS, chlorophyll content ranged from 35.90 to 42.50 SPAD units. The maximum value (42.50) was recorded under M3N3, which was significantly superior to other combinations, whereas M1N1 recorded the lowest value (35.90). At 90 DAS, values ranged from 32.80 to 38.23 SPAD units, with the highest chlorophyll content (38.23) again observed under M3N3, while M1N1 recorded the minimum (32.80).

A similar trend was recorded during 2024. At 30 DAS, chlorophyll content varied from 30.67 to 35.77 SPAD units, where M3N3 recorded the highest value (35.77) and M1N1 the lowest (30.67). At 60 DAS, values ranged between 36.5 and 42.9 SPAD units, with M3N3 recording the maximum chlorophyll content (42.9). At 90 DAS, chlorophyll content varied from 33.5 to 38.6 SPAD units, where again M3N3 recorded the highest value (38.6) and M1N1 the lowest. Overall, the interaction results indicated that the combination of M3 crop establishment method with the highest nitrogen level (N3) consistently produced the maximum chlorophyll content at all growth stages during both years, whereas M1 with the lowest nitrogen level (N1) resulted in the minimum chlorophyll content. This clearly demonstrates that optimum crop establishment method along with higher nitrogen availability enhances leaf chlorophyll concentration and improves physiological efficiency of rice plants.

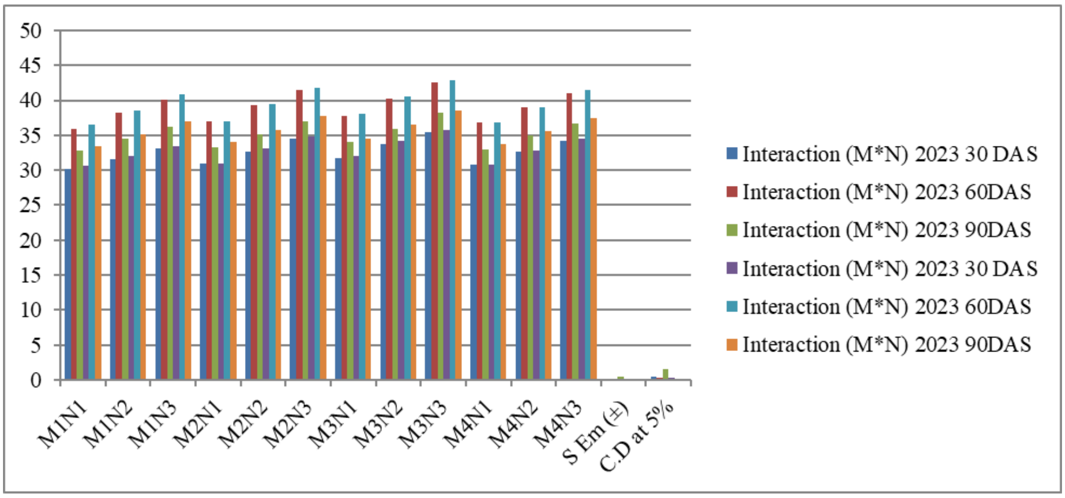

Fig 2: Chlorophyll content interaction at successive growth stages of rice as affected by crop establishment methods and nitrogen levels both years

Effect on nitrogen uptake of rice as influenced by crop establishment methods and nitrogen levels

The data presented in Table 2 and fig. 3 revealed that nitrogen uptake by rice was markedly influenced by different crop establishment methods and nitrogen levels during both the years of experimentation (2023 and 2024) [5, 12]. The values also showed considerable variation among treatments, indicating the differential response of rice plants to management practices.

Nitrogen uptake differed significantly among the crop establishment methods in both years. During 2023 [5], nitrogen uptake ranged from 63.83 to 70.26 kg ha^{-1}, whereas in 2024 it varied from 66.43 to 72.40 kg ha^{-1}. The maximum nitrogen uptake was recorded under M_3 (70.26 kg ha^{-1} in 2023 [5] and 72.40 kg ha^{-1} in 2024), which was statistically superior over other establishment methods. The higher nitrogen uptake under M_3 may be attributed to better root development, improved nutrient availability, and favorable soil–plant interactions that enhanced nutrient absorption by the crop. The next best treatment was M_2, which recorded nitrogen uptake of 67.88 kg ha^{-1} in 2023 [5] and 69.57 kg ha^{-1} in 2024, followed by M_4 with 66.24 and 68.07 kg ha^{-1}, respectively. The minimum nitrogen uptake was observed under M_1, which recorded 63.83 kg ha^{-1} in 2023 [5] and 66.43 kg ha^{-1} in 2024. The statistical analysis showed that the differences among establishment methods were significant as the calculated CD (5%) values were 7.10 in 2023 and 1.36 in 2024, with standard errors of 2.05 and 0.39, respectively. Overall, the results indicate that improved crop establishment techniques enhanced nitrogen uptake by providing better crop growth conditions and nutrient utilization efficiency.

Table 2: Nitrogen uptake of rice as affected by crop establishment methods and nitrogen levels both years

Treatments	2023	2024
M1	63.83	66.43
M2	67.88	69.57
M3	70.26	72.40
M4	66.24	68.07
S Em (±)	2.05	0.39
C.D at 5%	7.10	1.36
N1	53.91	55.93
N2	69.14	69.55
N3	78.11	81.88
S Em (±)	0.95	0.46
C.D at 5%	2.86	1.38
	Interaction (M*N) 2023	**Interaction (M*N) 2024**
M1N1	50.67	54.00
M1N2	68.83	66.50
M1N3	72.00	78.80
M2N1	56.67	56.20
M2N2	66.43	70.00
M2N3	80.53	82.50
M3N1	53.83	58.00
M3N2	76.10	73.20
M3N3	80.83	86.00
M4N1	54.47	55.50
M4N2	65.20	68.50
M4N3	79.07	80.20
S Em (±)	2.57	0.85
C.D at 5%	7.72	2.54

Nitrogen levels had a highly significant effect on nitrogen uptake during both years. Nitrogen uptake increased progressively with increasing nitrogen levels. In 2023 [5], the uptake ranged from 53.91 to 78.11 kg ha⁻¹, while in 2024 it ranged from 55.93 to 81.88 kg ha⁻¹.

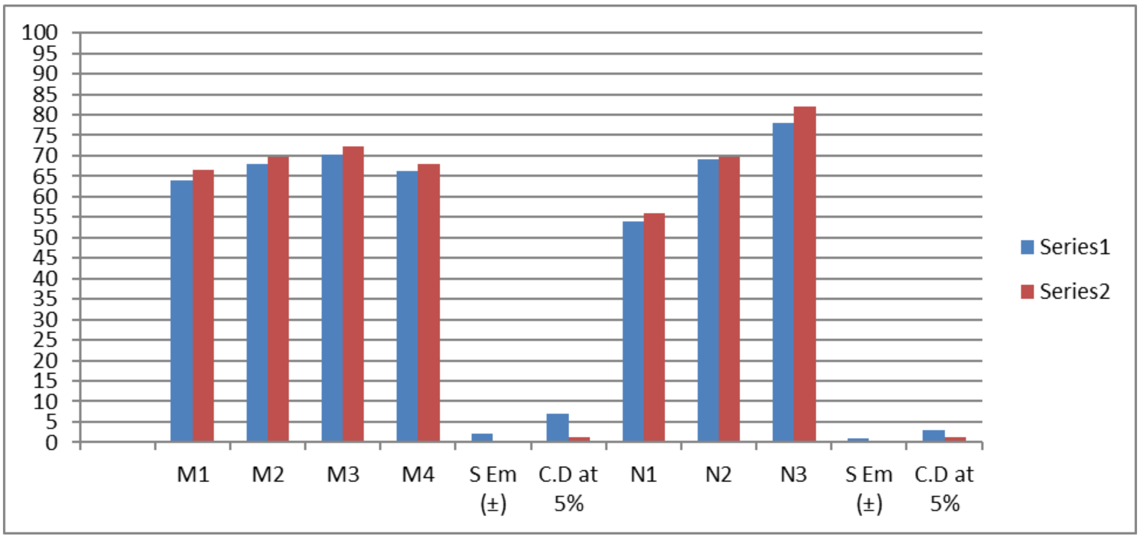

Fig 3: Nitrogen uptake of rice as affected by crop establishment methods and nitrogen levels both years

The highest nitrogen uptake was recorded with N_3 (78.11 kg ha⁻¹ in 2023 [5] and 81.88 kg ha⁻¹ in 2024), which was significantly superior to the other nitrogen levels. This might be due to the increased availability of nitrogen in the soil, which promoted higher biomass production and consequently greater nutrient absorption by the crop. The treatment N_2 recorded moderate nitrogen uptake of 69.14 kg ha⁻¹ in 2023 [5] and 69.55 kg ha⁻¹ in 2024, whereas the lowest uptake was observed under N_1, with values of 53.91 and 55.93 kg ha⁻¹, respectively. The statistical analysis indicated significant differences among nitrogen levels as the CD (5%) values were 2.86 in 2023 [5] and 1.38 in 2024, with corresponding SEm values of 0.95 and 0.46, respectively.

Interaction effect of crop establishment methods and nitrogen levels

The interaction effect between crop establishment methods and nitrogen levels (M × N) was also found to be significant during both the years. In 2023 [5], nitrogen uptake under interaction treatments ranged from 50.67 to 80.83 kg ha⁻¹, while in 2024 it ranged from 54.00 to 86.00 kg ha⁻¹. The maximum nitrogen uptake was observed with the combination M_3N_3, which recorded 80.83 kg ha⁻¹ in 2023 [5] and 86.00 kg ha⁻¹ in 2024. This was closely followed by M_2N_3 (80.53 and 82.50 kg ha⁻¹) and M_4N_3 (79.07 and 80.20 kg ha⁻¹). The higher nitrogen uptake in these treatments may be attributed to the combined effect of efficient crop establishment methods and higher nitrogen availability, which improved nutrient absorption and crop growth. On the other hand, the minimum nitrogen uptake was recorded with M_1N_1, which showed values of 50.67 kg ha⁻¹ in 2023 [5] and 54.00 kg ha⁻¹ in 2024. Other lower values were observed under combinations with lower nitrogen levels, indicating the strong influence of nitrogen supply on nutrient uptake. The interaction differences were statistically significant with SEm values of 2.57 and 0.85 and CD (5%) values of 7.72 and 2.54 for the years 2023 and 2024, respectively.

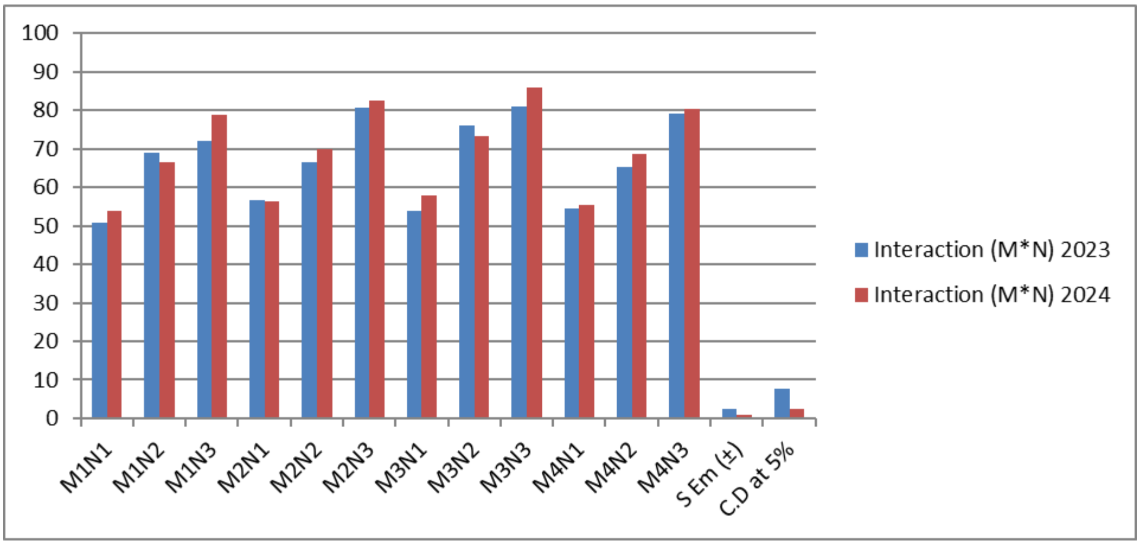

Fig 4: Nitrogen uptake interaction of rice as affected by crop establishment methods and nitrogen levels both years

Conclusion

The results of the study clearly demonstrated that crop establishment methods and nitrogen levels significantly influenced chlorophyll content and nitrogen uptake of rice. Chlorophyll content increased from early growth stages to 60 DAS and declined slightly thereafter, indicating maximum photosynthetic activity during the mid-growth stage. Among the establishment methods, M3 consistently recorded the highest chlorophyll content and nitrogen uptake during both years of experimentation. Similarly, higher nitrogen level (N3) significantly increased chlorophyll concentration and nitrogen uptake compared with N2 and N1. The interaction effect also revealed that the combination M3N3 produced the maximum chlorophyll content and nitrogen uptake, while M1N1 recorded the lowest values. These findings suggest that adoption of an appropriate crop establishment method along with adequate nitrogen supply enhances physiological efficiency, improves nutrient uptake and ultimately contributes to better growth and productivity of rice.

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