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Effect of integrated nitrogen management on growth and yield contributing characters in turmeric (*Curcuma longa* L.)

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Abstract
A field experiment was conducted during the kharif seasons of 2021-22 and 2022-23 to assess the impact of integrated nitrogen management on the growth, yield, and quality of turmeric Cv. PDKV Waigaon. The study evaluated organic and inorganic nitrogen sources, including vermicompost, neem cake, and urea, along with their application timings. Results revealed that the application of 90% RDN through neem cake + 10% RDN (N_2). It was at par in the treatment (N_1). Growth parameters like plant height 90 DAP, number of leaves 90 DAP, leaf area 90 DAP and yield characters i.e. number of mother rhizomes per plant, number of primary rhizomes per plant were maximized when this nitrogen management strategy was paired with application timings at 30, 60, 90, and 120 days after planting (D_1). While, the maximum number of secondary rhizomes per plant in turmeric was produced when, nitrogen was applied with four equal split at interval of 40, 70, 100 and 130 DAP (D_2). Thus, integrated nitrogen management with neem cake and strategic application timing can significantly enhance growth and yield contributing characters in turmeric.

Keywords: Neem cake, vermicompost, time of application

Introduction

India is the major producer, consumer, and exporter of turmeric in the world. It is found throughout south and south-east Asia with a few species exending to Australia, China, and South-Pacific. The highest diversity is concentrated in India and Thailand, with at least 40 species in each area, followed by Burma, Bangladesh, Indonesia, and Vietnam. Indian turmeric is the best in the world market because of its high curcumin content. India accounts for about 80 per cent of world turmeric production and 60 per cent of world exports. Other major producers are Pakistan, China, Haiti, Jamaica, Peru, Taiwan, and Thailand. Asian countries consume much of their turmeric production.

Turmeric (*Curcuma longa* L.) is an important spice crop in India and plays vital role in national economy. *Curcuma longa* L. Syn. *C. domestica*, commonly known as turmeric, in Sanskrit 'Haridra' in Hindi 'Haldi' is one of the most important spices crops. The genus *Curcuma* is a triploid with a somatic chromosome number of 63 (2n = 3x = 63) belonging to the family Zingiberaceae considered to have originated in the Indo-Malyan region (Purseglove, 1968) which comprises 40 genera and 400 tropical spices in the old world. Out of these three genera *viz.*, *Curcuma* (Turmeric), have commercial importance as spices. It is a perennial herbaceous plant with tall leafy branches bearing up to twelve (12) leaves that can grow up to two meters in height. The leaves are oblong or lanceolate, up to 1 m long, and dark green from above and pale green from below.

The sheath and petiole are about the same length as the blade. *Curcuma longa* has a sterile, pale yellow and reddish bloom, with a green and purplish flowering bract. (Fuloria and Mehta 2022, Jyotirmayee Mahalik 2022) [4, 8]. *Curcuma longa* has a rhizome that grows underground. The plant is mostly grown for its rhizome, which has tough segmented skins. (Prasad and Aggarwal 2011). The rhizome can grow to be 2.5-7.0 cm long and 2.5 cm in diameter. The rhizome has a pleasant aroma and a bitter taste. *Curcuma longa* plants are grown in the tropics and subtropics at temperatures between 20 and 30 degrees Celsius, with adequate rainfall. (Karłowicz and Bodalska 2017) [10].

In India during 2023-24, about 3.50 lakh ha^{-1} was cultivated area under turmeric Maharashtra occupies 89273 thousand ha^{-1} area was covered under turmeric. (Anonymous 2024). Turmeric is a tropical crop and needs a warm and humid climate with an optimum temperature of 20 °C to 30 °C for normal growth and satisfactory production. It thrives best on sandy, loamy, and alluvial, loose, friable, and fertile soil rich in organic matter status and having a pH ranged between 5 to 7.5. Alkaline soil is not suitable for its cultivation. The crop cannot withstand water logging. It grows at all places ranging from sea level to an attitude at 1200 meter above the mean sea level. As a rainfed crop, turmeric needs a well distributed annual rainfall of 250 to 400 mm for successful production.

Turmeric contains protein (6.3%), fat (5.1%), minerals (3.5%) and carbohydrates (69.4%) and moisture (13.1%). The essential oil (volatile oil termerol) obtained by steam distillation of rhizome has a-phellandrene (1%), sabinene (0.6%), cineol (1%), borneol (0.5%), zingiberene (25%) and sesquiterpines (53%) (Kapoor, 1990). Curcumin (diferuloylmethene) (3-4%) is responsible for the yellow colour and its comprised of curcumin | (94%) and curcumin II (6%) and curcumin III (0.3%) (Ruby *et al.*, 1995) [19].

Although curcumin has many health-promoting effects but still hard to find a place in mainstream drug application due to its poor bioavailability (Prasad *et al.*, 2014) [16]; therefore, to get the health-promoting effect one must need to have a high dose of curcumin to exert the positive and health-promoting effects (Vareed *et al.*, 2008) [22]. Curcumin is an oil-soluble pigment, sparingly soluble in water at acidic and neutral pH, and soluble in alkali condition.

Integrated Nitrogen Management (INM) is a critical component of sustainable agriculture, aimed at optimizing crop productivity while preserving soil health and environmental quality. Nitrogen, being one of the most essential macronutrients, plays a vital role in plant growth, chlorophyll formation, protein synthesis, and overall yield. However, the indiscriminate use of synthetic nitrogen fertilizers has led to several challenges, including soil nutrient imbalance, reduced microbial activity, groundwater contamination, and increased greenhouse gas emissions. INM addresses these issues by integrating chemical fertilizers with organic amendments such as, neem cake and vermicompost. This balanced approach enhances the soil's physical, chemical, and biological properties. Additionally, INM supports long-term soil fertility, improves crop resilience making it a vital practice for achieving both high productivity and environmental sustainability in agriculture.

Material and Methods

The experiment was carried out during year 2021-22 and 2022-23 at Chili and Vegetable Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola located in subtropical region between 22.42º N latitude and 77.02º E longitude at an altitude of 307.42 m above the mean sea level. The experimental plot was having very loose soil with uniform texture and structure with good drainage. The soil of experimental plots was slightly alkaline in reaction (pH 8.23), available N (191.37 kg ha^{-1}), available P (10.56 kg ha^{-1}) high in available K (371.43 kg ha^{-1}). The experiment employed a Factorial Randomized Block Design with three replications, comprising seven nitrogen management levels and three application timing levels, resulting in 21 treatment combinations. Neem cake, vermicompost, P_2O_5 and K_2O was applied at the time of planting and P_2O_5 and K_2O common all the treatment under the study. The planting was done in Kharif season of 2021-22 and 2022-23 on ridges and furrow at spacing of 60 X 30 cm. Recommended package of practices was followed. The high curcumin containing cultivar "PDKV Waigaon" developed by Dr. PDKV, Akola, Maharashtra was used. The pH of soil samples was determined by using glass electrode pH meter (Jackson, 1973) [7]. The statistical analysis of data for Factorial Randomized Block Design on observations recorded was done as suggested by Panse and Sukhatme (1985) [14].

Results and Discussion

Growth parameters (Plant height at 90 DAP, number of leaves at 90 DAP and leaf area at 90 DAP)

Effect of nitrogen management on plant height, number of leaves at and leaf area at 90 DAP

The data presented table 1 (a) revealed that, significantly the maximum (63.38cm, 9.39 and 186.29 cm^{-2}, respectively) Plant height number of leaves and leaf area at was recorded in turmeric crop due to the application of 90% RDN through neem cake along with 10% RDN (N_2) it was stastically at par in the treatment (N_1). Whereas, the significantly the minimum (58.04 cm, 7.33 and 177.76 cm^{-2}) Plant height, number of leaves and leaf area were recorded in turmeric with the application of 100% RDN through inorganic source (N_7). Among the nitrogen management treatments, the recommended dose of nitrogen (RDN) remained comparable. This response may be attributed to the improved water use efficiency associated with neem cake, which possibly promoted rapid shoot growth during the crop growth period by reducing vapour pressure deficit and minimizing evaporation losses. Moreover, the combined application of neem cake and RDN might have resulted in a synergistic effect, leading to enhanced nutrient availability and uptake by the crop. Similar beneficial effects could also be attributed to the application of vermicompost in combination with RDN in turmeric. These similar findings are in line with Shah *et al.* (2019) [20], Lohar and Hase (2021) [12] Amala *et al.* (2022) [1] and Kumar *et al.* (2013) [11] in turmeric.

Effect of days to split application of nitrogen on plant height, number of leaves and leaf area at 90 DAP (D)

The growth parameters were significantly influenced by the different days to split application of nitrogen. significantly the maximum (61.57, 9.33 and 183.88, respectively) Plant height, number of leaves and leaf area were obtained when nitrogen applied earlier than rest of the treatment with four equal splits at interval of 30, 60, 90 and 120 (D_1) days after planting (DAP). Whereas, significantly the minimum (59.39, 7.30 and 180.94, respectively) Plant height, number of leaves and leaf area were produced, when nitrogen was applied 20 days than rest of the treatment with four equal splits at interval of 50, 80, 110 and 140 (D_3) days after planting (DAP) in turmeric crop. The role of nitrogen in promoting cell elongation, phosphorus in enhancing nitrogen activity within the root zone, and potassium in supporting rhizome development collectively contributed to improved transformation of the stem into a modified rhizome. This improvement was primarily due to the timely availability of macronutrients compared to other treatment levels, where nutrient application was delayed by a 10-day interval. The present findings are in agreement with the results reported by Amala *et al.* (2022) [1] and Haque *et al.* (2007) [6] in turmeric.

Table 1(a): Effect of nitrogen management and days to split application of nitrogen on growth parameters in turmeric (pooled mean)

Treatments	Plant height (cm) at 90 DAS	Number of leaves at 90 DAS	Leaf area (cm^2) at 90 DAS
	Pooled	Pooled	Pooled
Nitrogen management (N)			
N_1-90% RDN through VC+10% RDN	62.09	9.39	185.40
N_2-90% RDN through NC+10% RDN	63.38	9.56	186.29
N_3-75%RDN through VC+25% RDN	60.27	8.15	183.00
N_4-75%RDN through NC+25% RDN	61.39	8.38	183.92
N_5-50%RDN through VC+50% RDN	58.39	7.45	179.51
N_6-50%RDN through NC+50% RDN	59.79	7.90	180.16
N_7-100% RDF through inorganic source	58.04	7.33	177.76
'F' test	Sig.	Sig.	Sig.
SE(m) ±	0.33	0.24	0.22
CD at 5%	0.96	0.68	0.63
Days to split application of nitrogen (D)			
D_1 (at 30, 60, 90 and 120 DAP)	61.57	9.33	183.88
D_2 (at 40,70,100 and 130 DAP)	60.47	8.29	182.05
D_3 (at 50, 80, 110 and 140 DAP)	59.39	7.30	180.94
'F' test	Sig.	Sig.	Sig.
SE(m) ±	0.22	0.15	0.42
CD at 5%	0.63	0.45	1.21
Interaction (N X D)			
'F' test	Sig.	Sig.	Sig.
SE(m) ±	0.58	0.41	1.12
CD at 5%	1.66	1.24	3.22

Table 1(b): Interaction effect of nitrogen management and days to application of nitrogen on growth parameters in turmeric (pooled mean)

Treatments	Plant height (cm)	Number of leaves	Leaf area (cm^2)
	pooled	pooled	pooled
N_1D_1	63.21	10.46	186.41
N_1D_2	62.10	9.39	185.31
N_1D_3	60.97	8.33	184.48
N_2D_1	64.49	10.63	188.42
N_2D_2	63.37	9.56	185.88
N_2D_3	62.28	8.51	184.59
N_3D_1	61.38	9.10	184.09
N_3D_2	60.28	8.15	182.76
N_3D_3	59.17	7.20	182.16
N_4D_1	62.50	9.30	185.94
N_4D_2	61.39	8.26	183.52
N_4D_3	60.28	7.59	182.30
N_5D_1	59.48	8.51	181.49
N_5D_2	58.37	7.44	179.32
N_5D_3	57.31	6.40	177.22
N_6D_1	60.93	8.97	182.01
N_6D_2	59.77	7.90	179.77
N_6D_3	58.68	6.84	178.72
N_7D_1	59.02	8.38	178.81
N_7D_2	58.05	7.33	177.82
N_7D_3	57.04	6.28	176.66
'F' test	Sig.	Sig.	Sig.
SE (m)	0.58	0.41	1.12
CD at 5 %	1.66	1.24	3.22

Interaction effect of nitrogen management and days to split application of nitrogen on plant height at 90 DAP, number of leaves at 90 DAP and leaf area at 90 DAP (NxD)

The data presented in Table 1b revealed that the growth parameters of turmeric were significantly influenced by different levels of nitrogen management and days to split application of nitrogen. The interaction effect between nitrogen management and days to split application of nitrogen on plant height, number of leaves per plant, and leaf area per plant was found to be statistically significant in the turmeric crop. significantly the maximum (64.49 cm and 10.63 and 188.42 cm^{-2}, respectively) Plant height at, number of leaves and leaf area were recorded by the treatment combination N_2D_1 90% RDN through neem cake along with 10% RDN and nitrogen was applied earlier than rest of the treatments with four equal split at an interval of 30, 60, 90 and 120 days after planting. However, significantly the minimum (57.04 cm, 6.28 and 176.66 cm^{-2}, respectively) Plant height at, number of leaves and leaf area were recorded by the treatment combination N_7D_3 100% RDN through inorganic source and when nitrogen was applied 20 days late than rest of the treatments with four equal split at 50, 80, 110 and 140 days after planting. similar result were reported Haque *et al.* (2007) [6].

Yield contributing characters number of mother rhizomes per plant, number of primary rhizomes per plant and number of secondary rhizomes

Effect of nitrogen management on number of mother rhizomes per plant (N)

The data presented in Table 2(a) revealed that, the pooled data indicated that, number of mother rhizomes per plant were significantly the maximum (2.76) due to the application of 90 % RDN through neem cake along with 10% RDN(N_2). It was stastically at par in the treatment (N_1). However, significantly the minimum (1.31) number of mother rhizomes per plant was recorded with the application of 100% RDN through inorganic sources (N_7). neem cake is known to improve soil physical properties and ensure a gradual and sustained release of nutrients throughout the crop growth period. The present findings are in conformity with the reports of Kamal and Yousuf (2012) [9] and Anuradha *et al.* (2018) [3], who recognized neem cake as one of the most effective natural manures for turmeric cultivation.

Effect of nitrogen management on number of primary rhizomes per plant (N)

The pooled data indicated that, number of primary rhizomes per plant was significantly the maximum (4.90) was produced in treatment (N_2) due to the application of 90 % RDN through neem cake along with 10% RDN. However, significantly the minimum (4.21) number of primary rhizomes per plant were recorded in the treatment (N_7) i.e. application of 100% RDN through inorganic sources. The higher number of fingers per plant may be attributed to the supply of macro-and micronutrients through organic manures and their constituents, which exerted a promotive effect on vegetative growth and ultimately enhanced photosynthetic activity. As a result, greater assimilate production and translocation towards the rhizomes occurred, leading to increased accumulation and a higher number of primary fingers per plant. These findings are in close conformity with the results reported by Shah *et al.* (2019) [20].

Effect of nitrogen management on number of secondary rhizomes

The pooled data indicated that, number of secondary rhizomes per plant were significantly the maximum (2.28) in treatment consisting of application of 90% RDN through neem cake along with 10% RDN through inorganic source (N_2). However, significantly the minimum (1.12) number of secondary rhizomes per plantwas recorded due to the application of 100% RDN through inorganic sources in turmeric (N_7). Plant height is an important growth attribute in crops like turmeric, as stem elongation leads to an increase in the number of leaves, expanded leaf area, and enhanced photosynthetic activity, thereby resulting in greater carbohydrate production. This process facilitates increased translocation of assimilates towards the rhizomes for accumulation, which in turn enhances the number of secondary rhizomes per plant. Similar improvements in yield attributes have been reported by Roy and Hore (2007) [18] in ginger, as well as by Kumar *et al.* (2013) [11] and Shah *et al.* (2019) [20] in turmeric.

Effect of nitrogen management on total rhizomes per plant in turmeric

The pooled data furnished in Table 2 (a) found that, significantly the maximum (9.97) total rhizomes per plant in turmeric crop were produced due to the application of 90% RDN through neem cake along with 10% RDN through inorganic source (N_2). It was found to be stastically at par with the treatment (N_1). However, significantly the minimum (6.64) total rhizomes per plant in turmeric crop was recorded with the application of 100% RDN through inorganic sources (N_7).

Days to split application of nitrogen on number of mother rhizomes, (D)

The pooled data indicated that, significantly the maximum (2.09) number of mother rhizomes per plant was recorded in the treatment (D_1), where nitrogen was applied earlier than rest of the treatments with four equal split at interval of 30, 60, 90 and 120 days after planting. However, significantly minimum (1.96) number of mother rhizomes per plant were observed in treatment (D_3), when nitrogen was applied 20 days late than rest of the treatments with four equal split at interval of 50, 80, 110 and 140 days after planting. This response may be attributed to the pivotal role of nitrogen in enhancing vegetative growth and tissue differentiation. Physiologically, nitrogen is a key component in the synthesis of proteins, nucleic acids, and protoplasm, all of which are essential for vigorous plant growth and development. Such enhanced growth likely resulted in the production of a maximum number of rhizomes per plant in the present study. These findings are in agreement with the results reported by Mekonen and Garedew (2019) [13] in turmeric.

Days to split application of nitrogen on number of primary rhizomes

The pooled data indicated that, significantly the maximum (4.64) number of primary rhizomes per plant were recorded in the treatment (D_1), where the nitrogen was applied earlier than rest of the treatments with four equal split at interval of 30. 60, 90 and 120 days after planting (DAP). However, significantly the minimum (4.54) number of primary rhizomes per plant were observed in treatment (D_3), where the nitrogen was applied 20 days late than rest of the treatments with four equal split at interval of 50, 80, 110 and 140 days after planting (DAP).In the present study, application of the recommended dose of nitrogen was tried to split in four equal doses, but at various timing. Physiologically, nitrogen plays a crucial role in the synthesis of proteins, nucleic acids, and protoplasm, thereby promoting active cell division and differentiation. This could be the underlying reason for the maximum number of primary rhizomes observed per plant in turmeric. Similar results have been reported earlier by Singh *et al.* (2016) [21] and Mekonen and Garedew (2019) [13] in turmeric.

Days to split application of nitrogen on number of secondary rhizomes

The pooled data indicated that, significantly the maximum (1.92) number of secondary rhizomes per plant were recorded in the treatment (D_2) wherein nitrogen was applied earlier than rest of the treatments with four equal split at an interval of 40, 70,100 and 130 days after planting (DAP). However, significantly minimum (1.81) number of secondary rhizomes per plant were observed (D_3) in which, nitrogen was applied 20 ays late than rest of the treatments with four equal split at interval of 50, 80, 110 and 140 days after planting (DAP). The maximum number of secondary rhizomes per plant with application of RDN at 40, 70, 100 and 130 DAP in present investigation. In turmeric, the formation of secondary rhizomes begins only after the establishment of primary rhizomes. This developmental stage requires the application of nitrogen at appropriate intervals, namely at 40, 70, 100, and 130 DAP. During this phase, rhizome bulking occurs through cell expansion driven by enhanced photosynthetic activity and subsequent dry matter accumulation. This physiological process may explain the production of a maximum number of secondary rhizomes compared to other treatments in the present study. These results are in conformity with the findings of George *et al.* (2002) [5] and Mekonen and Garedew (2019) [13] in turmeric.

Days to split application of nitrogen on total rhizomes per plant, (D)

The pooled data presented in Table 2 (a) revealed that, significantly the maximum (8.59) total rhizomes per plant was produced in the treatment (D_1), where nitrogen was applied earlier than rest of the treatments with four equal split at an interval of 30, 60, 90, and 120 days after planting. However, significantly minimum (8.31) total rhizomes per plant was observed in treatment (D_3), where nitrogen was applied 20 days late than rest of the treatments with four equal split at an interval of 50, 80, 110, and 140 DAP.

Table 2(a): Effect of nitrogen management and days to split application of nitrogen on yield contributing character in turmeric (pooled mean)

Treatment		No. of mother rhizomes plant^{-1}	No. of primary rhizomes plant^{-1}	No. of secondary rhizomes plant^{-1}	Total rhizomes plant^{-1}
Nitrogen management (N)					
N_1-90% RDN through VC+10% RDN		2.63	4.84	2.15	9.62
N_2-90% RDN through NC+10%RDN		2.76	4.90	2.30	9.97
N_3-75%RDN through VC+25% RDN		1.97	4.60	1.98	8.55
N_4-75%RDN through NC+25% RDN		2.13	4.72	2.12	8.97
N_5-50%RDN through VC+50% RDN		1.58	4.28	1.58	7.44
N_6-50%RDN through NC+50% RDN		1.78	4.61	1.79	8.18
N_7-100% RDN through inorganic source		1.31	4.21	1.12	6.64
'F' test		Sig.	Sig.	Sig.	Sig.
SE(m) ±		0.05	0.09	0.05	0.05
CD at 5%		0.15	0.26	0.16	0.16
Days to split application of nitrogen (D)					
D_1	at 30, 60, 90 and 120 DAP	2.09	4.64	1.86	8.80
D_2	at 40, 70, 100 and 130 DAP	2.03	4.60	1.92	8.62
D_3	at 50, 80, 110 and 140 DAP	1.96	4.54	1.81	8.45
'F' test		Sig.	Sig.	Sig.	Sig.
SE(m) ±		0.03	0.03	0.02	0.03
CD at 5%		0.10	0.08	0.05	0.09
Interaction (N x D)					
'F' test		NS	NS	NS	Sig.
SE(m) ±		0.10	0.18	0.09	0.09
CD at 5%		-	-	-	0.26

Table 2(b): Effect of nitrogen management and days to split application of nitrogen on yield contributing character in turmeric (pooled mean)

Treatment combination	No. of mother rhizomes plant^{-1}	No of primary rhizomes	No. of secondary rhizomes plant^{-1}	Total rhizomes plant^{-1}
N_1D_1	2.73	4.89	2.22	9.75
N_1D_2	2.65	4.84	2.14	9.71
N_1D_3	2.52	4.79	2.11	9.42
N_2D_1	2.83	4.95	2.35	10.06
N_2D_2	2.76	4.91	2.29	10.01
N_2D_3	2.71	4.86	2.26	9.83
N_3D_1	2.04	4.69	2.06	8.70
N_3D_2	1.98	4.60	1.97	8.64
N_3D_3	1.91	4.51	1.90	8.32
N_4D_1	2.21	4.75	2.17	9.08
N_4D_2	2.13	4.72	2.13	9.02
N_4D_3	2.07	4.68	2.08	8.82
N_5D_1	1.66	4.32	1.61	7.56
N_5D_2	1.57	4.28	1.59	7.45
N_5D_3	1.52	4.24	1.56	7.31
N_6D_1	1.81	4.65	1.88	8.23
N_6D_2	1.79	4.63	1.78	8.30
N_6D_3	1.76	4.55	1.71	8.01
N_7D_1	1.35	4.26	1.16	6.73
N_7D_2	1.32	4.22	1.13	6.69
N_7D_3	1.27	4.15	1.09	6.50
'F' test	NS	NS	NS	Sig.
SE (m)	0.09	0.18	0.09	0.09
CD at 5 %	-	-	-	0.26

Interaction effect of nitrogen management and days to split application of nitrogen on number of mother rhizomes per plant, number of primary rhizomes per plant and number of secondary rhizomes and total rhizomes in turmeric (NxD)

The data presented int table 2(b) the interaction effect of nitrogen management and days to split application of nitrogen to the number of mother rhizomes per plant, number of primary rhizomes per plant and number of secondary rhizomes, were found to be stastically non-significant in turmeric crop. The pooled data indicated that, significantly the maximum total rhizomes per plantin turmeric (10.06) was recorded with the treatment combination of N_2D_1 i.e. application of 90% RDN through neem cake along with 10% RDN through inorganic source and where nitrogen was applied earlier than rest of the treatment with four equal split at an interval of 30, 60, 90 and 120 days after planting. However, the minimum (6.50) total rhizomes per plantwas obtained with the treatment combination of N_7D_3 i.e. application of 100% RDN through inorganic source and when nitrogen was applied 20 days late than rest of the treatments with four equal split at an interval of 50, 80, 110 and 140 days after planting in turmeric crop. Total rhizomes produced by each turmeric plant consist of number of mother rhizomes, primary and secondary rhizomes, since all the three were calculated as total yield of the plant at last. These, treatments are responsible for getting maximum mother, primary and secondary rhizomes would naturally expressed the maximum number of total rhizomes by each turmeric plant in present study as summission of all such types of rhizomes.

Conclusion

The results of the present investigation clearly demonstrated that both nitrogen management and timing of split application significantly influenced the growth and yield attributes of turmeric. Application of 90% RDN through neem cake along with 10% RDN through inorganic source consistently recorded superior plant height, number of leaves, leaf area, and yield-contributing characters such as number of mother, primary, secondary, and total rhizomes per plant. Among the split application schedules, early application of nitrogen in four equal splits at 30, 60, 90, and 120 DAP proved most effective in enhancing growth and total rhizome production. The interaction effect revealed that the treatment combination N_2D_1 produced the maximum total rhizomes per plant, whereas delayed nitrogen application with sole inorganic fertilization resulted in inferior performance. The enhanced performance under integrated nutrient management may be attributed to improved nutrient availability, efficient uptake, better soil physical conditions, and sustained nitrogen release, ultimately leading to improved photosynthetic activity and assimilate partitioning towards rhizome development. Thus, integrated use of organic and inorganic nitrogen sources with timely split application is crucial for maximizing growth and yield of turmeric**.**

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