Plant Archives Vol. 26, Supplement 2, 2026 pp.81-88 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.008

EFFECT OF NANO NPK IN COMBINATION WITH COMMERCIAL FERTILIZERS ON GROWTH, YIELD AND QUALITY OF TURMERIC (*Curcuma longa* L.)

Anasuya Sil* and Jitesh Kumar Hore

Department of Plantation, Spices, Medicinal and Aromatic Crops, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur (741252), Nadia, West Bengal, India.

*Corresponding author E-mail: anasuya.sill1997@gmail.com

ORCID ID: https://orcid.org/0000-0001-7916-8946

(Date of Receiving : 09-03-2026; Date of Revision : 22-04-2026; Date of Acceptance : 17-05-2026)

ABSTRACT

Turmeric is one of the most important commercial spice crop, extensively cultivated in India. In recent years, nano-fertilizers have emerged as a promising tool in horticulture, enhancing crop growth, yield and quality while improving nutrient use efficiency, minimizing losses and production costs through precise nutrient management. Considering the facts, the present investigation was undertaken to evaluate the effect of nano NPK in combination with conventional fertilizers on sustainable turmeric production. The experiment was conducted during 2022–23 and 2023–24 at the Horticultural Research Station, Mondouri, Faculty of Horticulture, BCKV, Nadia, West Bengal, India following a randomized block design with three replications and eight treatments, including a control. Treatments involved different levels of N, P, and K along with foliar application of nano NPK (0.4%) at 45 and 90 days after planting. The application of 40% nitrogen and 75% phosphorus as basal, along with foliar sprays of 0.4% nano-NPK at 45 DAP and nano-NK at 90 DAP (T_8), resulted the maximum plant height (168.64 cm), number of tillers (2.77), leaves (19.27), clump weight (394.44 g) and plot yield (13.98 kg 3 m^{-2}). This treatment also exhibited enhanced quality attributes, including oleoresin (12.40%) and total phenols (66.18 mg GAE 100 g^{-1}). Whereas, maximum curcumin (6.03%) and dry recovery (23.73%) were observed under T_4 (40% N+100% P as basal + 0.4% nano N and K at 45 and 90 DAP). The control (T_1: RDF) recorded lower yield (24.31 t ha^{-1}). Treatment T_8 was found to be the most effective based on growth, yield, and quality.

Keywords **:** Curcumin, nanofertilizers, phenol, oleoresin, turmeric, yield.

Introduction

Turmeric (*Curcuma long* L.), 2n=3X=63 is an important perennial rhizomatous herb, commonly known as “Haldi” belongs to the family Zingiberaceae. It is one of the most important spice and medicinal crops cultivated in tropical and subtropical regions. The plant believed to be originated from South and Southeast Asia. India considers as the largest producer, consumer, and exporter of turmeric in the world (Sil *et al.*, 2026). The crop is primarily cultivated for its underground rhizome (modified stem) which contain bioactive compounds curcumin responsible for its characteristic yellow colour, distractive flavour, and therapeutic properties (Aggarwal *et al.,* 2003). Curcumin exhibits a wide range of biological activities, including antioxidant, anti-inflammatory, antimicrobial, and anticancer properties (Nguyen *et al.*, 2024). In addition to this, turmeric rhizomes are rich in essential oil (turmerol-2.5-7.25%), proteins (9.40%), carbohydrates (67.38%), vitamins (niacin- 2.30%, riboflavin-0.16%, and thiamine-0.89%), and minerals (calcium -0.02%, phosphorus- 0.63%, potassium-0.46%, and iron- 0.05%), contributing to its multifunctional applications in food, pharmaceutical, and cosmetic industries (Ikpeama *et al.,* 2014; Ronya *et al.,* 2020). Due to shallow and fibrous root system, long crop duration (8-9 months) and uneven nutrient demand throughout growth period, the plants required heavy fertilizer application for better growth and development (Chitdeshwari, 2019). Indiscriminate application of synthetic fertilizers often exhibit poor nutrient use efficiency leads to detrimental effects on soil quality and poses potential risks to the surrounding environment. It also escalates input costs and ultimately reduces farmers' economic returns (Diatta *et al.,* 2020). To address these constraints, nanofertilizers have emerged as a promising and efficient alternative in modern crop production systems for improving nutrient management and enhancing fertilizer use efficiency.

Nano-fertilizers are produced by modifying conventional fertilizers or bulk materials or they can be synthesized using extracts obtained from different vegetative or reproductive plant parts through chemical, physical, mechanical or biological approaches enabled by nanotechnology (Singh *et al.,* 2017). Their application aims to improve soil fertility, crop productivity and the quality of agricultural produce. Compare to traditional fertilizers, nano-fertilizers offer several advantages, including lower application rates, controlled or slow nutrient release, reduced transportation and application costs and comparatively lower salt build-up in soils. The research work on the effect of nano macro nutrients on growth, yield and quality of turmeric is very limited. Considering all of these facts and realizing the potentiality of nano fertilizers in sustainable horticulture the present study was conducted with an aim to assess the influence of nano macronutrient on growth yield and quality of turmeric.

Materials and Methods

The experiment was conducted for two consecutive year (2022-23 and 2023-24) at HRS, Mondouri, BCKV, Mohanpur, West Bengal. The field was laid out in randomized block design (RBD) comprising eight treatments with three replications such as T_1= 40% N + 100% P (Basal)→ 30% N + 50% K (45 DAP)→ 30% N + 50% K (90 DAP), T_2= 40% N + 100% P (Basal)→ 0.4% nano N + 50% K (45 DAP)→ 0.4% nano N + 50% K (90 DAP), T_3= 40% N + 100% P (Basal)→ 30% N + 0.4% nano K (45 DAP)→ 30% N + 0.4% nano K (90 DAP), T_4= 40% N + 100% P (Basal)→ 0.4% nano N and K (45 DAP)→ 0.4% nano N and K (90 DAP), T_5= 40% N + 75% P (Basal)→ 30% N + 0.4% nano P + 50% K (45 DAP)→ 30% N + 50% K (90 DAP), T_6= 40% N + 75% P (Basal)→ 0.4% nano N and P + 50% K (45 DAP)→ 0.4% nano N + 50% K (90 DAP), T_7= 40% N + 75% P (Basal)→ 30% N + 0.4% nano P and K (45 DAP)→ 30% N + 0.4% nano K (90DAP), T_8= 40% N + 75% P (Basal)→ 0.4% nano N, P and K (45 DAP)→ 0.4% nano N and K (90DAP). The turmeric variety Suguna was used in experiment. Raised beds of 3.0 m × 1.0 m with 15 cm height were prepared, and healthy seed rhizomes of 25–30 g were treated with blitox @ 4 g L^{-1} for 30 minutes before planting. Planting was carried out at a spacing of 30 cm × 25 cm during mid-June and harvesting was completed by the end of January during both years of study. The RDF of NPK @150:60:150 kg ha^{-1} was applied through urea, single super phosphate, and muriate of potash. Basal application included 40% nitrogen, full phosphorus, and FYM @ 25 t ha^{-1}, while the remaining nitrogen and potassium were applied in two split doses at 45 and 90 DAP as per treatment schedule. Irrigation was given immediately after planting and later scheduled based on soil moisture and weather conditions. Rhizomes were planted at 3–4 cm depth and mulched with paddy straw @ 10 t ha^{-1}, followed by additional mulching @ 5 t ha^{-1} at 45 and 90 DAP along with earthing up before the second and third mulching. Hand weeding was first carried out at 30 DAP and subsequently as required to maintain weed-free conditions throughout the crop growth period.

Observations

Growth parameters

Growth observations like plant height, number of tillers and leaves per plant were recorded at 120 and 180 DAP where leaf dimensions (length and breadth) were taken at 180 DAP from five randomly selected plant of each plot.

Yield parameters

After harvesting and cleaning off the roots and adhere soil the clump weight (g) and yield per plot (kg $3m^{-2}$) were recorded. The projected yield per hectare was calculated based on plot yield, considering 75% area occupied by turmeric in the present experiment (Anon, 1995).

Dry recovery

It was estimated using 100 g of uniformly chopped rhizomes collected from five selected samples. The samples were dried in a mechanical dryer at 55°C for 3–5 days until a constant weight was achieved. Dry recovery (%) was calculated by using the following formula (Kandiannan *et al.,* 2015) -

$$\text{Dry recovery}\ (\%) = \frac{\text{Dry weight of rhizome (g)} \times 100}{\text{Fresh weight of rhizome (g)}}$$

Oleoresin

A 5 g well-dried powdered sample was extracted in a Soxhlet apparatus using 200 ml acetone at about 50°C under continuous reflux for 4–5 hours to ensure complete oleoresin extraction. The extract was then heated in a water bath at 50–60°C to evaporate the acetone and obtain dry oleoresin. Oleoresin content (%) was calculated using following formula (Anon, 1984)-

$$\text{Oleoresin content (\%)} = \frac{\text{Weight of oleoresin (g)} \times 100}{\text{Weight of sample (g)}}$$

Total phenol content

It was estimated by extracting 1 g of finely powdered sample with 80% methanol, followed by centrifugation at 10,000 rpm for 20 mins. The extract was reacted with 0.5 ml Folin–Ciocalteu reagent and 2 ml of 20% sodium carbonate solution, and absorbance was measured at 760 nm using a UV–VIS spectrophotometer (Malik *et al.*, 2014).

$$\begin{array}{c}\text{Total phenol} \\ (\text{mg GAE. }100\text{g}^{-1})\end{array} = \frac{\begin{array}{c}\text{Graph factor} \times \text{O.D. of sample} \\ \times \text{Total volume}\end{array}}{\begin{array}{c}\text{Aliquoted volume} \times \\ \text{weight of sample} \times 1000\end{array}}$$

Curcumin

A 0.2 g dried turmeric powder sample was refluxed with 250 ml alcohol for 2.5–4 hours using a water-cooled condenser. The extract was filtered, made up to 100 ml with alcohol, and a 5 ml aliquot was further diluted. Absorbance of the final solution was measured at 425 nm using a spectrophotometer with alcohol as the blank -

$$\text{Curcumin (\%)} = \frac{\begin{array}{c}0.0025 \times \text{Absorbance at 425 mm} \times \\ \text{Volume made up} \times \text{Dilution factor} \times 100\end{array}}{\begin{array}{c}\text{Absorbance of standard (0.42)} \times \\ \text{Weight of samples} \times 1000\end{array}}$$

As 0.42 absorbance at 425 nm = 0.0025 g curcumin.

Results and Discussion

Plant height of turmeric was significantly influenced by integrated application of nano and conventional fertilizers at all growth stages. Among the treatments, T_8 [40% N + 75% P (Basal) → 0.4% nano N, P and K (45 DAP) → 0.4% nano N and K (90DAP)] recorded the maximum plant height *i.e.* 131.81 and 168.64 cm at 120 and 180 DAP, indicating the positive effect of combined nano N, P, K along with reduced doses of conventional fertilizer. The minimum plants height (92.22 and 129.15 cm at 120 and 180 DAP) was recorded under T_1 (40% N +100% P as basal→ 30% N + 50% K at 45 and 90 DAP). The findings are in close conformity with Chavan *et al.* (2024) who reported that integration of nano urea (50%) and nano potash (50%) along with conventional fertilizer treatment recorded maximum plant height in white onion (*Allium cepa*).

The number of tillers in turmeric increased progressively with crop growth and was significantly influenced by integrated nutrient management practices. Among all treatments, foliar application of 0.4% nano-N, P and K at 45 DAP and 0.4% nano-N and K at 90 DAP in combination with 40% N + 75% P as basal (T_8) recorded the highest number of tillers (2.77) at 180 DAP, where plants received 40% N + 100% P as basal in combination with 0.4% nano N and K at 45 DAP and 90 DAP (T_4) recorded the highest number of tillers (1.50) per clump at 120 DAP. The lowest tiller production (1.04 and 1.70 at 120 and 180 DAP) was observed in T_1 (40% N + 100% P as basal→ 30% N + 50% K at 45 and 90 DAP). The findings of the present study are in good agreement with Sreelaja (2018), who reported that application of nano NPK both in granular and foliar form @ 25 kg ha^{-1} and 0.5% respectively produced maximum number of tillers in ginger.

The number of leaves differed significantly among the treatments. Application of 0.4% nano N and K at 45 and 90 DAP along with 40% N + 100% P as basal (T_4) showed maximum number of leaves (11.99) at 120 DAP. Treatment T_8 [40% N + 75% P (Basal) → 0.4% nano N, P and K (45 DAP) → 0.4% nano N and K (90DAP)] recorded the highest number of leaves (19.27) at 180 DAP. While the lowest number of leaves (9.05 and 15.27 at 120 and 180 DAP) was observed in T_1 (40% N + 100% P as basal→ 30% N + 50% K at 45 and 90 DAP). The results are in close conformity with Dubey *et al.* (2023) who revealed that foliar application of 0.4% nano urea in combination with non nano NPK @ 75:50:50 kg ha^{-1} resulted in maximum number of leaves in *Allium cepa* L.

Leaf length varied significantly among the treatments at different growth stages. At 120 days after planting, foliar application of 0.4% nano-N, P and K at 45 DAP and 0.4% nano-N and K at 90 DAP integrated with 40% N + 75% P as basal (T_8) depicted maximum leaf length (59.22 cm). Where at 180 DAP foliar application of 0.4% nano-N at 45 and 90 DAP + 0.4% nano P at 45 DAP integrated with 40% N and 75% P as basal (T_6) recorded the longest leaf (79.85 cm). In contrast the lowest leaf length (65.68 cm) at 180 DAP was observed under untreated control (T_1: 40% N + 100% P as basal→ 30% N + 50% K at 45 and 90 DAP).

The highest leaf breadth (11.79 cm) was observed in the plants raised under foliar application of 0.4% nano-N and K at 45 and 90 days after planting along with 40% N and 100% P as basal (T_4) at 120 DAP. At 180 DAP application of 0.4% nano-N and P + 50% K at 45 DAP → 0.4% nano N + 50% K at 90 DAP along with 40% N and 75% P as basal (T_6) showed the highest leaf breadth (16.93 cm) which is statistically *at par* with T_8 (16.90 cm). The plants received only conventional fertilizers (T_1) recorded lowest leaf breadth (14.97 cm) at 180 DAP.

Nano fertilizers provide nutrients in nanoscale form which improves nutrient absorption through stomata and cuticular pathways when applied as foliar sprays, leading to improved cell division, elongation, enzymatic activity, chlorophyll synthesis, photosynthetic efficiency and better translocation of nutrients, aid in increased internodal elongation and biomass accumulation (Liu and Lal, 2015) that ultimately reflects on plant height, leaf length and breadth. Additionally, nano fertilizers improves the availability of amino acids and proteins required for rapid shoot development and enhanced root activity, leading to increased tiller and leaf number (Kottegoda *et al.,* 2011).

Clump weight varied significantly among the treatments with the values ranging from 256.79 g to 394.44 g (Table.3). The application of 0.4% nano-N, P and K at 45 DAP + 0.4% nano-N and K at 90 DAP along with 40% N + 75% P as basal (T_8) recorded the highest clump weight, followed by T_4 (40% N + 100% P as basal→ 0.4% nano N and K at 45 DAP and 90 DAP) [379.31 g] and T_6 (40% N + 75% P as basal→0.4% nano N and P + 50% K at 45 DAP→ 0.4% nano N + 50% K at 90 DAP) [357.34 g], while the lowest clump weight was recorded in T_1 (40% N + 100% P as basal→ 30% N + 50% K at 45 and 90 DAP).

The plot yield ranged from 9.73 kg 3 m^{-2} to 13.98 kg 3 m^{-2} showed a significant variations among the treatments (Table 3). Application of 40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP (T_8) recorded the highest plot yield, followed by T_4 (40% N + 100% P as basal→ 0.4% nano N and K at 45 DAP and 90 DAP) [13.34 kg 3 m^{-2}], while the lowest yield was observed under control. The projected yield followed the similar trend of plot yield, where T_8 recorded the highest value (34.95 t ha^{-1}), followed by T_4.These findings are in good conformity with the investigation of Chavan *et al.* (2024), Dubey *et al.* (2023) and Choudhary *et al.* (2023) who observed enhancement of yield on white onion, onion and garlic respectively with the integration of nano macro nutrients along with commercial fertilizers. The superior clump weight and yield under integrated nutrient treatments may be attributed to enhanced rhizome biomass accumulation due to balanced nutrient supply, improved root growth, and increased nutrient use efficiency. Nitrogen plays a critical role in chlorophyll synthesis and vegetative growth, phosphorus in root development and energy transfer, and potassium in carbohydrate transport and storage in rhizomes. The synergistic effect of these nutrients results in increased sink strength and higher rhizome yield (Marschner, 2012; Havlin *et al*., 2016).

The maximum dry recovery (23.73%) was noticed with the treatment combinations of 40% N + 100% P as basal→ 0.4% nano N and K at 45 DAP and 90 DAP (T_4), which was closely related with T_7 (40% N + 75% P as basal→ 30% N + 0.4% nano P and K at 45 DAP→ 30% N + 0.4% nano K at 90 DAP) [23.64%] and T_8 (40% N+75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP) [23.50%], while the minimum dry recovery (21.85%) was observed in untreated control (40% N + 100% P as basal→ 30% N + 50% K at 45 and 90 DAP). The higher dry recovery under integrated nutrient treatments may be attributed to enhanced rhizome maturity, increased dry matter accumulation, and improved carbohydrate synthesis. Adequate potassium nutrition is known to enhance translocation and storage of carbohydrates in rhizomes, leading to higher dry matter content.

Data presented in Table. 4 revealed that application of 40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP (T_8) recorded the highest oleoresin content (12.40%), followed by T_3 (40% N + 100% P as basal→ 30% N + 0.4% nano K at 45 DAP→ 30% N + 0.4% nano K at 90 DAP) [12.27%], whereas lowest oleoresin content (11.15%) was recorded in the plants treated with 40% N + 75% P as basal→ 30% N + 0.4% nano P + 50% K at 45 DAP→ 30% N 50% K at 90DAP (T_5). The enhancement of oleoresin content may be due to improved physiological activity and enhanced synthesis of secondary metabolites. Nitrogen and phosphorus play crucial roles in enzymatic activity and energy transfer pathways, which are directly associated with the biosynthesis of essential oils and oleoresins.

The maximum phenol content (66.18 mg GAE 100 g^{-1}) was observed under application of 40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP (T_8), followed by T_4 (40% N + 100% P as basal→ 0.4% nano N and K at 45 DAP and 90 DAP) [65.52 mg GAE 100 g^{-1}] whereas application of 40% N + 100% P as basal→ 30% N +

0.4% nano K at 45 DAP→ 30% N + 0.4% nano K at 90 DAP (T_3) recorded the lowest value (62.54 mg GAE 100 g^{-1}). The efficient delivery of nutrients in nano-form likely stimulated enzymatic pathways responsible for phenolic accumulation in rhizomes.

Curcumin content showed a significant variations among the treatment. Plants treated with 40% N +100% P as basal→ 0.4% nano N and K at 45 DAP and 90 DAP (T_4) recorded the highest curcumin content (6.03%) which is statistically *at par* with T_8 (40% N + 75% P as basal→ 0.4% nano N, P and K at 45 DAP→ 0.4% nano N and K at 90 DAP) [5.92%] and T_3 (40% N + 100% P as basal→ 30% N + 0.4% nano K at 45 DAP→ 30% N + 0.4% nano K at 90 DAP) [5.91%], whereas the lowest content (5.10%) was observed in under 40% N + 100% P as basal→ 30% N + 50% K at 45 DAP→ 30% N + 50% K at 90 DAP (T_1). Similar findings have been reported in turmeric where integrated nutrient management significantly improved curcumin and oleoresin content (Srinivasan *et al.*, 2016). Potassium is essential for the activation of enzymes and translocation of photosynthates from leaves to the rhizomes, where nitrogen influences protein and enzyme synthesis and phosphorus is involved in energy metabolism which collectively enhancing curcuminoid biosynthesis. Potassium, often in conjunction with nitrogen, acts as a catalyst in metabolic processes, which accelerates the synthesis of secondary metabolites like curcumin.

Conclusion

The present investigation demonstrated that integration of nano NPK fertilizers with conventional fertilizers significantly improved plant height, tiller production and overall vegetative growth, which ultimately contributed to higher rhizome yield and better quality such as oleoresin, curcumin and phenol content. The combined use of nano and commercial fertilizers also improved nutrient use efficiency and reduced dependence on chemical fertilizers. Among the treatments, foliar application of 0.4% nano-N, P and K at 45 DAP and 0.4% nano-N and K at 90 DAP in combination with 40% N + 75% P as basal (T_8) proved most effective. Thus, nano-fertilizer based integrated nutrient management can be considered a promising and sustainable approach for improving turmeric productivity and quality.

Table 1 : Influence of nano NPK integrated with commercial fertilizers on plant height and tiller number

Treatments	Plant height (cm)						Tiller number					
	120 DAP			180 DAP			120 DAP			180 DAP		
	2022-23	2023-24	2022-23	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	96.70	87.74	92.22	131.91	126.38	129.15	0.99	1.08	1.04	1.53	1.86	1.70
T_2	108.97	117.29	113.13	152.82	154.25	153.54	1.31	1.50	1.41	2.32	2.66	2.49
T_3	102.43	110.53	106.48	145.76	150.73	148.25	1.28	1.34	1.31	1.88	2.35	2.12
T_4	121.97	121.38	121.68	161.69	165.67	163.68	1.45	1.54	1.50	2.39	2.78	2.59
T_5	108.76	119.83	114.30	150.15	156.27	153.21	1.23	1.35	1.29	2.20	2.41	2.31
T_6	123.08	120.12	121.60	159.42	161.18	160.30	1.41	1.47	1.44	2.45	2.74	2.60
T_7	122.01	126.11	124.06	154.02	161.03	157.53	1.39	1.48	1.44	2.61	2.53	2.57
T_8	128.20	135.42	131.81	165.11	172.16	168.64	1.43	1.50	1.47	2.81	2.73	2.77
S.Em. (±)	**1.840**	**1.637**	**1.500**	**1.962**	**2.049**	**1.991**	**0.019**	**0.023**	**0.023**	**0.037**	**0.042**	**0.040**
C.D. (P=0.05)	**5.634**	**5.014**	**4.593**	**6.010**	**6.275**	**6.096**	**0.057**	**0.070**	**0.070**	**0.114**	**0.130**	**0.123**

T_1 = 40% N + 100% P (Basal)→ 30% N + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_2 = 40% N + 100% P (Basal)→0.4% Nano N + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90 DAP)
T_3 = 40% N + 100% P (Basal)→ 30% N + 0.4% Nano K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_4 = 40% N + 100% P (Basal)→ 0.4% Nano N and K (45 DAP)→ 0.4% Nano N and K (90DAP)
T_5 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_6 = 40% N + 75% P (Basal)→ 0.4% Nano N and P + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90DAP)
T_7 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P and K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_8 = 40% N + 75% P (Basal)→ 0.4% Nano N, P and K (45 DAP)→ 0.4% Nano N and K (90 DAP)

Table 2 : Influence of nano NPK integrated with commercial fertilizers on leaf number and dimension

Treatments	Number of leaves						Leaf length			Leaf breadth		
	120 DAP			180 DAP			180 DAP			180 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	8.23	9.87	9.05	14.72	15.81	15.27	61.22	70.14	65.68	14.57	15.38	14.97
T_2	10.89	11.96	11.43	16.61	17.05	16.83	72.66	73.46	73.06	16.13	16.68	16.41
T_3	8.96	9.39	9.18	16.18	16.79	16.49	71.28	72.27	71.78	16.59	16.79	16.69
T_4	11.85	12.13	11.99	17.63	19.30	18.47	73.86	76.17	75.01	16.48	16.81	16.65

T_5	9.63	10.06	9.85	15.81	17.54	16.68	70.48	72.86	71.67	16.37	16.56	16.46
T_6	11.03	10.96	11.00	17.85	18.89	18.37	74.07	85.62	79.85	16.69	17.17	16.93
T_7	11.25	11.94	11.60	16.37	18.93	17.65	71.91	76.32	74.12	16.91	16.71	16.81
T_8	11.41	12.08	11.75	18.79	19.74	19.27	77.86	75.38	76.62	16.57	17.24	16.90
S.Em. (±)	**0.174**	**0.188**	**0.189**	**0.284**	**0.300**	**0.287**	**1.203**	**1.245**	**1.243**	**0.274**	**0.274**	**0.280**
C.D. (P=0.05)	**0.532**	**0.575**	**0.578**	**0.868**	**0.919**	**0.879**	**3.684**	**3.813**	**3.806**	**0.838**	**0.838**	**0.858**

T_1 = 40% N + 100% P (Basal)→ 30% N + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_2 = 40% N + 100% P (Basal)→0.4% Nano N + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90 DAP)
T_3 = 40% N + 100% P (Basal)→ 30% N + 0.4% Nano K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_4 = 40% N + 100% P (Basal)→ 0.4% Nano N and K (45 DAP)→ 0.4% Nano N and K (90DAP)
T_5 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_6 = 40% N + 75% P (Basal)→ 0.4% Nano N and P + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90DAP)
T_7 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P and K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_8 = 40% N + 75% P (Basal)→ 0.4% Nano N, P and K (45 DAP)→ 0.4% Nano N and K (90 DAP)

Table 3 : Influence of nano NPK integrated with commercial fertilizers on clump weight and yield

Treatments	Clump weight (g)			Plot yield (kg 3m^{-2})			Projected yield (t ha^{-1})		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	237.13	276.44	256.79	9.13	10.32	9.73	22.83	25.80	24.31
T_2	302.16	318.29	310.23	11.40	12.07	11.74	28.50	30.18	29.34
T_3	290.92	306.58	298.75	11.18	11.52	11.35	27.95	28.79	28.37
T_4	360.46	398.16	379.31	12.58	14.09	13.34	31.45	35.23	33.34
T_5	301.83	341.63	321.73	11.43	13.15	12.29	28.58	32.87	30.72
T_6	332.05	382.63	357.34	12.11	14.03	13.07	30.28	35.09	32.68
T_7	336.74	365.95	351.35	12.31	13.48	12.90	30.78	33.71	32.24
T_8	384.56	404.32	394.44	13.45	14.51	13.98	33.63	36.28	34.95
S.Em. (±)	**4.282**	**5.446**	**4.660**	**0.184**	**0.214**	**0.201**	**0.487**	**0.536**	**0.510**
C.D. (P=0.05)	**13.114**	**16.679**	**14.273**	**0.564**	**0.655**	**0.616**	**1.491**	**1.641**	**1.561**

T_1 = 40% N + 100% P (Basal)→ 30% N + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_2 = 40% N + 100% P (Basal)→0.4% Nano N + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90 DAP)
T_3 = 40% N + 100% P (Basal)→ 30% N + 0.4% Nano K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_4 = 40% N + 100% P (Basal)→ 0.4% Nano N and K (45 DAP)→ 0.4% Nano N and K (90DAP)
T_5 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_6 = 40% N + 75% P (Basal)→ 0.4% Nano N and P + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90DAP)
T_7 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P and K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_8 = 40% N + 75% P (Basal)→ 0.4% Nano N, P and K (45 DAP)→ 0.4% Nano N and K (90 DAP)

Table 4 : Influence of nano NPK on quality parameters

Treatments	Dry recovery (%)			Oleoresin content (%)			Total phenol (mg GAE 100 g^{-1})			Curcumin content (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	21.43	22.26	21.85	10.54	11.87	11.21	61.72	63.71	62.72	5.04	5.16	5.10
T_2	21.01	23.61	22.31	12.49	11.62	12.06	62.56	65.38	63.97	4.98	5.47	5.23
T_3	22.36	23.76	23.06	11.58	12.95	12.27	60.48	64.59	62.54	5.59	6.23	5.91
T_4	24.19	23.27	23.73	11.75	11.58	11.67	66.89	64.15	65.52	6.12	5.94	6.03
T_5	21.73	23.35	22.54	10.28	12.01	11.15	64.37	62.74	63.56	5.11	5.68	5.40
T_6	22.05	24.59	23.32	10.71	12.80	11.76	63.21	64.91	64.06	5.28	5.45	5.37
T_7	24.21	23.06	23.64	11.24	12.89	12.07	63.09	63.57	63.33	5.76	6.04	5.90
T_8	22.68	24.32	23.50	12.21	12.58	12.40	66.83	65.52	66.18	5.68	6.16	5.92
S.Em. (±)	**0.365**	**0.404**	**0.388**	**0.202**	**0.207**	**0.195**	**1.051**	**1.083**	**1.116**	**0.092**	**0.095**	**0.090**
C.D. (P=0.05)	**1.119**	**1.236**	**1.189**	**0.618**	**0.634**	**0.598**	**3.218**	**NS**	**NS**	**0.281**	**0.291**	**0.274**

T_1 = 40% N + 100% P (Basal)→ 30% N + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_2 = 40% N + 100% P (Basal)→0.4% Nano N + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90 DAP)
T_3 = 40% N + 100% P (Basal)→ 30% N + 0.4% Nano K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_4 = 40% N + 100% P (Basal)→ 0.4% Nano N and K (45 DAP)→ 0.4% Nano N and K (90DAP)
T_5 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P + 50% K (45 DAP)→ 30% N + 50% K (90DAP)
T_6 = 40% N + 75% P (Basal)→ 0.4% Nano N and P + 50% K (45 DAP)→ 0.4% Nano N + 50% K (90DAP)
T_7 = 40% N + 75% P (Basal)→ 30% N + 0.4% Nano P and K (45 DAP)→ 30% N + 0.4% Nano K (90DAP)
T_8 = 40% N + 75% P (Basal)→ 0.4% Nano N, P and K (45 DAP)→ 0.4% Nano N and K (90 DAP)

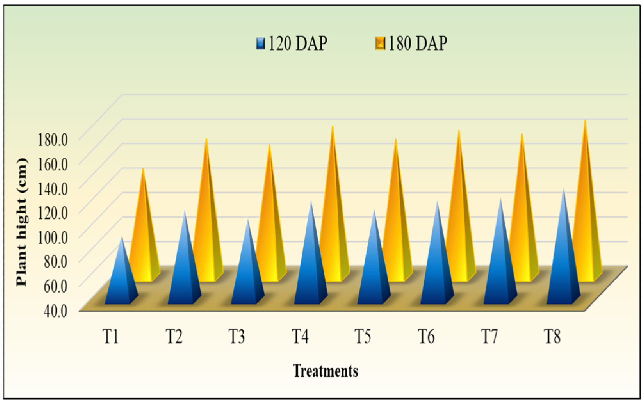

Fig. 1 : Influence of nano NPK on plant height

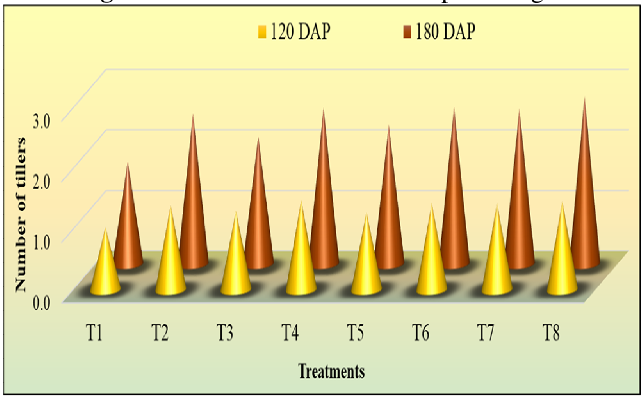

Fig. 2 : Influence of nano NPK on number of tillers per plant

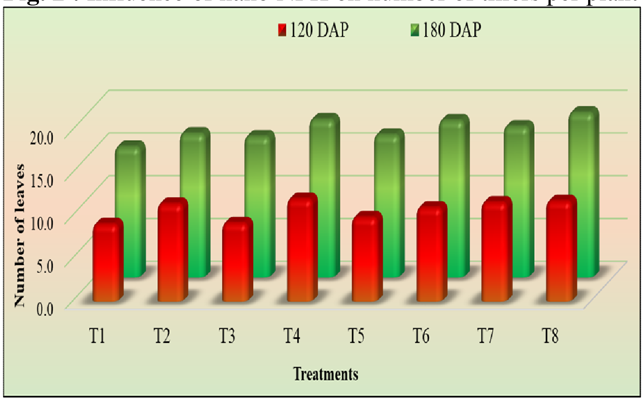

Fig. 3 : Influence of nano NPK on number of leaves per plant

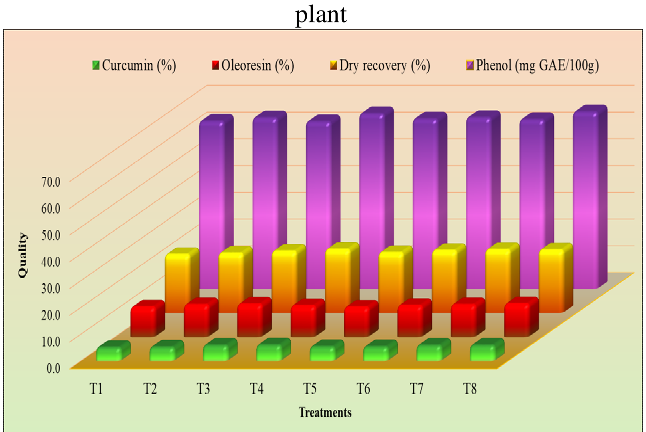

Fig. 4 : Influence of nano NPK on number of quality of turmeric

Acknowledgement

The authors express their sincere appreciation to the Department of Plantation, Spices, Medicinal and Aromatic Crops, Horticultural Research Station, Faculty of Horticulture, BCKV for all the necessary facilities that helps in smooth conduct of the research work.

Author's contribution

Field experiment, laboratory analysis, preparation of manuscript and manuscript edit (AS). Conceptualization of research work and methodology, manuscript reviewed (JKH).

Conflict of interest

Authors have declared that there is no conflict of interest.

References

Aggarwal, B. B., Kumar, A. and Bharti, A. C. (2003). Anticancer potential of curcumin-preclinical and clinical studies. *Anticancer Res.*, **23**(1/A), 363-398.

Anonymous. (1984). *Official Methods of Analysis*. Association of Official Analytical Chemists, 14th Ed. Washington, pp. 153.

Anonymous (1995). *IISR Annual Report, 1995-96*. Indian Institute of Spices Research. Calicut. pp. 45.

Chavan, Y. S., Bodake, P. S., Thorat, T. N., Kasture, M. C., Dalvi, S. G., Chavan, V. G., Rajemahadik, V. A., Bansode, P. B. and Kinge, P. B. S. (2024). Nutrient management in white onion (*Allium cepa*) and its effect on growth and yield. *Int. J. Res. Agron.*, **7**(8),278-282.

Chitdeshwari, T (2019). Esponse of turmeric (*Curcuma longa* L.) to micro nutrient fertilizer mixtures applied at various levels and methods on the growth, yield and quality of rhizomes. *J. Pharmacogn. Phytochem.*, **8**(2),2362-2365.

Choudhary, R., Choudhary, M. R., Sharma, Y. K., Choudhary, A. and Ujaniya, P. (2023). Effect of inorganic fertilizer, organic manures and nano urea on vegetative attributes and biochemical activity of garlic. *Biol. Forum*, **15**(2), 732 -736.

Diatta, A. A., Thomason, W. E., Abaye, O., Thompson, T. L., Battaglia, M. L., Vaughan, L. J., Lo, M. and Filho, J. F. D. C. L. (2020). Assessment of nitrogen fixation by mung bean genotypes in different soil textures using 15N natural abundance method. *J. Soil Sci. Plant Nut.*, **20**(4), 2230–2240.

Dubey, P. M., Upadhyay, J., Chowdhury, S. and Bagare, V. (2023). Response of onion (*Allium cepa* L.) to foliar application of nano urea and urea. *Int. J. Environ. Clim. Chang.*, **13**(11), 1816-1821.

Havlin, J. L., Tisdale, S. L., Nelson, W. L. and Beaton, J. D. (2016). *Soil Fertility and Fertilizers, An Introduction to Nutrient Management*. Pearson India Education, 8th Ed.

Ikpeama, A., Onwuka, G. I. and Nwankwo, C. (2014). Nutritional composition of turmeric (*Curcuma longa*) and its antimicrobial properties. *Int. j. sci. eng. res.*, **5**(10), 1085-1089.

Kandiannan, K., Anandaraj, M., Parthasarathy, U., Thankamani, C. K., and Zachariah, T. J. (2015). Study on yield and quality of flowered and non-flowered turmeric (*Curcuma longa* L.) plants. *J. Plant. Crops*, **43**(1), 71-73.

Kottegoda, N., Munaweera, I., Madusanka, N. and Karunaratne, V. (2011). A green slow release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood. *Curr. Sci.*, **101**(1),73–78.

Liu, R. and Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Sci. Total Environ.*, **514**, 131–139.

Malik, P., Ameta, R. K and Singh, M. (2014). Preparation and characterization of bio nano-emulsions for improving and modulating the antioxidant efficacy of natural phenolic antioxidant curcumin. *Chem. Biol. Interact.*. **222**, 77-86.

Marschner, P. (2012). *Marschner's Mineral Nutrition of Higher Plants*. Academic Press. 3rd Ed.

Ronya, T., Buragohain, N., Gautam, B. P., Langthasa, S., Choudhury, H. and Sarma, P. K. (2020). Effect of organics on growth, yield and quality attributes of turmeric (*Curcuma longa* L.) cv. tall clone. *J. Pharmacogn. Phytochem.*, **9**(2), 1151-1155.

Sil, A., Mondal, T., Swarnalatha, A., Hembram, S. and Hore, J. K. (2026). Biodiversity and characterization of Indian spices, a review. *Plant Arch.*, **26**(1), 151-163.

Singh, M. D., Chirag, G., Prakash, P. O., Mohan, M. H., Prakasha, G. and Viswajith. (2017). Nano-fertilizers is a new way to increase nutrients use efficiency in crop production. *Int. J. Agric. Sci.,* **9**(7), 3831-3833.

Sreelaja, K. (2018). Physiological studies on enhancing growth and yield of ginger (*Zingiber officinale* L.) by nano-NPK fertilizers and organic management. *Ph.D. Dissertation*. Submitted to College of Horticulture, Vellanikkara.