PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–06
https://doi.org/10.14719/pst.5837

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Insights of nano-NPK foliar application on growth and yield of maize (*Zea mays* L.)

Sanjeev Kumar KG[1], Parasuraman P[1], Kannan P[2*], Manivannan V[1] & Senthil A[3]

[1]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Center for Geospatial and Water Studies, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[3]Department of Plant Physiology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: kannan.p@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 15 October 2024
Accepted: 25 October 2024
Available online
Version 1.0 : 22 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Sanjeev KKG, Parasuraman P, Kannan P, Manivannan V, Senthil A. Insights of nano-NPK foliar application on growth and yield of maize (*Zea mays* L.). Plant Science Today.2024;11(sp4):01-06. https://doi.org/10.14719/pst.5837

Abstract

Maize (*Zea mays* L.), a nutrient-demanding crop, faces significant challenges when conventional fertilizers are applied excessively, leading to adverse effects such as soil degradation, nutrient leaching and environmental eutrophication. In response to the growing need for sustainable agricultural practices, innovative fertilization techniques and nano-fertilizers have emerged as viable solutions. The present study, conducted during the rabi season (2024) using a randomized block design with 8 treatments and 3 replications to investigate the impact of IFFCO Nano-NPK (8-8-8) foliar fertilizer on maize growth and yield. The study assessed the effectiveness of nano NPK through growth, yield and nutrient uptake measurements. Results indicated that applying a 100% recommended dose of NPK fertilizers (RDF) and two foliar sprays of 1% nano-NPK at critical growth stages (V6-V8 and V11-V12), significantly improved plant growth and yield attributes. Notably, this performance was statistically at par with 75% RDF with two foliar sprays of 1% nano-NPK. These findings suggest that nano-NPK foliar applications can reduce traditional fertilizer use by 25% while maintaining optimal growth, yield and nutrient uptake. Thus, nano-NPK application offers a sustainable pathway for maize production, enhancing nutrient efficiency and reducing fertilizer inputs.

Keywords

foliar application; growth and yield parameters; maize; nano-NPK fertilizers

Introduction

Maize, often called the queen of cereals, is highly valued for its adaptability to arid and semi-arid regions and its impressive yield potential over a short growing period. This adaptability makes maize crucial for current global food security, future food needs and global carbon budgeting (1). In 2020, global maize production reached 114.7 million tonnes, covering 193.7 million hectares with an average productivity of 5.75 tons per hectare. India ranks fourth in global maize cultivation area and seventh in production, cultivating 9.2 million hectares, which contributes 2% to global output and accounts for 4% of the world's maize-growing regions (2). The increase in food production has driven fertilizer use to unprecedented levels. In 2024, global fertilizer production reached 118.5 million tonnes of nitrogen, 48.27 million tonnes of phosphorus and 46.64 million tonnes of potassium (3). However, excessive reliance on chemical fertilizers negatively impacts both crop growth and ecosystems, leading to mineral volatilization, soil acidification and the loss of microbial activity and soil fertility (4).

In India, the efficiency of conventional fertilizers remains low, with nitrogen use efficiency ranging from 30 to 45%, phosphorus at 15 to 25% and potassium at 50 to 60% (5). Nanotechnology offers a promising solution to address the issues of excessive fertilizer use and environmental damage. Nano-materials, ranging in size from 1 to 100 nm, release nutrients gradually, enhancing plant uptake (6). With their high surface area, nano-fertilizers (NFs) penetrate crops easily, promoting better seed germination, metabolic activities, chlorophyll synthesis, stress tolerance and protein and carbohydrate production. By reducing nutrient loss through leaching and volatilization, NFs improve crop quality and soil fertility, offering a sustainable path to long-term productivity (7).

Trichomes, stomata and phloem pores are common structures on the leaf's surface, playing vital roles in the absorption of nanoparticles (NPs). NPs enter the plant via two primary pathways: the cuticle pathway and the stomatal pathway. Due to the high density of stomata, the stomatal route is considered the more efficient method for NP uptake. Once absorbed, NFsare transported throughout the plant via the phloem (8). Upon entering the plant, NPs can be absorbed through mechanisms such as endocytosis, water molecule pathways, carrier protein complex formations, or by binding with organic matter. Following endocytosis, NPs move to the plant roots via the phloem and are subsequently transported upwards through the xylem (9).

NFshave shown a significant positive impact on plant growth and yield. Once inside the plant, NPs are translocated through the phloem and contribute to the movement of essential photosynthetic pigments, such as sucrose, proteins and minerals, thereby enhancing plant growth (10). Research has demonstrated that applying 100% of the recommended dose of nitrogen (RDN) along with a nano-urea foliar application boosts plant height (229.3 cm), green seeker NDVI values (0.43, 0.58 and 0.73 at 30, 50 and 70 DAS) and grain yield (11). Furthermore, applying 75% RDN with a foliar spray of 0.1% nano-urea achieves yields statistically comparable to 100% RDN (12). In a related study on wheat, (13) found that applying 75% conventional phosphorus combined with two sprays of nano-phosphorus resulted in improved growth and yield. Despite the numerous studies on Nano-N, Nano-P and K, limited research has been conducted on combined Nano-NPK formulations. However, recent studies signify the benefits of using nano-NPK foliar applications alongside conventional fertilizers, showing improvements in growth, yield, nutrient uptake and fertilizer efficiency. This approach not only reduces the need for conventional fertilizers but also promotes sustainable crop production.

Materials and Methods

Study area

The experiment was carried out during the rabi season in the Eastern Block of Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The field trial followed a randomized block design, featuring eight treatments with three replications. The site is situated at a latitude of 11° 00' N, a longitude of 76° 56' E and an elevation of 426 m above mean sea level (MSL) in the western agro-climatic zone of Tamil Nadu. Also, the maximum and minimum temperature, relative humidity (RH %), wind speed (W. S kmph), sunshine hours (S. S hours), rainfall (mm) and evapotranspiration during the crop season, as shown in Fig. 1. The soil had a neutral pH of 7.05, electrical conductivity of 1.306 dS/m organic carbon content of 5.34 g/kg, available nitrogen of 234.5 kg/ha, available phosphorus 16.6 kg/ha and available potassium of 676 kg/ha. Notably, no rainfall was recorded during the crop's cultivation period. Maize CO 6 was taken as a test crop, which was sown on January 11, 2024, with seeds planted at a depth of 5 cm, maintaining a 25 cm gap between plants.

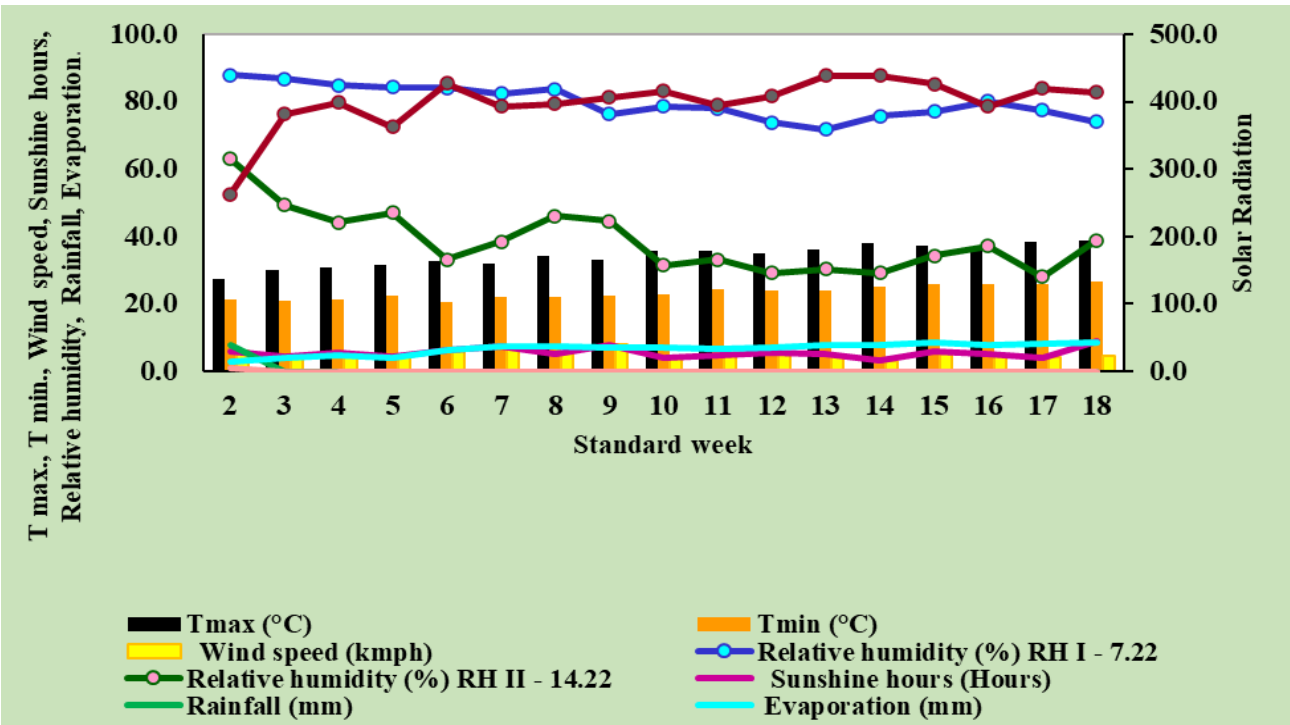

Fig. 1. Weather data.

Proper irrigation was carried out, along with thinning and gap filling. Pre-emergence herbicide atrazine was applied at a rate of 0.25 kg/ha on the second day, followed by one-hand weeding 30-35 days after sowing to control weeds. The foliar spray of IFFCO nano-NPK (8:8:8) was applied at 1% concentration during two key growth stages: V6-V8 (knee high) and V11-V12 (Before tasselling). To manage pests, emamectin benzoate 5 SG was applied at 0.4 g/lit of water to control *Spodoptera frugiperda*, while fertilizers were applied based on the treatment plans. The eight treatments consisted of T1- 100% RDF (250:75:75kg NPK/ha), T2-100% RDF + 2 sprays of 1% IFFCO nano-NPK, T3- 75% RDF (187.5: 56.25: 56.25 kg/ha), T4- 75% RDF + 2 sprays of 1% IFFCO nano-NPK, T5- 50% RDF (125: 37.5:37.5 kg/ha), T6-50% + 2 sprays of 1% IFFCO nano-NPK, T7- No NPK + 2 sprays of 1% IFFCO nano-NPK, T8- Absolute Control (no RDF).

Various growth and physiological parameters, such as plant height, leaf area index (LAI) and dry matter production (DMP) were recorded. Additionally, SPAD values, chlorophyll fluorescence and Normalized deference vegetative index (NDVI) were observed. Yield attributes, including grain and stover yield, were also studied.

Statistical analysis

The measurement data were represented as the mean and standard deviations of triplicate samples. All data processing was done using Excel 2021. For statistical analysis of experimental data across different treatments, the IRRI STAR software was employed, following the randomized block design method described by (14). Significant critical differences (C.D.) were calculated for the field experiment at a 5% probability level (p=0.05) to determine statistically significant variations among treatments.

Results

Impact of nano-NPK on physiological parameters of maize

Chlorophyll synthesis plays a critical role in Adenosine triphosphate (ATP) synthesis and electron transfer during photosynthesis. The application of nano-NPK foliar fertilizers has been shown to enhance chlorophyll synthesis and nutrient uptake in crops. In the early stages of plant growth, there were no significant differences among treatments. However, after applying nano-NPK fertilizers, significant differences (p=0.05) were observed between treatments (Table 1), particularly with the foliar application of nano-NPK combined with conventional fertilizers (T2, T4 and T6) compared to traditional fertilizer treatments (T1, T3 and T5). The highest SPAD value, 53.44, was recorded in the treatment receiving 100% RDF with two sprays of nano-NPK @ 1% (T2) during the V6-V8 and V11-V12 growth stages. This was statistically on par with the treatment receiving 75% RDF with two sprays of nano-NPK @ 1% (T4). The lowest SPAD value of 40.84 was recorded in the control (T8).

The nano-NPK treatments significantly improved photosynthetically active areas and assimilation rates, leading to increased chlorophyll content and enhanced vegetative growth. The highest quantum yield values, 0.86 and 0.82, were recorded at 45 and 60 DAS in treatment T2, followed closely by 0.84 and 0.80 in treatment T4. The lowest values, 0.70 and 0.68, were found in the control treatment (T8) (Fig. 2).

NDVI is an important parameter in understanding crop health. NDVI values vary from + to -1. NDVI value >0 to +1 indicates a healthy crop. NDVI value <0 to -1 indicates that the crop is under stress. NDVI values varied significantly across different crop stages, with the highest NDVI values recorded in treatment T2 (0.42, 0.53, 0.66 at 30, 45 and 60 DAS), followed by T4 (0.39, 0.52, 0.63 at the same stages). In contrast, the lowest values were recorded in the control treatment T8 (0.31, 0.34 and 0.49 at 30, 45 and 60 DAS) (Fig. 3).

Impact of nano-NPK on growth and yield of maize

***Growth parameters*:** Nutrients play a crucial role in plant growth, and the application of NFs significantly enhances nutrient absorption and plant development. In the experiment, applying 100% of the recommended dose of fertilizers (RDF) along with two foliar sprays of nano-NPK at 1% during the V6-V8 and V11-V12 growth stages resulted in the tallest plant growth across all stages (Table 1). This treatment (T2) was statistically at par (p=0.05) with 75% RDF with two sprays of nano-NPK at 1% (T4), while the lowest plant height was recorded in the control treatment (T8). Specifically, the tallest plant height was observed in T2 (217 cm), closely followed by T4 (213 cm) and T1 (205 cm), whereas the control recorded the shortest height of 174 cm.

Moreover, the leaf area index (LAI) also showed significant improvement in nano-NPK-treated plots compared to those treated with conventional fertilizers alone. The LAI (Table 1) increased gradually following the application of nano -NPK foliar sprays, as nano-NPK enhances the metabolic activities of the stomata and overall plant function. The highest LAI was recorded in T2, with 3.95 at 65 DAS and 3.02 at harvest, which was statistically comparable to T4, which

Table 1. Impact of nano-NPK on growth and physiology of maize

Treatments	Plant Height (cm)	LAI	DMP (kg/ha)	SPAD
T1- 100% RDF	205.80	2.67	13845	50.21
T2 - 100% RDF + 2 sprays of 1% nano-NPK	217.58	3.02	14557	53.44
T3 - 75% RDF	192.24	1.87	12755	48.02
T4 - 75% RDF + 2 sprays of 1% nano-NPK	213.60	2.78	14328	51.86
T5 - 50% RDF	188.55	1.70	11180	45.55
T6 - 50% RDF + 2 sprays of 1% nano-NPK	198.95	2.06	12910	48.67
T7 - No NPK + 2 sprays of 1% nano-NPK	183.00	1.51	9650	43.15
T8 - Absolute Control (no RDF)	174.41	1.49	9510	40.84
SEd	9.76	0.12	649	2.54
CD (p=0.05)	20.95	0.27	1392	5.46

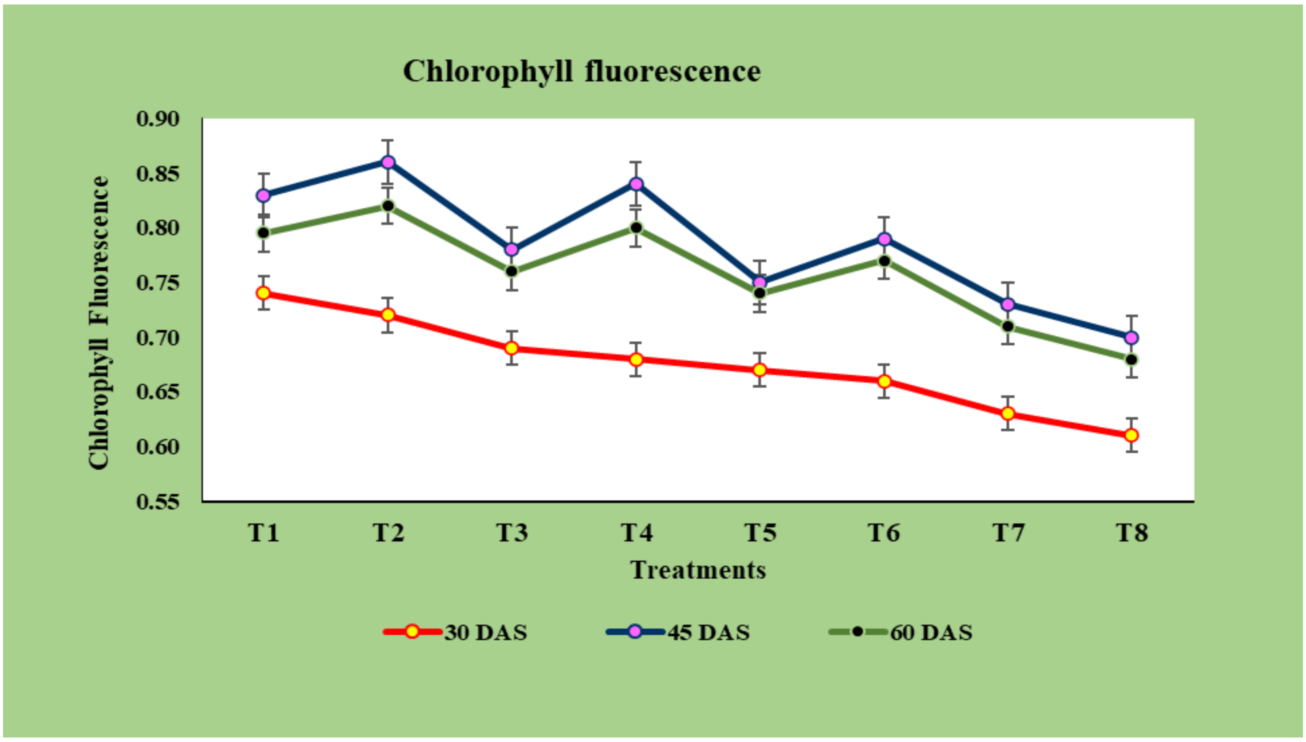

Fig. 2. Impact of nano-NPK foliar application on chlorophyll fluorescence.

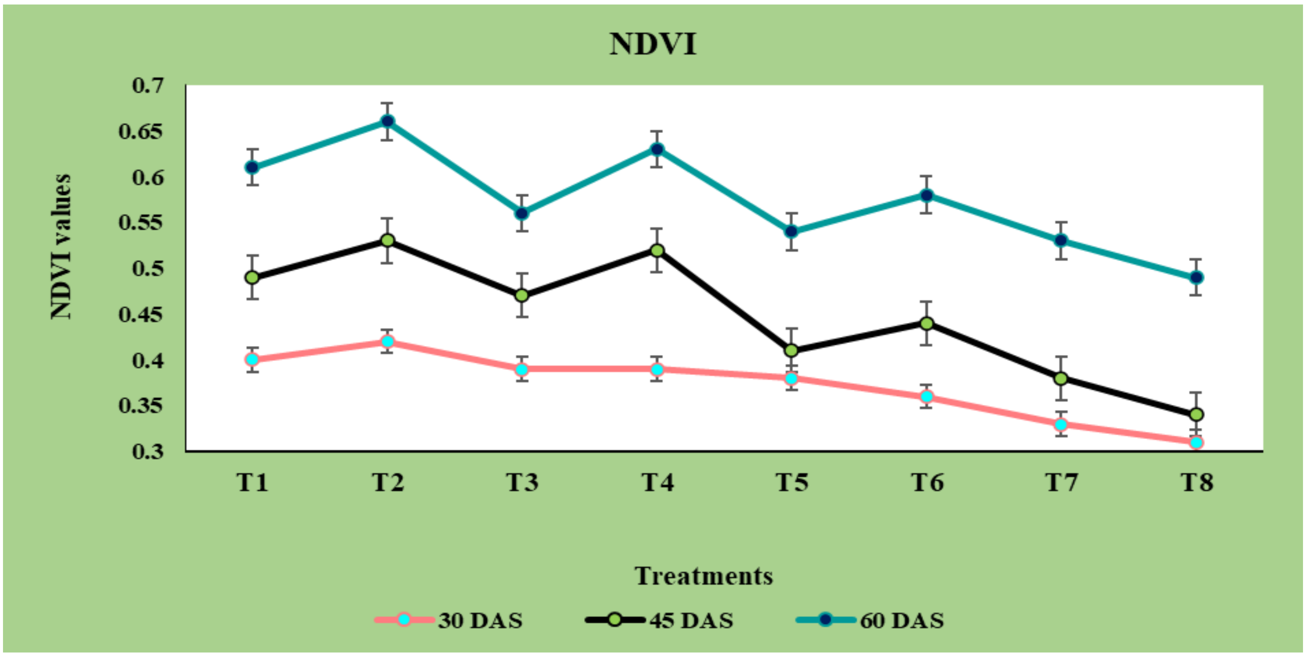

Fig. 3. Impact of nano-NPK foliar application on NDVI.

recorded 3.76 at 65 DAS and 2.78 at harvest. In contrast, the control (T8) had the lowest LAI values (2.24 at 65 DAS and 1.49 at harvest). The increased number of leaves, plant height and LAI subsequently led to higher dry matter production. Significant differences ($p=0.05$) in dry matter accumulation were observed at various crop stages (Table 1), with the highest dry matter recorded in T2 (14557 kg/ha), closely followed by T4 (14328 kg/ha). The control (T8) had the lowest dry matter production (9510 kg/ha).

***Impact of nano-NPK on yield of maize*:** The combination of nano-NPK foliar applications with conventional fertilizers significantly increased several yield attributes ($p=0.05$), as shown in Table 2. These include the number of grains per column, number of columns per cob, cob length, 100-seed test weight, cob weight and total number of grains per cob. Specifically, treatment T2 (100% RDF with 2 foliar sprays of nano-NPK @1%) showed the highest number of rows per cob (33.8), columns per cob (17.6), cob length (20.4 cm), 100-seed test weight (30.8 g), cob weight (137 g) and grains per cob (398). This was statistically at par with T4 (75% RDF with 2 nano-NPK sprays). In contrast, the control treatment (T8) recorded the lowest values: 27.5 rows per cob, 13.6 columns per cob, cob length of 15.1 cm, 100-seed weight of 28.2 g, cob weight of 107 g and 311 grains per cob.

Grain and stover yields were also significantly affected by the different treatments (Table 2). The highest grain yield of 6102 kg/ha and stover yield of 8930 kg/ha were achieved in T2, closely followed by T4 with grain and stover yields of 6064 kg/ha and 8751 kg/ha, respectively. The control treatment (T8) recorded the lowest yields.

Table 2. Impact of nano-NPK on yield attributes and yield of maize

Treatments	No. of kernels row^{-1}	No. of columns cob^{-1}	Cob Length (cm)	100 seed test weight (g)	Cob weight (g)	No. of grains cob^{-1}	Grain yield (kg/ha)	Stover yield (kg/ha)
T_1- 100% RDF	32.8	16.5	19.3	29.4	133.0	382.0	5988	8615
T_2- 100% RDF + 2 sprays of 1% nano-NPK	33.8	17.6	20.4	30.8	137.0	398.0	6102	8930
T_3- 75% RDF	32.5	15.4	18.2	29.6	125.0	354.0	5369	7510
T_4- 75% RDF + 2 sprays of 1% nano-NPK	33.6	16.8	19.7	30.0	136.0	394.0	6064	8751
T_5- 50% RDF	29.6	14.8	17.2	29.0	117.0	342.0	4700	6600
T_6- 50% RDF + 2 sprays of 1% nano-NPK	30.7	15.9	18.5	29.8	128.0	363.0	5406	7753
T_7- No NPK + 2 sprays of 1% nano-NPK	28.9	14.5	16.0	28.4	112.0	326.0	4103	5750
T_8- Absolute Control (no RDF)	27.5	13.6	15.1	28.2	107.0	311.0	4050	5630
SEd	1.9	0.9	1.0	1.6	6.9	20.1	265	377
CD (p=0.05)	4.1	2.0	2.1	NS	14.9	43.2	568	808

Discussion

Impact of nano-NPK on the physiological growth of maize

The effect of spraying of foliar fertilizer nano-NPK enhances the chlorophyll content of maize and actively helps in improving the production of ATP synthesis (15). The effective use of nano-NPK foliar fertilizers by the plants promotes the photosynthetically active parts and assimilation rates, leading to the production of more chlorophyll content and vegetative parts. This enables high nutrient absorption by the crop and improves the translocation of nutrients to plant growth physiologically (16). Chlorophyll fluorescence is an absorption of photons from chlorophyll molecules to an excited state which the fluorescence photon is emitted repeatedly during the return of molecules to the ground state. Fv / fm is the maximum quantum yield of dark-adopted Photo System II (17). Applying foliar NFsdirectly to the crop increases the photosystem-II activity in the thylakoid membrane and increases the effective quantum yield of photosystem-II (18).

The plant stress activity was monitored using the Green Seeker Analyzer, an optical sensor that assesses crop health and nitrogen status through the Normalized Difference Vegetation Index (NDVI). The sensor absorbs chlorophyll from leaves in the palisade layer, capturing 70-90% of light incidence in the red wavelength band. Mesophyll cells reflect the Near-Infrared (NIR) electromagnetic spectrum (720-1300 nm), which scatters and reflects up to 60% of incident NIR radiation (19). The application of 100% RDN with NDVI-based nano-N spray enhanced chlorophyll content and improved the photosynthetic ability of maize leaves at 30, 50 and 70 DAS (11). NFsenhance the uptake of nutrients. So the accumulation of dry matter in a limited time and space is more. This results in an increased absolute growth and crop growth rate. The results obtained in our experiment were consistent (20).

Impact of nano-NPK on growth and yield of maize

The superior growth of nano-NPK-treated plots is attributed to the NPs ability to bind and penetrate the leaf surface, ensuring direct and timely nutrient release through the stomata, as reported by (21). The nano-particles enter into the plant system via stomata, build up the cell division and cell elongation process and shore up the sink ability of leaves leading to a synergetic increase in leaf photosynthetic area by improving the carbohydrate and protein metabolism for better photosynthesis (22, 23). Dry matter accumulation is a critical indicator of the plant's photosynthetic efficiency, directly influencing grain and stover yield (20).

The application of foliar fertilizers, particularly nano-NPK, enhances nutrient uptake by storing nutrients in the vacuoles of the cell. Then stimulating nitrate reductase activity, which plays a crucial role in reducing ammonia assembled during photosynthesis, improving ATP synthesis, and balancing reactive oxygen species and antioxidants. The electron transport chain is responsible for chloroplast and adenosine tri-phosphate production, an increase in the orthophosphate level for better activation of photosystem II (24). The combined use of conventional and foliar fertilizers has been shown to significantly improve maize yield (25). These foliar applications of nano-NPK during critical growth stages boost yield by providing a synchronized supply of nitrogen, phosphorus, and potassium to the plants (26). Some research also concluded that nano fertilizers improve yield because of their positive impact on physiological effects in plants (27).

Conclusion

Based on the research findings obtained, we interpret that applying nano-NPK foliar fertilizers at key growth stages (V6-V8 and V11-V12) significantly enhances maize growth, physiology and yield. Our study demonstrated that combining a 100% recommended dose of fertilizers (RDF) with two foliar sprays of 1% nano-NPK led to a 1.2% yield increase compared to 100% NPK alone, with performance closely resembling that of 75% RDF combined with Nano-NPK. However, combining 50% RDF with nano-NPK resulted in a 10.33% yield reduction compared to 100% RDF. These findings suggest that nano-NPK foliar application, particularly with 100% and 75% RDF optimizes yield and soil health, offering an effective strategy for sustainable maize production.

Acknowledgements

The authors acknowledge the IFFCO [No: F37APS] for the funding. The authors thank the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India for providing resource facilities for conducting the research.

Authors' contributions

The conceptualization and methodology for the study were led by SKKG, who also prepared the original draft of the manuscript. KP and PP provided supervision and contributed to the writing through thorough review and editing. MV and SA further enhanced the manuscript by editing and improving its content.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare

Ethical issues: None

References

1. Cui H. Challenges and approaches to crop improvement through C3-to-C4 engineering. Front Plant Sci. 2021;12:715391. https://doi.org/10.3389/fpls.2021.715391
2. Shekhar M, Singh N. The impact of climate change on changing pattern of maize diseases in Indian subcontinent: a review. Maize Genetic Resources-Breeding Strategies and Recent Advances. 2021 Nov 25. https://doi.org/10.5772/intechopen.101053
3. Open Knowledge Repository. Available from: https://openknowledge.fao.org/ [Accessed 20 August 2024].
4. Kourgialas NN, Karatzas GP, Koubouris GC. A GIS policy approach for assessing the effect of fertilizers on the quality of drinking and irrigation water and wellhead protection zones (Crete, Greece). J Environ Manag. 2017;189:150-9. https://doi.org/10.1016/j.jenvman.2016.12.038
5. Gupta R, Benbi DK, Abrol IP. Indian agriculture needs a strategic shift for improving fertilizer response and overcoming sluggish foodgrain production. J Agron Res. 2021;4(3):1-6. https://doi.org/10.14302/issn.2639-3166.jar-21-4018
6. Raliya R, Saharan V, Dimkpa C, Biswas P. Nanofertilizer for precision and sustainable agriculture: current state and future perspectives. J Agric Food Chem. 2017;66(26):6487-503. https://doi.org/10.1021/acs.jafc.7b02178
7. Rautela I, Dheer PA, Thapliyal PR, et al. Current scenario and future perspectives of nanotechnology in sustainable agriculture and food production. Plant Cell Biotechnol Mol Biol. 2021;22:99-121.
8. Su Y, Ashworth V, Kim C, et al. Delivery, uptake, fate, and transport of engineered nanoparticles in plants: a critical review and data analysis. Environ Sci Nano. 2019;6(8):2311-31. https://doi.org/10.1039/C9EN00461K
9. Zahedi SM, Karimi M, Teixeira da Silva JA. The use of nanotechnology to increase quality and yield of fruit crops. J Sci Food Agric. 2020;100(1):25-31. https://doi.org/10.1002/jsfa.10004
10. Abdel-Aziz HM, Hasaneen MN, Omer AM. Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil. Span J Agric Res. 2016;14(1):e0902. https://doi.org/10.5424/sjar/2016141-8205
11. Parameshnaik C, Murthy KK, Hanumanthappa D, et al. Influence of nano fertilizers on growth and yield of maize. Mysore J Agric Sci. 2024;58(1).
12. Kundu AK, Chhabra V. Effect of application of nano-urea on maize (C-1415 variety) growth and yield under Punjab conditions. Eco. Env. & Cons. 2023;29(4):1604-07. http://doi.org/10.53550/EEC.2023.v29i04.023
13. Poudel A, Singh SK, Jiménez-Ballesta R, et al. Effect of nano-phosphorus formulation on growth, yield and nutritional quality of wheat under semi-arid climate. Agronomy. 2023;13(768):1-14. https://doi.org/10.3390/agronomy13030768
14. Gomez KA. Statistical Procedures for Agricultural Research. New York: Wiley & Sons; 1984.
15. Muhammad OA, Al-Falahi MH. Effect of spraying nano fertilizer NPK and nano fertilizer microelements on the growth characteristics of maize plants (*Zea mays* L.). IOP Conf Ser Earth Environ Sci. 2023;1252(1):1-10. https://doi.org/10.1088/1755-1315/1252/1/012063
16. Benzon HR, Rubenecia MR, Ultra Jr VU, Lee SC. Nano-fertilizer affects the growth, development and chemical properties of rice. Int J Agron Agric Res. 2015;7(1):105–17. https://doi.org/10.5539/jas.v7n4p20
17. Sánchez-Moreiras AM, Graña E, Reigosa MJ, Araniti F. Imaging of chlorophyll a fluorescence in natural compound-induced stress detection. Front Plant Sci. 2020;11(583590):1-15. https://doi.org/10.3389/fpls.2020.583590
18. Semida WM, Abdelkhalik A, Mohamed GF, et al. Foliar application of zinc oxide nanoparticles promotes drought stress tolerance in eggplant (*Solanum melongena* L.). Plants. 2021;10(421)1-17. https://doi.org/10.3390/plants10020421
19. Gurunath R. Investigation on sensor-based irrigation and nitrogen management in maize (*Zea mays* L.) [Doctoral dissertation]. Bangalore: University of Agricultural Sciences.
20. Lohar D, Singh M, Borah A, Srivastava RP. To study the effect of foliar spray of nano fertilizer on growth characters of rabi maize (*Zea mays* L.) in Mandsaur region (MP), India. Int J Plant Soil Sci. 2024. https://doi.org/10.9734/ijpss/2024/v36i44478
21. Abdel-Aziz H, Hasaneen MN, Omar A. Effect of foliar application of nano chitosan NPK fertilizer on the chemical composition of wheat grains. Egypt J Bot. 2018;58(1):87-95. https://doi.org/10.21608/ejbo.2018.1907.1137
22. Dhlamini B, Paumo HK, Katata-Seru L, Kutu FR. Sulphate-supplemented NPK nanofertilizer and its effect on maize growth. Mater Res Express. 2020;7(9):095011. https://doi.org/10.1088/2053-1591/abb69d
23. Azam M, Bhatti HN, Khan A, et al. Zinc oxide nano-fertilizer application (foliar and soil) effect on the growth, photosynthetic pigments, and antioxidant system of maize cultivar. Biocatal Agric Biotechnol. 2022;42:102343. https://doi.org/10.1016/j.bcab.2022.102343
24. Malhotra H, Vandana, Sharma S, Pandey R. Phosphorus nutrition: plant growth in response to deficiency and excess. In: Plant Nutrients and Abiotic Stress Tolerance. 2018:171-90. https://doi.org/10.1007/978-981-10-9044-8_7
25. Amanullah, Iqbal A, Irfanullah, Hidayat Z. Potassium management for improving growth and grain yield of maize (*Zea mays* L.) under moisture stress condition. Sci Rep. 2016;6(34627)1-12. https://doi.org/10.1038/srep34627
26. Kumar Y, Tiwari KN, Nayak RK, et al. Nanofertilizers for increasing nutrient use efficiency, yield and economic returns in important winter season crops of Uttar Pradesh. Indian J Fert. 2020;16(8):772-86.
27. Rashmi CM, Prakash SS. Effect of nano phosphorus fertilizers on growth and yield of maize (*Zea mays* L.) in central dry zone of Karnataka. Mysore J. Agric. Sci. 2023;57(2):286-93.