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Research Article

Response to nitrogen management through different sources and modes on the productivity of quinoa (*Chenopodium quinoa* Willd) in the North Cauvery deltaic zones of Tamil Nadu

Priyaharini Krishnan
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar - 608002 (Tamil Nadu), India
Ravikumar Chinnathambi *
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar - 608 002 Tamil Nadu, India; Institute of Agriculture, Tamil Nadu Agricultural University, Kumulur - 621712 (Tamil Nadu), India
Thirupatthi Modakkutti
Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar - 608002 (Tamil Nadu), India
Senthilvalavan Pitchamuthu
Department of Soil Science and Agricultural Chemistry, Annamalai University, Annamalai Nagar - 608002 (Tamil Nadu), India; Radioisotope (Tracer) Laboratory, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore - 641003 (Tamil Nadu), India

*Corresponding author: E-mail: ravikumarchinnathambi@gmail.com

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Abstract
Intensive agriculture with mono-cropping leads to many losses in terms of soil fertility concerns. Similarly, the inclusion of quality protein and dietary fibre in food consumption is quite alarming due to the majority of health issues faced by human beings. However, several crops are on the list, and only a few crops, pseudo-cereal like quinoa, can survive in climate-resilient conditions with higher protein content in their grain. Though quinoa (*Chenopodium quinoa* Willd.) is a new emerging crop in India, the present study aimed to ascertain its productivity response for different sources and modes of nitrogen. The field experiments were conducted in farmers' fields in Sivapuri village, Cuddalore district of Tamil Nadu, from February to May 2022-23. The experiment was laid out in Randomized Block Design (RBD) with eight treatments and replicated thrice. The growth parameters and yield components of quinoa increased due to nano fertilizers sprayed under the vegetative and flowering stages. The results exposed that positive influence noticed on the growth and yield attributes such as Plant height (139.7), Leaf Area Index (LAI) (2.44), Dry Matter Production (1018.8 kg ha^{-1}), Number of branches $plant^{-1}$ (38.08) yield attributes such as panicle length (35.9) number of panicle $plant^{-1}$ (8.69) number of grains $panicle^{-1}$ (3182.5), grain yield 2655 kg ha^{-1} and stalk yield of 3331.8 g ha^{-1} in RDF (NF) + 0.5% N through Nano Urea (Foliar) imposed treatment (T_8) over other combination of fertilizers sources and modes of treatments which added another platform to the beginners of quinoa growing farmers in north Cauvery deltaic zones of Tamil Nadu.

Keywords: Foliar, Nano fertilizers, Nitrogen, Pseudo cereal, Quinoa, Yield

INTRODUCTION

Cycloidal practice of crop production/selection in the inevitable changing climate scenario might not be successful often. Agricultural production is under threat due to climate change in food-insecure regions, especially in Asian countries. Various climate-driven extremes, i.e., drought, heat waves, erratic and intense rainfall patterns, storms, floods, and emerging insect pests, have adversely affected the livelihood of the farmers. Future climatic predictions showed a significant increase in temperature and erratic rainfall with higher intensity, while variability exists in climatic patterns for climate extremes prediction (Habib-ur-Rahman *et al*., 2022). Climate change is a noteworthy phenomenon that plays a significant role in the agricultural sector, where people depend on the quantity of food grains rather than the quality in developing and underdeveloped countries. Meanwhile, the diversification of adverse climate change affects the agriculture sector due to the diversity of farming and cropping systems that depend on climate. According to the sixth assessment report of the IPCC, higher flood and drought risks make Asian agricultural productivity highly susceptible to changing climate (IPCC, 2019).

Intensive agriculture might be the only way to fulfil the global food requirement. At the same time, intensive agriculture with mono-cropping leads to many losses in terms of soil fertility concerns. Similarly, the inclusion of quality protein and dietary fibre in food consumption is quite alarming due to the majority of health issues faced by human beings. Though several food crops are on the list to supply the required energy to humankind, only a few crops have succeeded in the climate-resilient situation. Rice and wheat crops are considered the staple food for most of the population in the world (Banjara *et al*., 2021). The rice-wheat cropping system, a significant cropping system which fills half of the food demand in Asia, is under threat due to climate change (Ghaffar *et al*., 2022). Climate change adversely affects the quantity and quality of wheat and rice crops (Din *et al*., 2022; Wasaya *et al*., 2022). Due to the vagaries of climate, erratic rainfall, and considerably lower protein content, the alternative protein-rich crop might gain momentum, leading to healthy generations. To conquer this, we must pay more attention to the potential for exploiting and utilizing unfamiliar crops such as pseudo cereals.

Quinoa (*Chenopodium quinoa* Willd.) is an annual herbaceous plant that belongs to the Amaranthaceae family and is considered a pseudo-cereal. Its popularity has dramatically increased in recent years because it is gluten-free (helpful for diabetic patients) and high in proteinprotein (Lan *et al*., 2023). It has been recognized as a pivotal crop to improve world food security because of its potential to grow on salt-affected soils unsuitable for other major food crops (Ruiz *et al*., 2015). Quinoa grain is the only vegetable food that provides all amino acids essential to the life of humans in optimum quantities and is comparable with milk. The protein content of quinoa ranges from 7.47 to 22.08 per cent, with higher concentrations of lycine, isoleucine, methionine, histidine, cysteine and glycine (Mu *et al*., 2023). Quinoa has more remarkable plasticity in terms of adaptation to photoperiod, altitude, soil pH, etc. Considering the high genetic diversity of quinoa, it can be grown under varying climatic conditions (Gutiérrez and Portugal, 2022). Considering the high genetic diversity of quinoa, it can be grown under varying climatic conditions. The diversified genetic pool of quinoa allowed its cultivation possible from 2° North latitude to 40° South latitude, higher elevations up to 4000 m above mean sea level, case of soils alkaline soils up to pH 9 as well as in acidic soils up to pH 4.5 (Jacobsen, 2003). The base temperature of quinoa is 3°C with an optimum temperature of 15-30° C and can tolerate a maximum temperature of 50°C.

Soil nutrient management is one of the most essential agronomic management techniques for controlling plant growth and ascertaining the yield potential of any crop production. However, it is proven that a plant's ability to carry out its physiological activities efficiently during its various stages of growth and achieve its maximum yield potential is determined by the balance between nutrient supply and absorption (Mengel and Kirkby, 2012). Over-exploitation of nutrients from the soil and poor nutrient loss replenishment, depleted nutrients from the soil are often unable to be replenished by artificial crop fertilization, resulting in an imbalance in the soil nutrients pool (Paramesh *et al*., 2020). Using chemical fertilizers causes major environmental problems, such as heavy metal accumulation in soil and plant systems (Abdel *et al.,* 2017). Therefore, modern ideas of Nano fertilizer are the most advanced technology in supplying mineral nutrients to crops. Compared to chemical fertilizers, their supplemental pattern of nutrients for plant needs minimises leaching and improves fertilizer use efficiency (Subbarao *et al.,*2013). The improvement of crops in agriculture is a continuous process. Nano fertilizers contain nutrients and growth promoters encased in nano-scale polymers; they supply the nutrients to the crop as needed in a phased manner. It is designed to supply nutrients in a regulated pattern in response to crop needs, increasing nutrient use efficiency (Manikandan and Subramanian, 2016). Nanotechnology can provide N fertilizers that release N when crops need it. It eventually increases N efficiency through decreased N leaching and emissions and long -term incorporation by soil microorganisms (Davarpanah *et al.,* 2016). Recent advancements in sustainable agriculture have seen the beneficial usage of various Nano fertilizers for increased crop production. However, the intentional use of this technology in agricultural activities could have several unforeseen and irreversible consequences. The application of Nano fertilizers through soil and irrigation ensures double advantages, i.e., soil improvement and to optimize plant development productivity (Mahapatra *et al*., 2022) because the application of more significant amounts of inorganic fertilizers to farming land may not be available to plants (Tarafder *et al*., 2020). Therefore, Nano fertilizers could be a better approach for nutrient absorption by the roots. Various edaphic parameters regulate the range of mineral elements in the soil. They may also change microbial colonies and rhizospheric

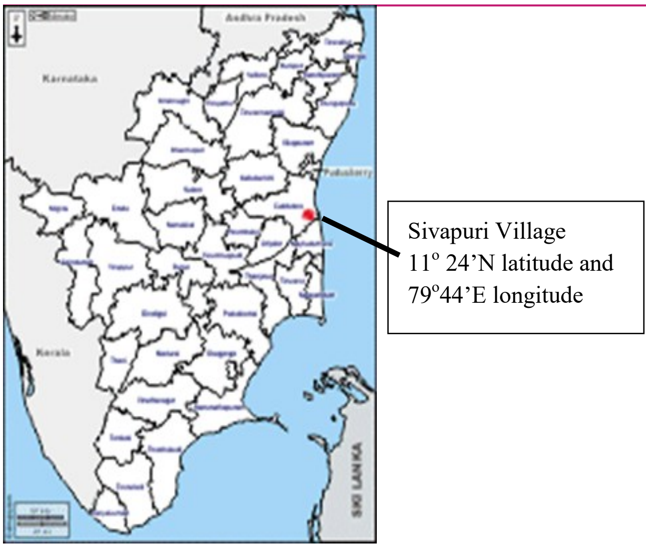

Fig 1. *Map showing the site of Sivapuri village*

microbial biomass to enhance soil fertility (Wang *et al*., 2021), water availability, and plant growth (Verma *et al*., 2022). Nano fertilizers harmonized the release of nutrients N, P and K with their uptake by crops, so preventing undesirable nutrient losses to soil, water and air via direct entry by crops and avoiding the interaction of nutrients with soil, microorganisms, water and air (Adisa *et al.,* 2019). In this preview, very little nano fertilizer work has been initiated in the quinoa crop, and there are unearthed areas that might be considered for future development to sustain food security with minimum health promise. Therefore, the present study aimed to evaluate the effect of different sources and forms of conventional and nano-nitrogenous fertilizers on the productivity of quinoa

MATERIALS AND METHODS

Study site

Nutrient response trials were conducted on farmer's fields in Sivapuri village, Cuddalore District, Tamil Nadu, for two consecutive years (2022–2023) to study the response to nitrogen management through different sources and modes on the productivity of quinoa (*Chenopodium quinoa* Willd) under the North Cauvery deltaic zones of Tamil Nadu.". The experimental site (Sivapuri village) is geographically located at 11° 24'N latitude and 79°44'E longitude and at an altitude of ± 5.79 m above the mean sea level (MSL).

During the cropping period (February to June 2022 and 2023), the weekly mean maximum temperature recorded ranged from 30.5°C to 36.4°C, and the weekly minimum temperature recorded ranged from 16.8°C to 22.6°C. The relative humidity ranged from 69.85% to 77.28%. A composite soil sample was collected at 0-30 cm depth. It was air-dried, crushed, and tested for physical and chemical properties (Table 1).

Table 1. Physicochemical and biological properties of the experimental site

Parameters	Analytic results
Soil Characteristics	
A. Physical properties (Mechanical Analysis)	
Clay (%)	34.06
Silt (5%)	17.96
Coarse sand (%)	19.98
Fine sand (%)	27.99
Textural class	Clay Loam
B. Chemical analysis	
Available nitrogen (kg ha^{-1})	230
Available phosphorus (kg ha^{-1})	21.5
Available potassium (kg ha^{-1})	279
Organic Carbon (%)	0.58
Soil reaction pH (1:2 soil water suspension)	7.8
EC (1:2 soil water suspension) (dS m^{-1})	0.64

Methodology

Analysis of soil samples

The initial soil samples were analysed for both mechanical and chemical compositions (Table 1) following standard methods (Alam *et al*., 2024) viz., soil pH was measured in the suspension of (1:2.5 soil: water) using a pH meter, and conductivity was measured in the same suspension using a conductivity meter. The organic carbon content was determined by the modified Chromic acid wet digestion titration method (Walkley and Black,1934). The alkaline permanganate method determined the available nitrogen (K) (Subbiah and Asija, 1956). Available phosphorus (P) was quantified by the spectrophotometer method (Olsen *et al*.,1954). Available potassium (K) (using neutral normal ammonium acetate extract) was determined by the Flame photometric method (Standford and English,1949). A Spectro-Zphotometer determined the P content of the plant in the digest, and P uptake was computed by multiplying the grain and straw yield by respective P concentrations.

Treatments

The experiments were laid out in a Randomized Block Design (RBD) with eight treatments and replicated thrice. The treatments comprised T_1 – RDF alone (100:50:50 kg NPK ha-1) through (CF), T_2 – RDF alone through (NF), T_3 – RDF (CF) + 0.5% N through urea, T_4 – RDF (CF)+ 0.5% N through ammonium sulphate, and T_5– RDF (CF) + 0.5%. N through Nano urea, T6– RDF (NF) (25 kg ha^{-1}) + 0.5% N through urea, T7– RDF (NF) (25 kg ha^{-1}) + 0.5% N through ammonium sulphate, T8– RDF (NF) (25 kg ha^{-1}) + 0.5% N through

Nano urea. Observations on growth parameters were taken on 30 DAS, 60 DAS and at harvest. The yields were taken during the harvesting stage.

Crop management

The field was thoroughly ploughed with a tractor-drawn implement in a crisscross manner and levelled correctly. The plots were prepared with dimensions of 5 × 4 m, and seeds of white-seeded quinoa were sown with a spacing of 30×10 cm. For fertilization, the recommended dose of fertilizer (RDF) treatment of 100% of P through single super phosphate (SSP), 50% of N through urea, and K through (muriate of potash) MOP was applied basally as a soil application (Rane *et al.,* 2019). The remaining 50% of N and K were applied at the pre-flowering stage.

Application of nano- fertilizers:

Nano fertilizers used in the study were protein-Lacto Gluconate–based N, P, and K in nano form fertilizers purchased from the Tropical Agro system Indian Pvt and Ltd. This productwas formulated with the nano micronutrient technology of ICAR Govt. of India, with the carrier material of nutritional mycelium derived from a probiotic fermentation process. Nano N, P, K contains multiple organic acids chelated significant nutrients (N, P2O5., K2O) min (4-4-4%) along with amino acid @ 6.00%(min), organic carbon @10.00% & formulated with organic micronutrient/trace element vitamins and probiotics. Nano fertilizers were applied as soil application @ 25 kg/ha^{-1} as they were water-soluble, and the entire dose was applied as a basal as per the treatment schedule. At the same time, appropriate concentration was prepared and applied against different nitrogen sources per the schedule. Quinoa seeds were treated with *Pseudomonas fluorescence* @ 10g ha^{-1} of seeds before sowing. A seed rate of 20 kg ha^{-1} was followed, and the treated seeds were mixed with sand in a ratio of 1:2 and sown in a line with a spacing of 30 cm between the rows at a depth of 5 cm and then covered with soil.

Statistical analysis

The experimental data were statistically analyzed using the web-based agricultural software package (Wasp 2.0). The critical difference was worked out for significant results at a five-percent probability level. Treatment differences that were not significant were denoted by ‘NS’.

RESULTS AND DISCUSSION

Growth parameters

Growth parameters such as plant height (139.72 cm), number of branches plant^{-1} (38.08), Dry matter production (1018.88 kg ha^{-1}), and leaf area index (2.44) were significantly enhanced by foliar application of RDF (NF) + 0.5% N through Nano urea (T_8) during the crop period. This indicates that the combined application of Nano fertilizers encourages the plant to absorb and utilize nutrients efficiently (Table 2). It may create a continuous nutritional balance for the different growth stages of the quinoa plant, especially Nanomaterial, which stimulates crop growth, improves the soil environment and promotes.

The increased plant height recorded by Nano fertilizer applied treatment (T_8) ~~is~~ might be due to its physiological role in stimulating porphyrin molecules present in important metabolic compounds such as chlorophyll and cytochrome pigments necessary for photosynthesis and respiration as well as coenzymes that activate phosphorous, which are essential for the function of many enzymes and the production of amino acids used in protein synthesis when applied as a foliar application. The above findings align with the observations of Al-jury and Saadoun (2019) regarding wheat crops by foliar application of nano NPK, NK and PK combinations. Similarly, the increase in LAI was due to the early and better availability of macro and micronutrients to the meristic tissues, which increased the number of leaves and the total leaf area. Nano N, P, and K application in submerged conditions efficiently facilitated this compared to conventional fertilizer. These results corroborate the findings of Nouraein (2019), where the nano fertilizers were applied @ 2000 ppm as a foliar spray in 3 different stages in the maize crop.

The prerequisite for getting higher yield in any crop depends on total dry matter production and the maximum translocation of photosynthates to sink. Dry matter production depends upon the plant's photosynthetic ability. Here, the combined application of conventional fertilizers and Nano fertilizers along with soil application, significantly increased the availability of nutrients to the plants, which eventually increased the chlorophyll formation, thereby keeping the leaves green for an extended period, which helps to actively participate in the photosynthesis, which in turn increased the photosynthesis rate, dry matter production and improve overall growth of the plant.

The lowest values of growth attributes, viz., plant height (85.78 cm), number of branches plant^{-}1(15.97), LAI (1.67), and DMP (542.05 kg ha^{-1}) in quinoa crops, were observed in RDF alone (100:50:50 kg NPK ha^{-1}) through (CF) T_1 treatment, which might be due to the availability of nutrients in a shorter period comparatively with nano fertilizers in the soil. This fails to perform the same function as other combinations of treatments done with the physiological process at the right/needy time.

Yield attributes and yield

Applying nano fertilizers through the soil and foliar nutri-

Table 2. Effect of different sources and modes of nitrogen on growth components of quinoa (2 years pooled data of 2022 and 2023)

Treatments	Plant height cm		Number of Branches per plant^{-1}	DMP (kg ha^{-1})		LAI
	60 DAS	At Harvest		60 DAS	At Harvest	60 DAS
T_1- RDF alone (100:50:50 kg NPK ha^{-1}) through conventional fertilizer (CF)	69.87	85.78	15.97	332.58	542.05	1.67
T_2- RDF alone through Nano fertilizer (NF)	77.43	92.99	20.13	379.36	590.50	1.79
T_3- RDF (CF) + 0.5% N through urea (Foliar)	77.29	100.28	24.07	415.52	637.16	1.99
T_4- RDF (CF) + 0.5% N through ammonium sulphate (Foliar)	83.42	107.63	27.08	477.38	698.77	2.01
T_5- RDF (CF) + 0.5% N through Nano urea (Foliar)	89.98	115.66	29.80	514.69	755.97	2.08
T_6- RDF (NF) + 0.5% N through urea (Foliar)	97.54	122.39	32.86	556.47	818.83	2.17
T_7- RDF (NF) + 0.5% N through ammonium sulphate (Foliar)	104.31	131.17	35.14	605.52	916.11	2.31
T_8- RDF (NF) + 0.5% N through Nano urea (Foliar)	111.90	139.72	38.08	672.58	1018.88	2.44
S.Em	**2.79**	**6.02**	**0.93**	**15.85**	**20.09**	**0.23**
CD (p=0.05)	**5.98**	**12.88**	**1.99**	**33.9**	**42.99**	**0.49**

DMP: DMP stands for Dry Matter Productivity; **LAI:** The amount of leaf area (m2) in a canopy per unit ground area (m2)/ Leaf Area Index

Table 3. Effect of different sources and modes of nitrogen on yield attributes and yield of quinoa (2 years pooled data of 2022 and 2023)

Treatments	Panicle length (cm)	No. of panicle plant^{-1}	No. of grains per panicle	Grain yield (kg ha^{-1})	Stalk yield (kg ha^{-1})
T_1- RDF alone (100:50:50 kg NPK ha^{-1}) through conventional fertilizer (CF)	17.85	4.17	846.5	1146	1446.0
T_2- RDF alone through Nano fertilizer (NF)	20.25	4.81	1007.5	1376	1744.3
T_3- RDF (CF) + 0.5% N through urea (Foliar)	22.75	5.47	1317.5	1613	2012.9
T_4- RDF (CF) + 0.5% N through ammonium sulphate (Foliar)	25.55	6.12	1672.5	1828	2264.1
T_5- RDF (CF) + 0.5% N through Nano urea (Foliar)	28.15	7.10	2048.5	2030	2548.6
T_6- RDF (NF) + 0.5% N through urea (Foliar)	31.05	7.10	2302.5	2220	2810.5
T_7- RDF (NF) + 0.5% N through ammonium sulphate (Foliar)	33.3	8.04	2520.5	2413	3068.4
T_8- RDF (NF) + 0.5% N through Nano urea (Foliar)	35.9	8.69	3182.5	2655	3331.8
S.Em	**1.03**	**0.16**	**74.19**	**75.19**	**102.4**
CD (p=0.05)	**2.20**	**0.34**	**158.83**	**160.28**	**219.13**

tion significantly enhanced yield attributes, such as the number of panicle plants^{-1} (8.69), panicle length (35.9 cm), and the number of grains panicle^{-1} (3182.5), 1000 grain weight (2.5g) than other treatment combinations during the crop period (Table 3). This might be due to the NPK promoting the plant, root, and shoot efficiency to absorb and translocate the available macro and micronutrients from soil, thereby enhancing photosynthesis and significantly increasing the grain yield by nano NPK over conventional fertilizers. Similar results were observed by (Al-Khuzai *et al.*, 2020) in the rice crop through DAP with nano silicon application.

Applying T_8– RDF (NF) + 0.5% N through nano urea recorded the highest grain and straw yield among the treatments. The increase in yield might be due to the significant increase in yield attributes, viz., panicle length and number of panicles plant^{-1}, thereby increasing the yield. This might be due to the influential role played by the N and K nano form and their extended availability to the crop, especially in the later stages (reproductive stage), which increased the yield. Further, the active role of nanoparticles is integrated with other elements and acts as a catalyst in increasing the enzymatic reactions due to their bulk surface area. In addition, the higher yield is associated with the combined use of Nano N, P, K and conventional fertilizers along with basal, which increased the availability and uptake of macro and micronutrients (Elavarasan *et al*., 2021).

Conclusion

The present investigation proved that combining the recommended fertilizer (NF) and foliar application through nano urea @ 0.5% (T_8) on 30, 60 DAS and at harvest enhanced the growth, viz., plant height, leaf area index, dry matter production, and test weight, yield components viz, number of panicle plant^{-1}, panicle length, number of grains per panicle, and grain and stalk yield of quinoa (*Chenopodium quinoa* Willd). In light of the above facts, it can be concluded that soil application of the recommended dose of fertilizer (RDF) (NF) + foliar application of 0.5% N through nano urea was agronomically efficient and ecologically viable for augmenting quinoa yield.

Conflict of interest

The authors declare that they have no conflict of interest.

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