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Comparative analysis studies on different forms of 'N' nutrient on the uptake, post-harvest soil status and economics of quinoa (*Chenopodium quinoa* Willd.)

K. Priyaharini [1], C.Ravikumar[1&4], M.Thirupathi[1], P.Senthilvalavan [2&5], R.Kannan[3&4]*
A.Vijayaprabhakar[4], and V.Sathiya Aravindan[3]

[1] Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India

[2] Department of Soil Science and Agricultural Chemistry, Annamalai University, Annamalai Nagar, Tamil Nadu, India

[3] Department of Plant Pathology, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India

[4] Institute of Agriculture, Department of Agronomy, Tamil Nadu Agricultural University, Kumulur 621 712, Tamil Nadu, India

[5] 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**
ORCID ID:0000-0002-1564-6475

Abstract:

In the present scenario, promising food security with balanced, nutritious dietary habits is inevitable, while sustaining soil fertility by conserving resources and energy is a significant challenge. Quinoa is a new pseudo-cereal crop with fascinating traits that can be introduced to developing countries like India, which has diversified climatic conditions. The use of nanotechnology-based fertilizers paves a potential pathway for achieving higher yields with lower conventional fertilizer usage, and conserving energy is gaining momentum. The field experiments were conducted in farmers' fields in Sivapuri village, Varagoorpettai, Cuddalore district of Tamil Nadu, from February to May 2022 and 23 to study the consequences of nitrogen management on the nutrient uptake, post-harvest soil status and economics of quinoa." The experiments were laid out in a Randomised Block Design (RBD) with eight treatments and replicated thrice. The results described that foliar application of RDF (NF) + 0.5% N through Nano urea (T8) exhibited significantly higher nutrient uptake of N (38.51), P (28.36) and K (30.73) kg ha^{-1}, post-harvest soil nutrient status of N (145.02), P (8.09) and K (254.09) kg ha^{-1} over other combination and modes of treatments. These nano-scale polymers ensure a low and target-efficient release for sustainably providing nutrients to the crop during its life cycle. These could also release their active ingredients in response to environmental triggers and biological demands more precisely and play a beneficial role in soil health by building up carbon uptake and improving soil aggregation and water holding capacity, which paves higher availability of post-harvest soil nutrients.

Keywords: Conventional form, Nano form, Nitrogen, Nutrient uptake and Quinoa

Introduction:

Quinoa (*Chenopodium quinoa* Willd.) is a pseudo-cereal from the Amaranthaceae family, originating from South America. Quinoa has emerged as a fascinating crop among pseudo cereals for research, production, and consumption in the United States, Europe, and developing countries like Asia and Africa. In India, quinoa is cultivated in 440 hectares with 1053 tonnes of production (1). Quinoa was discovered as a healthy food, and its popularity has dramatically increased in recent years because it is gluten-free (helpful for diabetic patients) and high in protein. As per the United Nations Organisation for Agriculture and Food, quinoa grain is the only food that provides all the essential amino acids for human life in optimum quantities and is comparable to milk. It contains protein (14%), iron (12.6%), carbohydrates (68%), fat (0.5%), fibre (7%), calcium (0.2%) and phosphorus (0.5%). The protein content ranges from 7.47 to 22.08 per cent, the oil content is 1.8 to 9.5 per cent, and it is rich in essential fatty acids. The grain protein is rich in amino acids like lysine and methionine, which are deficient in cereals. In India, dryland Agriculture plays a distinct role by occupying 60% of the cultivated area and supporting 40% of the human population and 60 % of the livestock population. If India is to provide adequate food to 1000 million people by the end of the 21st century, the contribution of dry lands will have to be 60 per cent (Technical Bulletin by ICAR-National Institute of Abiotic Stress Management). Quinoa can thrive from sea level to 3,900 metres above mean sea level, with a pH range of 6 to 8.5, and also in temperatures ranging from subtropical to tropical and humid areas, with a base temperature of 3°C, an optimum temperature of 15-30°C, and a tolerance for a maximum temperature of 50 °C, quinoa's potential is reassuring (2). Therefore, we need to promote crops like quinoa, which have the potential for increased production even under adverse climatic conditions. Several agro techniques are available to improve the production potential of quinoa. Nutrient management is a primitive tool to enhance the production potential of quinoa in tropical climatic conditions prevailing in countries like India.

Nitrogen (N) is considered a boon and the most demandable nutrient among the macronutrients to meet any crop's successful vegetative growth phenomenon. Most of the Indian soils were affected by widespread deficiency. About 87% of samples were deficient in organic carbon, 97% in available nitrogen, 83% in phosphorus, and 71% in potassium among the 50 million soil samples collected across the country. However, more than 50 per cent of the chemical fertilizers consumed in India are in the form of urea as a molecular form. Those States and Union territories with higher consumption of chemical fertilizers (than the national per hectare consumption of 133.4 kg in 2019–20) did not necessarily report a lesser number of soil samples deficient in organic carbon, nitrogen, phosphorus and potassium (3). The external application of nitrogenous fertilizers is necessary to meet the crop demand and ensure successful growth. The molecular form of nitrogenous fertilizers is subject to various losses, and the use efficiency is less than 35-50%. On the other hand, a higher rate of application or indiscriminate usage of these molecular nitrogenous fertilizers leads to pollution hazards. Nano-fertilizers and slow-released fertilizers are appropriate alternatives to conventional fertilizers for a gradual and controlled supply of nutrients in the soil. Alternatively, nano-fertilizers such as nano chelate with chemical fertilizers reduce pollution, which is also economical (4). Meanwhile, the 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 (5). 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. 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 minimal health risk. Therefore, the present study aimed to evaluate the different sources and forms of conventional and nano-nitrogenous fertilizers on the nutrient uptake and post-harvest availability of nutrients in quinoa cultivation.

Materials and methods:

Study area:

The study was conducted at a farmer's field in Sivapuri village, varagoorpettai, Cuddalore district of Tamil Nadu, geographically located at 11º 24'N latitude and 79º44'E longitude and at an altitude of ± 5.79 m above the mean sea level (MSL) Fig.1. The site received a mean maximum temperature ranging from 30.5ºC to 36.4ºC, a minimum temperature ranging from 16.8ºC to 22.6ºC, and relative humidity ranging from 69.85% to 77.28% during the cropping period (February to June 2022 and 2023). The study site's weather is moderately warm, with a hot climate in the morning and preferably a cool climate in the late evening and the same condition extended up to the mid-stage (Flowering) of the crop. Afterwards, the hot climate continued till the crop harvesting stage. Supplemental irrigations were given to meet the crop demand.

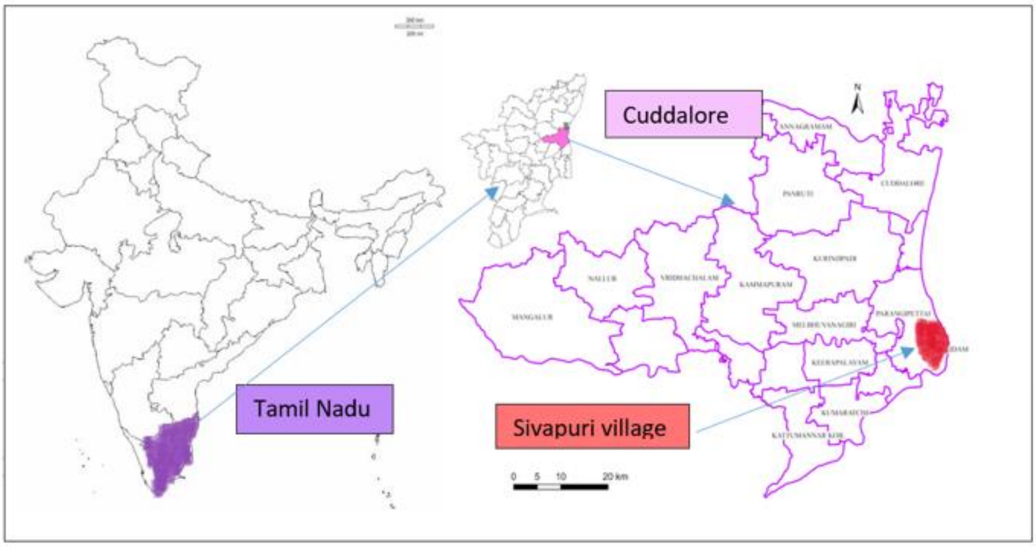

Fig1. Site Map

Experimental Design:

The experiments were laid out in a Randomised Block Design (RBD) with eight treatments and replicated thrice. The treatment comprised of

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,

T_5– RDF (CF) + 0.5% N through Nano urea,

T_6– RDF (NF) + 0.5% N through urea,

T_7– RDF (NF) + 0.5% N through ammonium sulphate,

T_8– RDF (NF) + 0.5% N through Nano urea.

Note

CF- Conventional Fertilizers NF- Nano-formulated Fertilizers RDF- Recommended Dose of Fertilizers

Crop management:

The field was thoroughly ploughed with a tractor-drawn implement in a crisscross manner and levelled unanimously. The plots were laid out with 5 × 4 m dimensions, and seeds of white-seeded quinoa were sown as a solid planting method. Being small-sized, quinoa seeds are mixed with sand at a 1:2 ratio to enhance the sowing and minimise the crowding effect of crops. After the establishment of the crop, thinning procedures are followed with a spacing of 30×10 cm. For fertilization, the RDF treatment of 100% of P through SSP, 50% of N through urea, and K through MOP was applied basally as a soil application. 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 product is 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, P_2O_5. K_2O) 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, an 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.

Methodology:

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).

Analysis of soil samples:

The initial soil samples were analysed for both mechanical and chemical compositions (Table 1) following standard methods, 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 (6). The available nitrogen (N) was determined by the alkaline permanganate method (7). Available phosphorus (P) was quantified by the spectrophotometer method (8). Available potassium (K) (using neutral standard ammonium acetate extract) was determined by the Flame photometric method (9).

Table 1 Physicochemical and biological properties of the experimental site

Particulars	Details	Methods followed
Soil Characteristics		
A. Physical properties (Mechanical Analysis)		
Clay (%)	34.06	International Pipette method
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	Alkaline permanganate method (Subbiah and Asija, 1956)
Available phosphorus (kg ha^{-1})	21.5	Spectro photo meter method (Olsen *et al.*, 1954)
Available potassium (kg ha^{-1})	279	Flame photometric method (Standford and English, 1949)
Organic Carbon (%)	0.58	Chromic acid wet digestion method (Walkley and Black, 1934)
Soil reaction pH (1:2soil water suspension)	7.8	Potentiometry, PH meter
EC (1:2 soil water suspension) (dSm^{-1})	0.64	Conductometry method

Collection of Plant Samples:

Plant samples were collected at harvest after fertilizer application was scheduled for the respective treatments. The collected plant samples were cleaned, shade-dried, and dried in a hot oven at 65 °C. After drying, the samples were powdered and stored for chemical analysis.

Plant analysis:

The N uptake was determined by the nitrogen content of crop samples using the Micro Kjeldhal method, as suggested by (10) and expressed in percentages on an oven-dry basis. The total N uptake by crop was determined by multiplying the crop DMP with the percentage of nitrogen content in the respective treatments and expressed in kg ha^{-1}. Similarly, the P and K uptake was determined using the P and K content of the crop multiplied by the crop dry matter production of the respective treatments and expressed in kg ha^{-1}.

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-per cent probability level. Treatment differences that were not significant were denoted by 'NS'.

Results and Discussion:

Influence of the Nano form of nitrogen on the yield of quinoa:

The impacts of fertilizer application through different forms and modes on grain and stalk yield are shown in Fig.2. Applying RDF (NF) + 0.5% N through nano urea (T_8) recorded the highest grain yield of (2655 kg ha^{-1}) and straw yield of (3331.8 kg ha^{-1}), which was registered 10.06 % more grain yield than the subsequent significant treatment (T_7) and 92.9% than (T_1) (Fig.2). This yield was quite comparable with (T_7) RDF (NF) + 0.5% N through ammonium sulphate (Foliar) applied treatment, which produced 2413.0 and 3068.4 kg of grain and stalk per hectare. In contrast, a lower grain and stalk yield was noticed in (T_1) RDF alone (100:50:50 kg ha^{-1}) (CF) imposed treatment, with a value of 1146.0 and 1446.0 kg of grain and stalk yield per hectare.

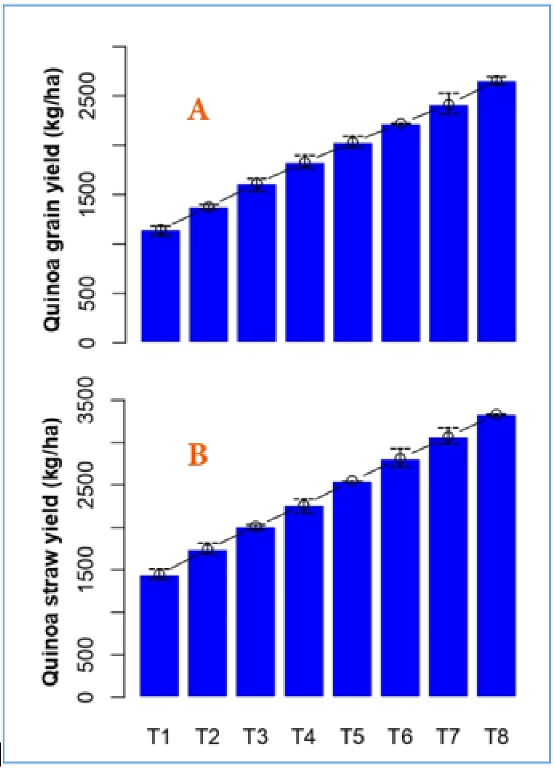

Fig.2 Effect of different sources and modes of nitrogen on the grain and stalk yield of quinoa

Influence of Nano form of nitrogen on the Nutrient Uptake of Quinoa:

The application of foliar nutrition significantly enhanced nutrient uptake. Among the treatments, plots imposed with RDF (NF) + 0.5% N through nano urea (T_8) recorded higher nutrient uptake (38.51, 28.36, 30.73 kg ha^{-1} of N, P_2O_5 and K_2O) (Table 2). Which was registered at 13.76, 8.86, and 19.24 % more nutrient uptake of N, P, and K than the subsequent significant treatment (T7) and 192.9% of the total (T_1). The higher uptake of N, P_2O_5, K_2O in T_8 - RDF (NF) + 0.5 % N through nano urea due to the cumulative effect of nano-formulated fertilizer application in both soil and foliar forms paves the way to precise absorption through roots and leaves in various stages of the crop. Similarly, these nano-based fertilizer formulations confirm nutrient availability for a more extended period through increased specific surface area and many particles per unit area of a fertilizer that provides more opportunity to contact Nano-fertilizers, which leads to more penetration and uptake of the nutrient. These are in line with the findings of Sharmila (13), who reported that the longevity of nutrients released by Nano and conventional fertilizers is more (>1000 hrs) and (< 500 hrs). In contrast, the lower uptake was registered comparatively in (T_1) RDF alone (100:50:50 kg ha^{-1}) N through (CF) due to the transformation of fertilizer molecules into various unavailable forms viz., denitrification, volatilization, etc., may decrease the use efficiency of the fertilizer which fails to extend the availability period and impairs with critical growth stages of the crop. Similar results were reported by (4,14).

Table 2 Effect of different sources and forms of nitrogenous fertilizers on the nutrient uptake of quinoa.

Treatments	Nutrient uptake (kg ha^{-1})		
	N	P_2O_5	K_2O
T1	13.13^h	14.96^h	15.24^h
T2	15.42^g	17.26^g	16.75^g
T3	17.54^f	18.87^f	18.05^f
T4	21.55^e	20.47^e	19.58^e
T5	26.87^d	22.12^d	22.05^d
T6	30.63^c	23.96^c	23.74^c
T7	33.85^b	26.06^b	25.77^b
T8	38.51^a	28.36^a	30.73^a
S.Em ±	0.96	0.64	0.57
CD (p=0.05)	2.06	1.38	1.23

RDF- Recommended Dose of Fertilizers as per the state Govt., CF- Conventional Fertilizers, NF- Nano fertilizers

Influence of Nano form of nitrogen on the post-harvest soil nutrient status:

Post-harvest soil nutrient status results reveal that the highest available N. P and K in soil were recorded in T_1– RDF alone (100:50:50 kg ha^{-1}) N through (CF) during the crop period. The effect of the application of different forms and modes of N fertilization on quinoa significantly transformed the soil's available nutrient status after harvest, as presented in Table 3. The higher available soil N (181.5 kg ha^{-1}), P (13.2 kg ha^{-1}), and K (254.8 kg ha^{-1}) were recorded in T_1– RDF alone (100:50:50 kg ha^{-1}) N through (CF) imposed treatment. Available N showed significantly higher results with a value of 176, P 12.3 and P 244.5 kg ha^{-1} in T_2-RDF alone @ 25 kg ha^{-1}) applied treatment. In contrast, a lower level of post-harvest soil N of 145.2, P of 8.9 and K of 254.9 kg ha^{-1} registered in T8 (RDF(NF)+0.5% N through Nano urea (Foliar) imposed treatment. The lower availability of N, P_2O_5, and K_2O was registered in T8- RDF (NF) + 0.5% N through nano urea. This might be due to better utilization of released nutrients throughout the crop growth period, evidenced by higher DMP and N, P_2O_5, and K_2O uptake. However, the available N, P_2O_5, and K_2O in the soil were lower than in other treatment combinations. Using nano fertilizer in the soil leads to increased efficiency of the elements, reduced toxicity, and reduced frequency of fertilizer application. These results are in line with (11). With the present study, similar results were obtained by (15, 16); in T_8– RDF (NF) + 0.5% N through nano urea were recorded the lower values of available N, P_2O_5, and K_2O when compared to other treatments, due to low capturing capacity of nutrients during the crop growth, which reflects in fewer growth attributes and low yield (Table 3).

Table 3 Effect of different sources and forms of nitrogenous fertilizers on the post-harvest nutrient status of soil

Treatments	Post-harvest soil nutrient status (kg ha^{-1})		
	N	P_2O_5	K_2O
T1	181.5ᵃ	13.2ᵃ	254.8ᵃ
T2	176.0ᵃ	12.3ᵇ	244.5ᵃ
T3	169.4ᵃ	11.9ᵇ	238.0ᵃ
T4	163.2ᵃᵇ	11.2ᶜ	232.9ᵃᵇ
T5	158.0ᵃᵇ	10.7ᵈ	227.7ᵃᵇ
T6	155.0ᵇ	10.2ᵉ	228.0ᵃᵇ
T7	153.5ᵇ	9.5ᶠ	219.5ᵇ
T8	145.2ᵇ	8.9ᵍ	254.9ᵃ
S.Em ±	6.22	0.19	7.92
CD(p=0.05)	13.33	0.42	16.95

RDF- Recommended Dose of Fertilizers as per the state Govt., CF- Conventional Fertilizers, NF- Nano fertilizers

Economics:

Among the treatments, the highest net return and BCR were obtained under T8– RDF (NF) + 0.5% N through nano urea due to higher growth and yield attributes. The least net return and BCR were recorded under the RDF alone (100:50:50 kg NPK ha^{-1}) through (CF) T1 due to the lesser growth and yield attributes (Table 4). Compared to conventional fertilizer requirements, nano fertilizers are economically cheap and required in lesser amounts. Economic analysis of different treatments revealed a higher gross income (Rs.1,57,119 ha^{-1}), net income (Rs. 1,01,677 ha^{-1}) and Benefit-cost ratio of 2.83. This might be due to higher yield accompanied by the low cost of inputs viz., conventional, Nano fertilizer. These agree with the findings of (11) and (12).

Table 4 Effect of different sources and forms of nitrogenous fertilizers on the economics of quinoa.

Treatments	TCC (Rs.)	Gross Return (Rs.)	Net Return (Rs.)	BCR
T1	49330	64694	15364	1.31
T2	54380	78792	24412	1.45
T3	49860	93280	43420	1.87
T4	49962	106432	56470	2.13
T5	50393	118836	68444	2.36
T6	54910	130498	75588	2.38
T7	55012	142336	87324	2.59
T8	55443	157119	101677	2.83

RDF- Recommended Dose of Fertilizers as per the state Govt., CF- Conventional Fertilizers, NF- Nano fertilizers TCC- Total Cost of cultivation, GR- Gross Return, NR- Net Return, BCR- Benefit Cost Ratio

Correlation studies:

The data about correlation studies between and within the uptake and available nutrients of N, P and K during the quinoa cropping period shown in Fig.3. Nitrogen uptake concern, there was a negative correlation (P>0.05) found between nitrogen with K uptake (-0.98) and no significant correlation was registered with P uptake. Meanwhile, the available N registers a positive, strong correlation (P>0.05) with the availability of P (0.98) and moderately correlates with available K (0.36), which is denoted as non-significant Fig.4.

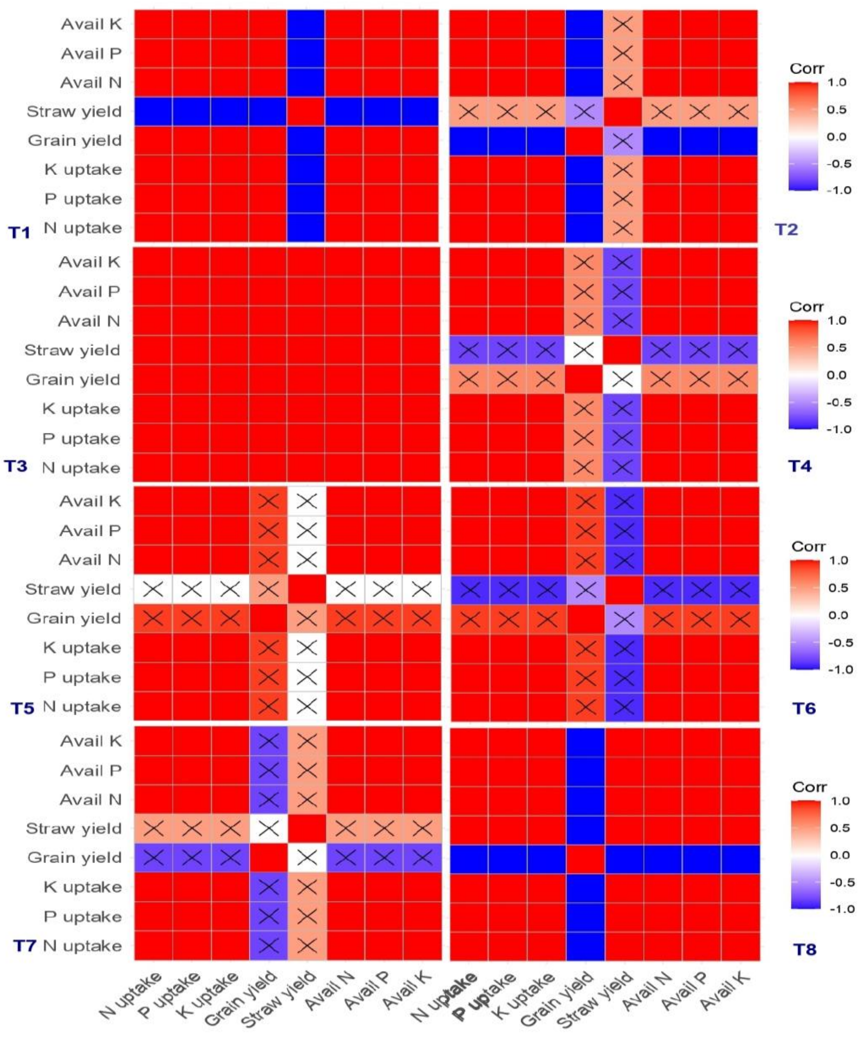

Fig 3 Correlation matrix between NPK uptake and Availability in quinoa at treatment-wise

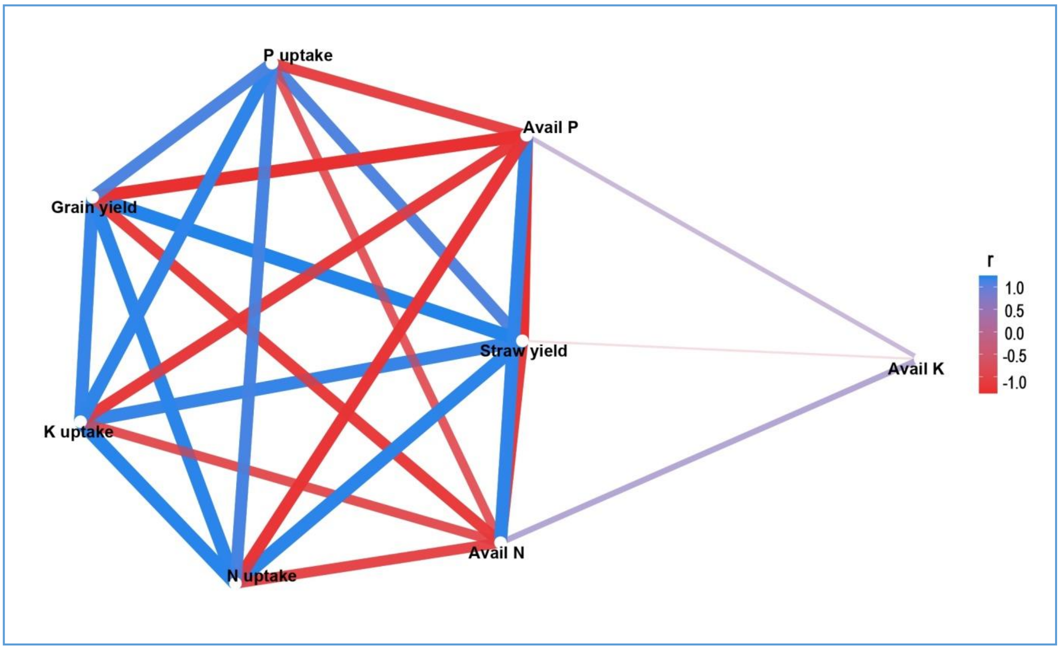

Fig 4 Correlation matrix between NPK uptake and Available in quinoa from cumulative data

Conclusion:

The present investigation concluded that RDF (NF) + 0.5% N through nano-urea (foliar) positively enhanced the nutrient uptake (N, P, and K) and economics of quinoa. In light of the above facts, it can be concluded that the foliar application of RDF (NF) + 0.5% N through Nano urea (foliar) is an ecologically viable and economically feasible technology for augmenting quinoa productivity without impairing soil health.

A. General view of the trial plot

B. Vegetative Stage of the crop

C. Flowering Stage of the crop

D. Best Vs Least treatment of the trial plot

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Ethical issues: *None*

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