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Effect of nitrogen and potassium on production potential of quinoa (*Chenopodium quinoa*) in India

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ABSTRACT

A field study was carried out during late rainy (*kharif)* season of 2022 and winter (*rabi)* season of 2022–23 at the Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu to explore the best nutrient management strategies for enhancing quinoa (*Chenopodium quinoa* Willd.) production. The experimental field was arranged in a randomised complete block design (RCBD) with nine treatments [T_1, 75:0 kg N: K_2O/ha; T_2, 100:0 kg N: K_2O/ha; T_3, 125:0 kg N: K_2O/ha; T_4, 150:0 kg N: K_2O/ha; T_5, 75:50 kg N: K_2O/ha; T_6, 100:50 kg N: K_2O/ha; T_7, 125:50 kg N: K_2O/ha; T_8, 150:50 kg N: K_2O/ha and T_9, Without N and K_2O fertilisers (Control)], each replicated thrice. The results revealed that the application of 150:30:50 kg N: P_2O_5: K_2O/ha (T_8) led to superior growth parameters (plant height, leaf area index, dry matter production and number of branches/plant), yield attributes (number of panicle/plant, panicle length, panicle conversion efficiency, number of grains/panicle and test weight), yield (grain and stalk), and economic parameters (gross returns, net returns and benefit: cost ratio) for quinoa, outperforming other treatments except for 150:30:0 kg N: P_2O_5: K_2O/ha (T_4) during both seasons. The lowest values across all parameters were recorded for the control (T_9). It can be inferred from the investigation that the application of 150:30:50 or 150:30:0 kg N: P_2O_5: K_2O/ha significantly enhanced quinoa's growth, yield and economic parameters compared to lower nutrient doses in India.

Keywords: Economics, Growth, Leaf area index, Nitrogen, Quinoa, Yield

Cereals play a vital role in human nutrition and are a dietary staple globally. Rice, maize, and wheat are the most produced crops in the world, and fulfilling the major food requirement. Other crops such as most of millet, sorghum, oats, and barley are next in the order. Pseudocereals like grain amaranth (*Amaranthus spinosus* L.), quinoa (*Chenopodium quinoa* Willd.), canihua (*Chenopodium pallidicaule* Aellen) and buckwheat (*Fagopyrum esculentum* Moench) have also gained popularity in recent decades and grown worldwide according to their climatic requirement. Among pseudocereals, quinoa has notably become a focus of research, production, and consumption in the United States, Europe, Asia, and Africa, with its cultivation expanding to over 70 countries. Quinoa grains are characterised by high protein content (10–18%), moderate carbohydrate levels (67–74%), and higher crude fat content (4.5–8.5%) compared to other cereals (Sukhmandeep and Navjot 2017) besides containing high fibre, many minerals, vitamins and beneficial antioxidants. The Food and Agricultural Organization has identified quinoa as a promising for ensuring food security in the coming century, particularly in response to the predicted future challenges of increasing salinization and aridity (Yamuna Devi *et al.* 2022). Though it is under cultivation in many parts of the globe, its spread is meagre in India and research evidence is scanty.

In agricultural production systems, inorganic fertilisers play a crucial role by providing readily available nutrients for immediate plant use (Thavaprakaash and Malligawad 2002, Thavaprakaash and Velayudham 2009). For a fast-growing crop like quinoa, an adequate supply of nutrients is essential for normal growth and development, leading to higher yields and quality. Among the various plant nutrients, nitrogen is important for influencing the growth and yield of quinoa (Gomaa 2013). Potassium provides resistance to drought and high temperatures and helps maintain the crop's condition for a longer period. However, there is a lack of information on the optimal and economically viable doses of inorganic fertilisers required for quinoa production in India. Therefore, the current study was undertaken to explore the best nutrient management strategies for enhancing quinoa production.

MATERIALS AND METHODS

A field study was carried out during late rainy (*kharif)* season of 2022 and winter (*rabi)* season of 2022–23 at Tamil

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Nadu Agricultural University, Coimbatore (11.01236°N, 76.93559°E; 426.7 m amsl), Tamil Nadu. The soil in the experimental field was determined to be sandy clay loam in texture, with a moderately alkaline reaction (0.15–0.16 dS/m). Organic carbon estimated in the soil was low (4.54–4.72 g/kg) with low available nitrogen (234.8–244.3 kg/ha), but high in available phosphorus (23.05–24.03 kg/ha) and potassium (600.4–613.2 kg/ha). All the weather parameters that prevailed during the cropping periods of both seasons were normal and within the permissible limit to grow the quinoa crop.

The field layout followed during the investigation was a randomised complete block design (RCBD) with eight treatments replicated thrice and compared with the control. The treatments were as follows, T_1, 75:0 kg N: K_2O/ha; T_2, 100:0 kg N: K_2O/ha; T_3, 125:0 kg N: K_2O/ha; T_4, 150:0 kg N: K_2O/ha; T_5, 75:50 kg N: K_2O/ha; T_6, 100:50 kg N: K_2O/ha; T_7, 125:50 kg N: K_2O/ha; T_8, 150:50 kg N: K_2O/ha and T_9, Without N and K_2O fertilisers (Control). A common dose of 30 kg P_2O_5/ha was given as basal for all the treatments including control.

The seed rate used for sowing of quinoa was 2.0 kg/ha. Seeds were treated with Chlorpyriphos 50% EC @5 g/kg just one hour before sowing. The seeds were dibbled at 2.0 cm depth uniformly on the side of ridges, with a spacing of 30 cm × 10 cm. Fertilisers (urea, muriate of potash) were supplied to the crop as per the treatments, with phosphorus (single super phosphate) supplied at 30 kg/ha as a common dose. Nitrogen was applied in two equal split doses, while phosphorus and potassium were applied as basal dose. The first split of nitrogen was given as basal, and the second was made available on 30 days after sowing (DAS). Two hand weedings were performed at 20 and 40 DAS.

The standard procedure was followed for recording growth parameters such as plant height (cm), leaf area index (LAI), dry matter production (DMP) (kg/ha) and number of branches/plant and yield attributes like number of panicle/plant, panicle length (cm), number of grains/panicle and test weight (g). Panicle conversion efficiency (%) was worked out based on the formula given by Thavaprakaash (2019). At the physiological maturity stage, the plants were harvested, dried, threshed, and the grains were further dried to 14% moisture level to arrive at the grain yield (kg/ha). The threshed stalks were dried in the sun for three days and weighed as stalk yield (kg/ha). The economic parameters of the experiment [cost of cultivation (₹/ha), gross returns (₹/ha), net returns (₹/ha), benefit: cost ratio] were worked out based on the prevailing price of input used and the cost of grain. Data collected in the present investigation were analysed statistically using a RCBD (Gomez and Gomez 2010).

RESULTS AND DISCUSSION

Growth parameters: Nutrient management options attempted during both the late *kharif* and *rabi* seasons exerted a significant impact on the growth of quinoa (Table 1). The application of 150:50 kg N: K_2O/ha (T_8) to quinoa significantly increased plant height (121.9 and 128.4 cm), LAI (3.608 and 3.975), DMP (8,753 and 11,308 kg/ha) and number of branches/plant (40.27 and 44.93) during late *kharif* and *rabi* seasons, respectively over all other treatments, barring T_4 (150:0 kg N: K_2O/ha). These were closely followed by T_7 (125:50 kg N and K_2O/ha) and T_3 (125:50 kg N and K_2O/ha) treatments. Differences in growth parameters due to T_7 and T_3 were found to be non-significant. These results clearly shows that higher doses of nitrogen and potassium had a greater impact on the growth of quinoa than lower doses. The results also explicitly pronounced the role of nitrogen rather than potassium. Nitrogen is known to synthesise amino acids and plant growth-promoting hormones, such as auxins and cytokinins. These compounds regulate meristematic tissue activity, cell division, elongation, and differentiation, ultimately leading to increased internodal length of the plant. The increase in plant height of quinoa with an increase in nitrogen fertiliser dose was reported by Nguyen *et al.* (2022) strongly supports the present study. Similarly, the number of branches/plant of quinoa was also higher with the increased nitrogen and potassium, more specifically, nitrogen as in plant height. This might be owing to the role of nitrogen in synthesizing cytokinin, which promotes metabolic activity and leads to the accumulation of metabolites in plants. These metabolites play a key role in the production of more branches at each node of the shoot. Previous reports by Fawy *et al.* (2017) indicated that a higher number of branches of quinoa with higher doses of nitrogen (240 kg/ha) are in line with the present study. The increase in leaf area index with each successive increased dose of nitrogen along with or without potassium might be because nitrogen is a key integral part of photosynthetic machinery (chlorophyll) whose accumulation accelerates the process of photosynthesis. Improvement in the photosynthetic process promotes cell elongation and expansion, in turn, results in higher photosynthetic leaf area. Besides, nitrogen application also involves the formation of proteins and carbohydrates that promote vegetative growth by accumulating in different plant parts ultimately increasing the DMP of plants. In the present study also, increased plant height, number of branches and LAI in turn, improved the DMP of quinoa. The results is supported by Turcios *et al.* (2021), whose study reports that increasing nutrient application particularly nitrogen and potasium, enhance quinoa growth. Notably, the lowest growth parameters were observed in the control (T_9), indicating that the absence of major nutrients, such as nitrogen and potassium, significantly impaired the growth of quinoa.

Yield attributes: Quinoa applied with 150:50 kg N: K_2O/ha (T_8) displayed significantly higher numbers of panicles, longer panicles, higher panicle conversion efficiency, increased number of grains and more test weight during both late *kharif* season (25.40/plant, 31.24 cm, 63.38%, 4917/panicle, and 2.141g, respectively) and *rabi* season (29.93/plant, 33.14 cm, 66.53%, 5140/panicles, and 2.185 g, respectively) (Table 2). This was followed by applying 150:0 kg N: K_2O/ha (T_4) but without significant difference

Table 1 Effect of nutrient management on growth parameters of quinoa

Treatments	Plant height (cm)		LAI		DMP (kg/ha)		Number of branches/plant	
	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)
T_1	89.5	94.7	2.500	2.878	5,611	8,136	28.20	32.20
T_2	93.6	103.5	2.770	3.187	6,361	9,342	30.93	35.90
T_3	104.1	113.9	3.053	3.507	7,333	10,417	35.27	39.27
T_4	116.4	124.6	3.397	3.839	8,305	11,262	39.07	43.73
T_5	91.6	96.0	2.593	2.924	5,898	8,417	29.93	33.03
T_6	96.3	105.5	2.828	3.250	6,638	9,700	32.37	36.33
T_7	109.4	116.8	3.161	3.584	7,611	10,537	36.03	40.73
T_8	121.9	128.4	3.608	3.975	8,753	11,308	40.27	44.93
T_9	71.0	75.8	1.956	2.380	4,405	6,578	22.00	26.00
SEM±	2.1	2.3	0.074	0.084	195	237	0.90	0.92
CD (p=0.05)	6.1	6.9	0.220	0.252	585	711	2.74	2.80

LAI, Leaf area index; DMP, Dry matter production. Treatment details are given under Materials and Methods.

between these two treatments. These treatments were closely followed by quinoa fed with 125 kg N/ha with or without potassium (T_7 and T_3). This may be attributed to the higher availability of nutrients providing the quinoa plant with abundant photo-assimilates (LAI), plant height and DMP, thus providing a chance to enhance the sink capacity (panicle characteristics). Efficient partitioning of accumulated photosynthates from the source (leaf and stem) to the sink (panicles and grains), ultimately leading to improved yield characteristics. Branches of quinoa are the base to produce panicles. More number of branches produced from the T_8 allowed the quinoa to produce an increased number of panicles. Higher panicle conversion efficiency evidenced in the T_8 ensured the application of increased nitrogen and potassium converted the branches efficiently into panicles. Availability of improved nutrients also ensured to production of a greater number of grains/plants and increased test weight of quinoa. These findings are in agreement with Biswas *et al.* (2021) who demonstrated that increased nitrogen and potassium levels resulted in better yield attributes of quinoa. Conversely, the control treatment (T_9) resulted in the least yield characteristics for quinoa in both late *kharif* and *rabi* seasons, due to a lack of fertilisers which leads to insufficient nutrient availability. Poor source (growth characters) eventually leads to deprived yield contributing characters of quinoa in the control treatment.

Yield: There was a substantial difference in both seasons due to nutrient management strategies on grain and stalk yields of quinoa (Fig. 1). The quinoa fed with 150:50 kg N: K_2O/ha (T_8) produced significantly higher grain yield (2,608 and 3,639 kg/ha) and stalk yield (4,343 and 5,219 kg/ha) during the late *kharif* and *rabi* seasons, respectively, compared to other lower doses of nutrients. However, the treatment (T_8) remained on par with T_4 (150:0 kg N: K_2O/ha). The next best treatment in terms of production of quinoa grain yield was T_7 (125:50 kg N and K_2O/ha) which was in turn on par with T_3 (125:0 kg N and K_2O/ha). The percentage increase of grain yields due to treatments T_8 and T_4 was 163 and 145, respectively, during the late *kharif* season and 151 and 138, during the *rabi* season over control. The grain yield outcome of any research is the combined result of many morphological and physiological processes (Farhood *et al.* 2017). These morphological and physiological processes influence crop growth in every developmental stage and finally the grain yield. An adequate supply of nitrogen, along with or without potassium, improves the ability of the plants to mobilise the absorbed nutrients, which enhances biomass accumulation through photosynthetic processes. The efficient translocation of these accumulated photosynthates resulted in enhancing the growth characteristics (plant height, leaf area index, DMP and number of branches/plant) which efficiently translocated to produce more yield parameters (number of panicles/plant, panicle length, panicle conversion efficiency number of grains/panicle and test weight) and ultimately, the yield of the plant. An increase in nitrogen and potassium dose resulted in enhanced grain and biomass yield of quinoa (Wissam and Kefah 2021, Nguyen *et al.* 2022) was documented earlier and supports the current results. Supporting the present study results, Kukharenkova *et al.* (2024) recorded a beneficial impact on the grain yield of quinoa with the increase in the dose of nitrogen. The lowest grain during the late *kharif* and *rabi* seasons sown quinoa was recorded with control (T_9). This was due to the nutrient deficiencies that resulted in the least source (growth characters) and sink (yield attributes), and in turn, the lowest grain and stalk yields.

The stalk yield was alike the grain yield of quinoa. More nitrogen application with or without potassium

Table 2 Effect of nutrient management on yield attributes of quinoa

Treatments	Panicle length (cm)		Number of panicles/ plant		Panicle conversion efficiency (%)		Number of grains/ panicle		Test weight (g)	
	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)
T_1	18.41	19.03	14.83	17.27	52.49	53.56	3054	3365	1.879	1.918
T_2	21.90	23.43	17.07	20.13	55.52	56.10	3493	3789	1.927	1.967
T_3	25.57	27.52	20.90	24.50	59.09	62.35	4157	4377	1.966	2.027
T_4	29.88	31.30	24.47	28.90	62.96	66.21	4729	5007	2.069	2.134
T_5	19.46	20.29	16.07	18.23	53.75	55.47	3235	3407	1.899	1.941
T_6	22.88	24.48	18.10	21.30	55.97	58.60	3662	3993	1.956	1.996
T_7	27.33	29.08	21.53	25.67	59.78	62.95	4385	4502	2.002	2.071
T_8	31.24	33.14	25.40	29.93	63.38	66.53	4917	5140	2.141	2.185
T_9	14.90	16.31	10.77	13.00	48.91	50.05	1771	2682	1.808	1.826
SEM±	0.66	0.63	0.53	0.56	1.00	1.02	111	120	0.052	0.047
CD (p=0.05)	1.99	1.89	1.58	1.67	2.99	3.06	334	360	0.157	0.141

Treatment details are given under Materials and Methods.

produced increased stalk yield. Increased DMP due to the application of more quantity of nitrogen with (50 kg/ha) or without potassium (0 kg/ha) had resulted higher stalk yield of quinoa. The discussions made in the grain yield also hold good for the stalk yield of quinoa.

Economic parameters: The alteration of economic parameters for quinoa during the late *kharif* and *rabi* seasons, as affected by different nutrient management treatments, is given in Table 3. The highest cost of cultivation, gross returns, net returns, and benefit-to-cost ratio during the late *kharif* season (₹79,705/ha, ₹208,624/ha, ₹128,919/ha and 2.62, respectively) and *rabi* season (₹84,605/ha, ₹291,120/ha, ₹206,515/ha and 3.44, respectively) was realised with the application of 150:50 kg N: K_2O/ha (T_8), followed closely

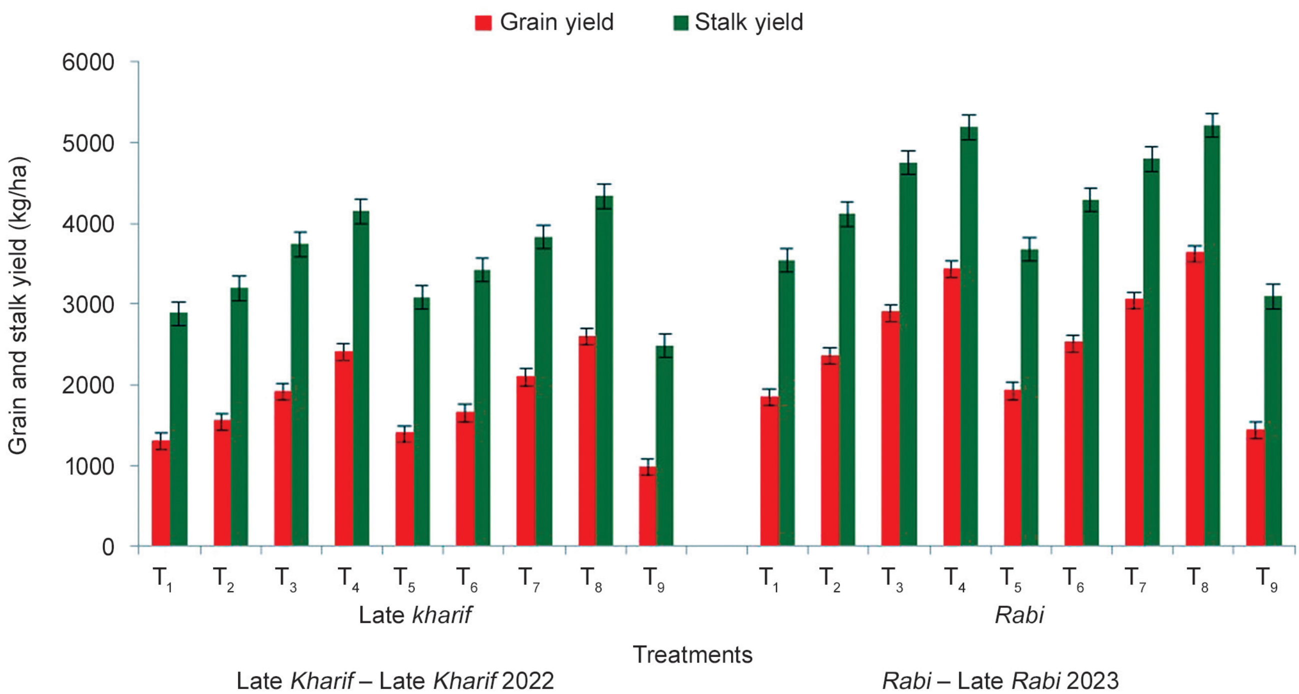

Fig. 1 Effect of nutrient management on the yield of quinoa.
Vertical bars indicate the standard error. Treatment details are given under Materials and Methods.

Table 3 Effect of nutrient management on the economics of quinoa

Treatments	Cost of cultivation (₹/ha)		Gross returns(₹/ha)		Net returns (₹/ha)		B: C ratio	
	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)	Late *kharif* (2022)	*Rabi* (2022–23)
T_1	77,166	82,066	105,104	148,480	27,938	66,414	1.36	1.81
T_2	77,485	82,385	124,560	189,733	47,075	107,349	1.61	2.30
T_3	77,803	82,703	154,171	232,133	76,367	149,430	1.98	2.81
T_4	78,128	83,028	193,861	275,440	115,734	192,412	2.48	3.32
T_5	78,743	83,643	112,211	154,880	33,468	71,237	1.43	1.85
T_6	79,062	83,962	133,227	202,133	54,165	118,172	1.69	2.41
T_7	79,380	84,280	168,832	244,600	89,452	160,320	2.13	2.90
T_8	79,705	84,605	208,624	291,120	128,919	206,515	2.62	3.44
T_9	73,650	78,550	79,120	115,867	5,470	37,317	1.07	1.48

Cost of quinoa, ₹80.00/kg. Data not statistically analysed. Treatment details are given under Materials and Methods.

by the 150:0 kg N: K_2O/ha (T_4) treatments. Quinoa applied with the highest dose of fertilisers (150:50 kg N: K_2O/ha) resulted in higher fertiliser and application costs leading to increased cost of cultivation. Increased grain yield in the T_8 treatment and closely followed by the T_4 treatment, led to higher gross returns than other treatments. Higher gross returns with a small increase in the cost of cultivation resulted in increased net returns and benefit-cost ratio in these treatments. Higher gross returns, net returns, and benefit-cost ratio with the increased application of nutrients to quinoa were also reported by Shams (2012). The minimum cost of cultivation was obtained with the control (T_9) due to the minimum usage of fertilisers. Poor grain yield in the control treatment was the sole reason for the least gross returns, net returns, and benefit-cost ratio.

Two seasons of field experiments concluded that quinoa is highly responsive to the applied fertilisers. Compared to other primary nutrients, nitrogen influenced more on the growth and yield of quinoa. Precisely, the application of 150:30:50 or 150:30:0 kg N: P_2O_5: K_2O/ha resulted in significantly higher growth, yield parameters, yield, and economic parameters of quinoa. Hence, 150 kg/ha of nitrogen and 30 kg/ha of phosphorus with (50 kg/ha) or without (0 kg/ha) potassium can be recommended for the profitable cultivation of quinoa in India.

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