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Comparison of different plant densities and fertilization on growth and yield attributes of Quinoa (*Chenopodium quinoa* Wild.) under the Eastern zone of Uttar Pradesh, India

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ABSTRACT

To investigate the effect of spacing and nitrogen level on Quinoa growth and yield, a field experiment was conducted at the Crop Research Farm, Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj (UP) in 2019-20 and 2020-21. The Split Plot Technique was used to duplicate 20 treatments with varying combinations of crop stand geometry and nitrogen delivery doses using urea. The major goal of the study was to determine how crop stand geometry and nitrogen treatment dosages affected Quinoa development and yield. Crop stand geometry include (15 x 10) cm, (25 x 10) cm, (35 x 10) cm, and (45 x 10) cm, with nitrogen management options including control, 25 Kg/ha, 50 Kg/ha, 75 Kg/ha, and 100 Kg/ha of RDN. Growth attributes *viz.*, leaf area and number of leaves significant and maximum were recorded in the treatment spacing and (S_4) crop spacing 45cm x 10 cm except leaf area index because it was recorded in (S_1) crop spacing 15 cm x 10 cm, respectively. Based on the data obtained of yield and yield attributes significant and maximum by planting (S_1) crop spacing 15cmx10cm (Grain yield, 2.35 and 2.33 t/ha) and (S_4) crop spacing 45 cm x 10 cm spacing (Number of panicle per plant, 19.75 and 16.93) and (Number of spikelet's per panicle, 18.67 and 16.65) during both the year, respectively. Nitrogen management treatment rate of 100 kg/ha of RDN was recorded significant and maximum growth attributes and yield attributes (Number of panicle per plant, 19.32 and 16.34), (Number of spikelet's per panicle, 18.78 and 18.02) (Grain yield, 2.27 and 2.30 t/ha) during both the year, respectively.

Key words: *Quinoa, RDN, Crop Stand geometry, Nitrogen, Growth, Yield*

Introduction

Quinoa (*Chenopodium quinoa* Wild.) is a high-nutrition food crop that has been produced for thousands of years in South America. It contains exceptional protein content and a wide spectrum of vitamins and minerals that give nutraceutical benefits to customers, making it a potential cereal substitute (James, 2009). Quinoa is also twice as high in essential amino acids and protein as cereal grains, earning it the moniker "functional food" (Graf *et al.* 2015). It's an annual herbaceous plant with a growing season ranging from 70 to 200 days and a wide range of adaptability (Ramesh *et al.* 2019). This crop is becoming increasingly popular since its seeds are suitable for human eating and have a high nutritional

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value. Quinoa's adaptability to a wide range of ecological zones contributes to its widespread production. Quinoa, in other words, could survive at altitudes of 4000 metres and temperatures of -8 to 38 degrees Celsius. Despite its vast geographical distribution, significant production differences have been documented depending on cultivar, soil, water, cultivation practises, and climate changes (Scanlin and Lewis, 2017).

Adoption of proper crop cultivation measures ensures that the crop environment is conducive for optimal development and yield (Bilalis *et al*., 2012; Roussis *et al*., 2019). Soil nutrient management is one of the most important agronomic management techniques for controlling plant growth and yield potential. However, it's a proven fact 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). So optimization of proper cultivation practices is necessary to get better yields from the crop. However, In comparison to other countries, India's quinoa productivity is poor (Ramesh *et al*., 2019). This could be owing to the lack of optimization of an appropriate nutrition and planting density management system in India. So, by following an optimum nutritional and spatial management of the crop, it is possible to increase the development and yield potential of quinoa.

Row spacing manipulations have an impact on crop productivity. As the row spacing increases, the crop plant density lowers, allowing the crop to more effectively access nutrients, light, and water due to less competition among plants for these resources. As a result, the yield potential increases whereas plants that are spaced closer together display phytochrome-mediated responses, which results in narrow leaves, long stems, and decreased root mass contributing to decline in crop yield potential (Kasperbauer and Karlen, 1994; Castilla, 2013). As a result, optimising row spacing is critical if we want to get improved crop yields.

It was recently revealed that increasing the nitrogen application rate boosts the seed yield and protein content of the quinoa plant (Taylor and Parker, 2002). According to certain reports, greater nitrogen application lowers seed production due to lodging and late maturity (Oelke *et al*., 1992). As a result, optimizing an appropriate dose of nitrogen application rate is critical if Quinoa plants are to achieve a better growth and yield potential.

Materials and Methods

The experiment took place in the Crop Research farm of the department of Agronomy, Naini Agricultural Institute, (25° 24' 42" N latitude and 81° 50' 56" E longitude) during the growth seasons 2019-20 and 2020-21. The experiment employed a split plot design with four row spacing levels (15 cm × 10 cm, 25cm x10cm, 35cm x10cm, and 45 cm × 10 cm) as main plots and five nitrogen fertilization levels (0 kg/ha as control, 25 kg/ha, 50 kg/ha, 75 kg/ha, and 100 kg/ha) as sub-plots. Three replication each treatment was carried out.

The leaf area of the leaves of the crop was measured by using millimeter graph paper method as proposed by Pandey and Singh (2011). Leaf area index (LAI) was determined at 80 and harvest respectively by following the formula of Williams (1946):

Leaf area index (LAI): (Leaf area per plant)/ (Ground area occupied by the plant)

When the plants reached maturity, yield characteristics such as the number of panicles per plant and the number of spikelet's per panicle were recorded. After the plants achieved harvestable maturity and had a moisture content of roughly 10-12 percent after sun drying, the grain yield per plot was recorded and afterwards converted to yield per hectare.

Table 1. Quantity and used formula in fertilizers

Sr. No.	Treatments	Source	Fertilizer formula	Quantity of fertilizer
1.	N_0: Control	-	Nutrient (kg/ha)/Nutrient in fertilizer (%) *100	Nil
2.	N_1: N applied 25 kg/ha of RDN	Urea	Nutrient (kg/ha)/Nutrient in fertilizer (%) *100	54.34 kg
3.	N_2: N applied 50 kg/ha of RDN	Urea	Nutrient (kg/ha)/Nutrient in fertilizer (%) *100	108.69 kg
4.	N_3: N applied 75 kg/ha of RDN	Urea	Nutrient (kg/ha)/Nutrient in fertilizer (%) *100	163.04 kg
5.	N_4: N applied 100 kg/ha of RDN	Urea	Nutrient (kg/ha)/Nutrient in fertilizer (%) *100	217.39 kg

Statistical analysis

ANOVA was used to assess the effects of row spacing and nitrogen level on quinoa growth and yield characteristics. To compare the means, Fisher's least significant difference test was performed (LSD). The data collected throughout the inquiry was subjected to statistical analysis using the analysis of variance approach (Fisher, 1950).

Results and Discussion

Effect of crop stand geometry (S)

Significant and maximum leaf area (894.45 and 885.50 cm^2) and (754.95 and 746.00 cm^2), and number of leaves (109.76 and 107.11) and (87.94 and 84.15) at 80 DAS and harvest under the treatment sown by the (S_4) Crop spacing (45 cm x10cm), respectively, based on data (Table 2). During both years, however, the treatment (S_1) Crop spacing (15 cmx10 cm) had the largest leaf area index (3.37 and 3.40) and (3.25 and 3.28) correspondingly. It could be because crops grown at optimal spacing efficiently utilize available resources, resulting in increased crop height, increased leaf area index, and increased sun light capture, allowing the plant to use photosynthesis more efficiently, resulting in increased dry matter accumulation and increased leaf area (Golla *et al.*, 2018).

It was discovered that when the crop size decreased, grain output increased gradually. This could be because a larger number of plants could be accommodated in a smaller plant spacing, whereas in a larger plant spacing, the plants were more or less equidistant, allowing plants to make more efficient use of water, nutrients, and sunlight, resulting in the production of more grains that were nearly on par with the treatments with narrower spacing. These results were in agreement with the findings reported by Sief *et al*. (2015) and Ramesh *et al*. (2017). However, we also observed that with increase in nitrogen level, the grain yield per ha increased. This might be due to the fact that increase in nitrogen level leads to increase in vegetative growth of the plant. The plant produces more number of leaves and leaf area index of the leaves also gets increased due to application of nitrogen. This ultimately leads to a higher photosynthetic rate and photosynthate

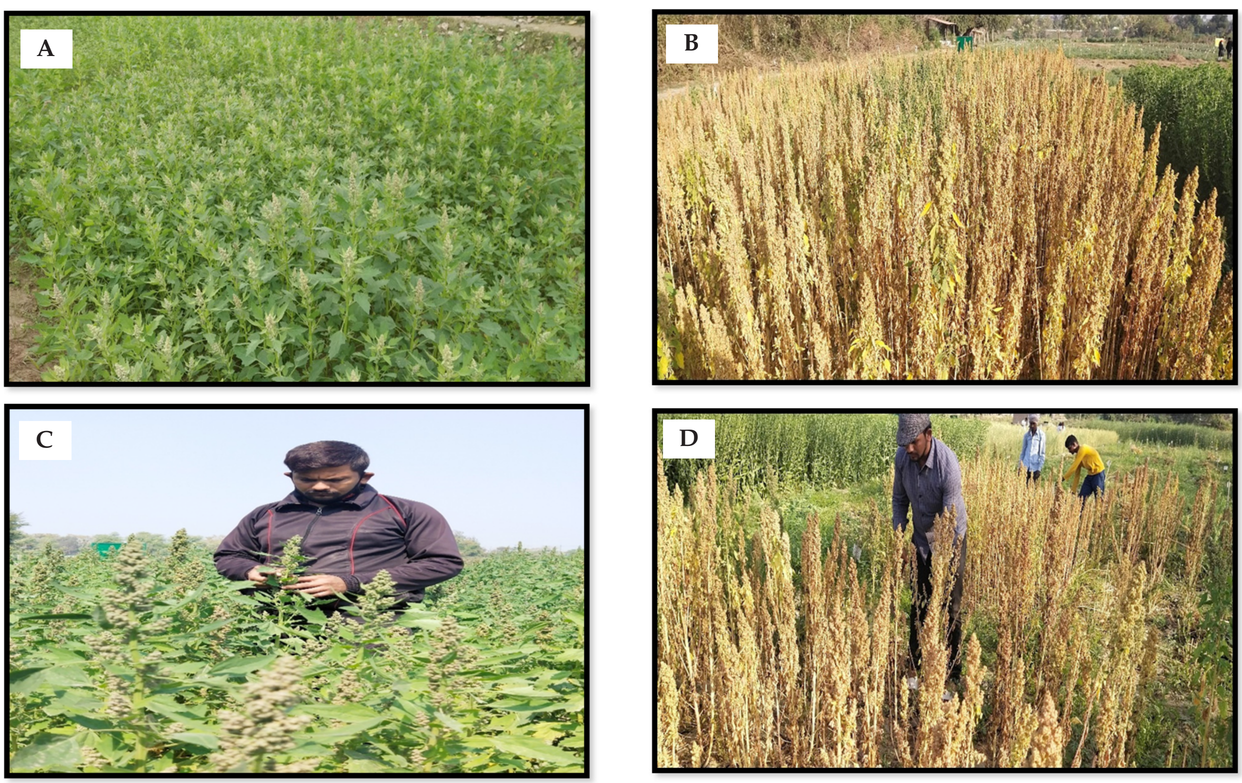

Fig. 1. A and B at 80 DAS and harvest stage 2019-20 for observation to be recorded during C and D at 80 DAS and harvest stage for plant growth observation to be recorded during 2020-21

Table 2. Effect of crop stand geometry and nitrogen management approach on Leaf area index of quinoa (*Chenopodium quinoa* Willd).

Treatments	Leaf area				Leaf area index				Number of Leaves			
	80DAS		At harvest		80DAS		At harvest		80DAS		At harvest	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Crop stand geometry (S)												
S_1: Crop spacing (15 × 10cm)	505.23d	509.41c	487.23c	491.41c	3.37a	3.40a	3.25a	3.28 a	78.37d	76.63d	52.55d	49.16d
S_2: Crop spacing (25 × 10cm)	644.98c	672.85b	582.48b	610.35b	2.58b	2.69b	2.33b	2.44b	90.77c	90.31c	65.70c	61.73c
S_3: Crop spacing (35 × 10cm)	799.95b	813.53a	701.95a	715.53a	2.29c	2.32c	2.01c	2.04c	99.15b	100.98b	76.46b	71.97b
S_4: Crop spacing (45 × 10cm)	894.45a	885.50a	754.95a	746.00	1.99d	1.97d	1.68d	1.66d	109.76a	107.11a	87.94a	84.15a
F-test	S	S	S	S	S	S	S	S	S	S	S	S
SEm±	25.37	33.06	25.37	33.06	0.077	0.093	0.077	0.093	1.89	1.54	1.53	1.44
CD (P=0.05)	87.79	114.43	87.79	114.43	0.266	0.323	0.266	0.323	6.55	5.33	5.31	4.98
CV (%)	13.81	17.78	15.55	19.98	11.662	13.947	12.871	15.369	7.75	6.37	8.41	8.35
Nitrogen management approach through urea (N)												
N_0: Control	623.07c	636.73d	543.57c	557.23d	2.26c	2.33d	2.02c	2.09d	87.73b	86.76b	67.82c	64.02c
N_1: Nitrogen applied 25 kg/ha of RDN	650.41b	666.41c	570.91b	586.91c	2.40b	2.46c	2.16b	2.22c	95.19a	93.85a	70.21b	65.86b
N_2: Nitrogen applied 50 kg/ha of RDN	729.30a	720.96b	649.80a	641.46b	2.60a	2.58b	2.36a	2.34b	95.01a	94.54a	70.55b	66.58b
N_3: Nitrogen applied 75 kg/ha of RDN	769.30a	759.60a	689.80a	680.10a	2.73a	2.72a	2.49a	2.48a	96.49a	96.45a	71.24a	67.63a
N_4: Nitrogen applied 100 kg/ha of RDN	783.69a	817.92a	704.19a	738.42a	2.79a	2.88a	2.55a	2.64a	98.13a	97.20a	73.49a	69.67a
F-test	S	S	S	S	S	S	S	S	S	S	S	S
SEm±	30.06	24.61	30.06	24.61	0.090	0.078	0.090	0.078	1.26	1.51	0.91	0.88
CD (P=0.05)	87.00	71.21	87.00	71.21	0.260	0.225	0.260	0.225	3.66	4.36	2.62	2.55
CV (%)	14.64	11.83	16.48	13.30	12.179	10.368	13.442	11.424	4.64	5.56	4.44	4.57

RDN: Recommended dose of nitrogen (N_1-54.34 kg/ha, N_2-108.69 kg/ha, N_3-163.04 kg/ha, N_4-217.39 kg/ha) translocation from source to sink of the plant to promote. In case of yield attributes (Table 3) *viz.*, Number of panicle per plant (19.75 and 16.93), Number of spikelet's per panicle (18.67 and 16.65) were recorded significant and maximum under the treatment when crop sowed with the spacing of raw to raw and plant to plant (S_4) Crop spacing (45 × 10cm), during both the years, respectively. However, grain yield (2.35 and 2.33 t/ha) of crop significantly the highest was recorded under the treatment (S_1) Crop spacing (15 × 10 cm), during both the years, respectively. It could be due to seed drill planting with a 45 x 10 cm spacing, which results in an increased light interception and a lower light transmission ratio, as well as wider spacing sowing of the cover crop, which lowers photosynthetic efficiency. Plants grown widely apart will not have to compete for resources in any way. They may have greater yield attributes per plant than plants that are more crowded.It may be due to wider crop spacing, the plant used nutrients, water and sunlight efficiently. As a result, the plant produced more number of branches per plant, thus there was more number of panicles per plant due to wider spacing as compared to closer spacing. This result was in confirmation with the findings of Chaudhari *et al.* (2009).

Effect of nitrogen management approach through urea (N)

Leaf area was significantly larger (Table 2) in the treatment (N_4) Nitrogen administered 100 kg/ha of RDN, with values of (783.69 and 817.92 cm^2) and (704.19 and 738.42 cm^2), respectively, for both years. Furthermore, during both years, the leaf area index (2.79 and 2.88) and (2.55 and 2.64) as well as the number of leaves (98.13 and 97.20) and (73.49 and 69.67) were considerably greater in similar treatments. It's possible that the increased number of leaves and likely higher chlorophyll content under higher nitrogen levels caused the crop to be more photosynthetically active, resulting in more leaf area at all growth stages. Thanunathan *et al.* (2002) and found similar results (2005).

Crop fertilized by the nitrogen management (Table 3) treatment (N_4) Nitrogen applied 100 kg/ha of RDN significant and maximum was recorded number of panicle per plant (19.32 and 16.34), number of spikelet's per panicle (18.78 and 18.02) and grain yield (2.27 and 2.30 t/ha) during both the year, respectively. Kamiji *et al.* (2011) demonstrated that nitrogen administration is extremely beneficial in boosting spikelet generation, and we obtained comparable findings in our investigation. The number of secondary branches on the panicle and the length of

Table 3. Effect of crop stand geometry and nitrogen management approach on yield attributing traits of quinoa

Treatments	Number of panicle per plant		Number of spikelet's per panicle		Grain yield t/ha	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Crop stand geometry (S)						
S_1: Crop spacing (15 × 10cm)	16.13b	13.03c	13.98c	12.46b	2.35a	2.33a
S_2: Crop spacing (25 × 10cm)	17.03b	14.48bc	15.45bc	13.61b	1.77b	1.76b
S_3: Crop spacing (35 × 10cm)	17.73a	14.71b	16.76b	14.14b	1.74b	1.57c
S_4: Crop spacing (45 × 10cm)	19.75a	16.93a	18.67a	16.65a	1.59c	1.49c
SEm±	0.678	0.428	0.511	0.549	0.034	0.048
CD (P=0.05)	2.347	1.480	1.63	1.899	0.12	0.17
CV (%)	14.876	11.204	12.190	14.952	6.97	10.53
Nitrogen management approach through urea (N)						
N_0: Control	15.82c	12.76d	14.54d	9.96c	1.42c	1.25d
N_1: Nitrogen applied 25 kg/ha of RDN	17.23bc	14.32c	15.19c	10.74b	1.79b	1.66c
N_2: Nitrogen applied 50 kg/ha of RDN	17.39b	14.59b	15.69b	13.40b	1.89b	1.81b
N_3: Nitrogen applied 75 kg/ha of RDN	18.54a	15.93a	16.91b	18.96	1.95b	1.90b
N_4: Nitrogen applied 100 kg/ha of RDN	19.32a	16.34a	18.78a	18.02a	2.27a	2.30a
SEm±	0.520	0.505	0.400	1.027	0.065	0.067
CD (P=0.05)	1.505	1.462	1.18	2.971	0.19	0.19
CV (%)	10.201	11.835	8.541	25.020	12.16	13.07

RDN: Recommended dose of nitrogen (N_1-54.34 kg/ha, N_2-108.69 kg/ha, N_3-163.04 kg/ha, N_4-217.39 kg/ha) the panicle are major indicators of spikelet. As a result, the number of spikelet was connected to the length of the panicle and the number of secondary branches in a substantial and favorable way. The longer panicle and more branches gave more area for spikelet to grow, resulting in a higher spikelet density per panicle. It could be due to increased essential nitrogen nutrient availability for plant growth, increased photosynthesis efficiency, chlorophyll formation, healthy and greenish vegetative growth, and improved disease and insect resistance due to more quantity treatment of nitrogen N_4 100 RDF through urea with split dose. Other reason increased the nitrogen level it fulfill the requirement of the growth and development of critical plant tissues and cells such as cell membranes, chlorophyll and a component of nucleic acid, which creates DNA, which is important for the transmission of particular agricultural traits and qualities that help plant survival. It also aids in the preservation of the genetic code in the nucleus of the plant. Chlorophyll is an organelle that is required for carbohydrate creation during photosynthesis and is responsible for the plant's green colour. Nitrogen is a component of chlorophyll that helps to enhance these characteristics. Photosynthesis and other plant functions require nitrogen. As a result, plants with sufficient nitrogen will experience high rates of photosynthesis and will grow and develop rapidly. Increase in level of Nitrogen leads to increase in Nitrogen availability for the plants of Quinoa. The increased Nitrogen Use Efficiency leads to increased photosynthetic rate. The increased photosynthetic rate leads to profuse vegetative growth and increase in number of branches per plant. The results were in conformity with the findings of Ramesh *et al.* (2017).

Conclusion

It study recommended to the farmer quinoa crop variety EC507740 spacing of 15cm × 10cm or 45cm × 10cm ensure better crop performance. Further, in nitrogen management nitrogen application @ 100 kg/ha of RDN will ensure better crop growth attributes, yield potential than rest other treatments.

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