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Influence of crop geometry and nitrogen levels on growth indices of quinoa (*Chenopodium quinoa* Willd.)

Lalit Kumar Sanodiya, Umesha C, Mesharm MR and Randhir Kumar

Abstract
Crop spacing is very important management practices for efficient crop production and nitrogen takes part in many physiological and biochemical plant processes and is a structural unit of amino acids, nucleic acids, enzymes and proteins, chlorophyll, and cell wall. Efficient crop management through spacing and with fertilization is necessary in both economic and environmental terms. This minimizes nutrient losses to the environment while producing optimum crop yields. A field experiment was conducted during *Rabi* season of 2019-20 and 2020-21 at experimental field of Crop Research Farm, Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj (U.P.) to determine the "Influence of Crop Geometry and Nitrogen Levels on Growth Indices of Quinoa (*Chenopodium quinoa* Willd.)". The experiment consisted of four crop geometry (15 cm × 10 cm, 25 cm × 10 cm, 35 cm × 10 cm, 45 cm × 10 cm,) and five doses of nitrogen (control, 25, 50, 75 and 100 kg/ha). The experiment was arranged in a statistical design of Split Plot Design (SPD) with three replications. Report of study indicate that, among different nitrogen levels the application of 100 kg N/ha at 45cm × 10 cm spacing produced significantly superior plant dry weight (30.77 and 33.61 g) and AGR (1.18 and 0.17 g/day). The highest AGR produced by the 60-80 DAS application of 100 kg N/ha at 35 cm × 10 cm spacing. However, the highest CGR produced by the 60-80 DAS application of 100 kg N/ha at 15 cm × 10 cm was found to be significantly. However, the highest RGR absorbed at 25 kg N/ha at 35 cm × 10 cm was found to be non-significant.

Keywords: Quinoa, nitrogen level, spacing, AGR, CGR, RGR

Introduction
Quinoa (*Chenopodium quinoa* willd.*)* a pseudo-cereal crop and member of *Chenopodiaceae* family and chromosome number is 2n=36. There is a marked increase in the available information about genetics of quinoa, *viz.*, its allo-tetraploid nature, self-pollination and small flowers. Quinoa is considered to be "Golden grains", also seed is "Power food", "complete food" and "Mother of all grains". It is nutritionally, termed as "Super-food" by dieticians and nutritionists. Saponin-free or sweet quinoa varieties are currently available being 'Atlas' the first one launched outside of the Andean region (Jacobsen, 2015). It is a seed crop that has been cultivated for thousands of years for its nutritious grain and leaves (Geren, 2015) [5]. It is an annual broad-leaved plant, also adaptable to the conditions of marginal lands (Rana *et al*., 2009) [13]. Quinoa is a quick-rising plant, grows up to 2 m tall with exchange, thickly ragged, triangular to ovate vegetation. Every inflorescence produced hundreds of little achiness, approximately 2 mm in width. Quinoa is an achene (a seed-similar to fruit with a firm fur) with diversified colours ranging from white or pale yellow to orange, red, brown and black. An ideal average temperature for quinoa would be around 15–20°C, but some specific landraces can also withstand extreme temperatures from −8°C to +38°C (Bazile *et al*., 2015) [3]. It is only the single food which can supply complete protein, all essential life sustaining nutrients and can reduce the risk of various diseases like blood cholesterol, blood pressure, diabetes, sexual weakness etc. in very effective and preventive way. The seeds of quinoa can be ground into flour and used in the same way as a cereal grain for either direct consumption or food development. Despite their similarities with cereals, quinoa, amaranths and kaniwa (*Chenopodium pallidicaule)* do not belong to the family *Gramineae*. For this reason, they are botanically defined as pseudo-cereals instead of cereals. The organization of the United Nations for Food and Agriculture (FAO) has declared the year 2013 as the "year of quinoa" (Anonymous, 2013). Quinoa is mainly used for cooking, baking, and various value added products for people allergic from gluten, animal feed, green fodder, and pellets (Jacobson, 2003). Quinoa has been introduced to Europe, North America, Asia, and Africa.

Quinoa is a traditional crop in South America, particularly in the regions around the Andes Mountains where subsistence farming is common (Jacobsen 2003; Bhargava *et al*., 2006) [4, 7]. In India, the area under quinoa cultivation during 2017-18 was 8630 hectares and production 20.626 million tons. Andhra Pradesh, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra and Tamil Nadu are major quinoa growing states.

The plant development is mainly affected by plant stand, planting geometry, soil fertility and soil-moisture availability. Among these factors, planting geometry is one of the main factor in which row spacing plays an important role in plant development (Rajput *et al.*, 1993) [11]. Optimum row spacing plays an important role for obtaining having thick plant population will not get proper light for photosynthesis and it can easily be attacked by disease. In other constraints, less plant population will also reduce the yield. Due to these reasons, optimum population is necessary for high yield (Bashir, 1994) [2]. The canopy population of leaves, as the main organ of photosynthesis, is affected by nitrogen. Appropriate nitrogen application rate could ensure that the crop canopy population reached a higher LAI. In addition, the formation of seed quality is also closely related to nitrogen (Zhang *et al*, 2020) [22]. Considering the above facts, the present study was undertaken to study the influence of Crop Geometry and Nitrogen Levels on Growth Indices of Quinoa (*Chenopodium quinoa* Willd.).

Materials and Methods

The field experiment was conducted during *Rabi* season of 2019-20 and 2020-21, at the experimental area of the Crop Research Farm, Department of Agronomy, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj (U.P.), Geographically, Prayagraj is located at 25º 24' 42" N latitude, 81º 50' 56" E longitudes and at an altitude of 98 m above the mean sea level. The average annual rainfall during the cropping season namely 2019-20 and 2020-21 *rabi*, rainfall was 21.40 mm received 1 rainy day and 18.60 mm received 1 rainy day, respectively. Climate is sub-tropical and semi-arid. With both extremes of temperature, i.e., winter and summer the year. The soil chemical analysis revealed that soil was central Gangetic alluvium is neutral and deep on sandy clay loam soil of Eastern Uttar Pradesh condition, normal to saline (pH 7.78 and 7.65) medium in organic carbon (0.42% and 0.43%) and potassium (256.44, 260.44 kg/ha), high in available phosphorus (20.05, 22.85 kg/ha). The electrical conductivity of the soil was 0.29, 0.31 dS/m. The experiment was laid out in Split Plot Design (SPD), having four, crop geometry (15 cm × 10 cm, 25 cm × 10 cm, 35 cm × 10 cm, 45 cm × 10 cm,) and five doses of nitrogen (control, 25, 50, 75 and 100 kg/ha). There were twenty treatments replicated thrice, with plot size of 12 m^2 (4 m × 3 m) each. Twenty treatments combinations, comprising (*i*) 15 cm × 10 cm spacing + Control (*ii*) 15 cm × 10 cm spacing + 25 kg N/ha (*iii*) 15 cm × 10 cm spacing + 50 kg N/ha (*iv*) 15 cm × 10 cm spacing + 75 kg N/ha (*v*) 15 cm × 10 cm spacing + 100 kg N/ha (*vi*) 25 cm × 10 cm spacing + Control (*vii*) 25 cm × 10 cm spacing + 25 kg N/ha (*viii*) 25 cm × 10 cm spacing + 50 kg N/ha (*ix*) 25 cm × 10 cm spacing + 75 kg N/ha (*x*) 25 cm × 10 cm spacing + 100 kg N/ha (*xi*) 35 cm × 10 cm spacing + Control (*xii*) 35 cm × 10 cm spacing + 25 kg N/ha (*xiii*) 35 cm × 10 cm spacing + 50 kg N/ha (*xiv*) 35 cm × 10 cm spacing + 75 kg N/ha (*xv*) 35 cm × 10 cm spacing + 100 kg N/ha (*xvi*) 45 cm × 10 cm spacing + Control (*xvii*) 45 cm × 10 cm spacing + 25 kg N/ha (*xviii*) 45 cm × 10 cm spacing + 50 kg N/ha (*xix*) 45 cm × 10 cm spacing + 75 kg N/ha (*xx*) 45 cm × 10 cm spacing + 100 kg N/ha. Crop variety 'EC507740 (AICRP UAS Bangalore)' was seeded manually on first fortnight of November and harvested on first fortnight of February. The crop geometry was maintained as per the spacing prescribed for the particular treatments. The N was applied as specified by the treatments while the P and K fertilizers were applied at 50 and 50 kg/ha in all the treatments. Nitrogen, phosphorus and potassium were supplied through urea, single super phosphate and muriate of potash respectively. Full dose of phosphorus and potassium were applied uniformly as basal to all the plots. Half dose of nitrogen was applied as basal and remaining half dose applied two split dose 30, 45 days after sowing. The observation on growth parameters *viz.* plant height, number of leaves and dry weight were taken at 20, 40, 60, 80 and 100 days after sowing. The data on growth indices i.e. Absolute growth rate (AGR), Crop growth rate (CGR) and Relative growth rate (RGR) was evaluated as per standard process. Measurement of Absolute growth rate (AGR) was calculated by adopting the formula suggested by Kvet *et al.* (1971) [10], AGR = $(W2 - W1)/(T2 - T1)$ and expressed in g/plant/day. Crop growth rate (CGR) is the increase in plant dry materials per unit area of land per unit time. CGR values were estimated at 20-day interval as described by Watson (1952) [20], CGR was calculated using the formula CGR = $[(W2 - W1)/(T2 - T1)][1/S]$, where $W1$ is total dry weight at time $T1$ and $W2$ is the total dry weight at time $T2$ and S is the ground spacing and expressed in g/m^2/day. The RGR was determined by adopting the formula suggested by Williams (1946) [21], RGR = $(\ln W1 - \ln W2)/(T1 - T2)$, where $W1$ is total dry weight at time $T1$, $W2$ is total dry weight at time $T2$, and ln is natural logarithm and expressed in g/g/day. All the data were subjected to analysis of variance (ANOVA) by using a split-plot design and main effects and interactions were tested for significance. Treatment means obtained by ANOVA were compared using critical difference (CD) at P=0.05 level of significance (Gomez and Gomez, 1984) [6].

Results and Discussion

Effect on dry weight (g)

The data concerned with dry weight per plant as influenced by different treatment combinations during the year 2019-20 and 2020-21 has been depicted in table 1. The data showed that the dry weight of plant increased with the growth of the plant. Crop spacing had a non-significant effect on dry weight per plant at 20 DAS, 40 DAS and 60 DAS. Among the four crop stand geometry, highest dry weight per plant (30.77 and 33.61 g) at 80 DAS and at harvest was influence significantly in treatment S4 (45cm×10cm), respectively. While observations recorded in S2 (25cm×10cm) and S3 (35cm×10cm) were statistically at par with the treatment S4 and lowest dry weight per plant (24.03 and 25.98 g) was recorded in treatment S1 (15cm×10cm).

Table 1: Influenced by crop stand geometry and nitrogen management approach on dry weight per plant (g) at different growth interval of quinoa (Two year pooled analysis).

Treatments	Dry weight (g) per plant				
	20 DAS	40 DAS	60 DAS	80 DAS	At harvest
Crop stand geometry (S)					
S_1: Crop spacing (15 × 10cm)	0.063	0.619	5.96	24.03	25.98
S_2: Crop spacing (25 × 10cm)	0.069	0.798	6.78	29.08	30.67
S_3: Crop spacing (35 × 10cm)	0.071	1.004	6.96	30.56	33.14
S_4: Crop spacing (45 × 10cm)	0.076	1.117	7.51	30.77	33.61
F-test	NS	NS	NS	S	S
SEm(±)	0.004	0.11	0.43	0.51	0.76
CD (P=0.05)	0.015	0.38	1.51	1.77	2.63
CV (%)	23.913	47.94	24.76	6.92	9.56
Nitrogen management approach through urea (N))					
N_0: Control	0.068	0.861	5.37	20.49	23.52
N_1: Nitrogen applied 25 kg/ha of RDN	0.067	0.985	6.19	24.77	27.51
N_2: Nitrogen applied 50 kg/ha of RDN	0.071	0.755	6.73	29.07	31.34
N_3: Nitrogen applied 75 kg/ha of RDN	0.076	0.708	7.19	32.19	33.78
N_4: Nitrogen applied 100 kg/ha of RDN	0.067	1.11	8.54	36.52	38.08
F-test	NS	NS	S	S	S
SEm(±)	0.005	0.17	0.28	0.62	0.73
CD (P=0.05)	0.016	0.51	0.80	1.80	2.11
CV (%)	27.024	68.35	14.12	7.52	8.18

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).

In case of Nitrogen level had non-significant influence on dry weight per plant at 20 DAS and 40 DAS, however, significant effect of nitrogen level on dry weight per plant was recorded at 60, 80 DAS and at harvest. At 60, 80 DAS and at harvest highest dry weight per plant (8.54, 36.52 and 38.08gm) was recorded in the treatment N4 (100 kg/ha of RDN) followed by N3 (75 kg/ha of RDN), N2 (50 kg/ha of RDN) and N1 (25 kg/ha of RDN) and N3 were statistically at par with each other. The increase in dry weight of the plant can be attributed to proportionately increase with spacing between plants (Barzinjy *et al*., 1999) [1]. This increase in dry matter might be due to lesser competition for nutrients, water, and light. Similar results were also reported by Kumari (2009) [9], Sharma *et al*. (2001) [16, 17] and Al-Ramamneh *et al*. (2013) [12]. There was also an increase in dry weight of plant with increase in level of dose of Nitrogen. Nitrogen is one of the most influential factor affecting yield and biomass of plant through its influence on photosynthetic capacity per unit area of the leaf and leaf area index (receiving radiation) (Tuli, 1965). According to experts, the presence of nutrients in a plant, can regulate the plant's growth rate (Tesar, 1984) [18]. The nitrogen given to the leaf improves nitrogen use efficiency and thus leading to absorption of carbon-di-oxide and production of dry matter.

Absolute Growth Rate (AGR)

Periodical observation of data concerned with absolute growth rate (AGR, g/plant/day) has been depicted in Table 2. The crop stand geometry at initially showed non-significant effect on absolute growth rate at 20-40 and 40-60 DAS. However at 60-80 DAS and 80-at harvest were showed significant effect. Absolute growth rate 0.05 and 0.32 g/plant/day were recorded significantly maximum with spacing S_4: Crop spacing (45 cm x 10 cm) at 60-80 and 80 DAS-at harvest and found superior among rest of the spacing. While in case of Nitrogen levels, maximum absolute growth rate 0.37 and 1.40 g/plant/day were recorded significantly with N_4: Nitrogen applied @ 100 kg/ha which was statistically on par to Nitrogen application of N_3: 75 kg/ha at 40-60. The results are in conformity with the James Lowell Fowler (1996) [8] who reported that the absolute growth rate was significantly higher in high plant densities however the absolute growth rate or efficiency of the leaf surface in producing dry matter was reduced as plant population increased. This was apparently the result of less favorable light relationships or perhaps some other modification of the micro-environment of the crop as a result of the moderating effect of the leaf canopy in the closer spacing's Sangeeta and Surakod (2018) [15].

Table 2: Influenced by crop stand geometry and nitrogen management approach on absolute growth rate (AGR) at different growth interval of quinoa (Two year pooled analysis).

Treatments	Absolute Growth Rate (AGR) (g/plant/day)			
	20-40 DAS	40-60 DAS	60-80 DAS	80-at harvest
Crop stand geometry (S)				
S_1: Crop spacing (15 × 10cm)	0.03	0.27	0.90	0.06
S_2: Crop spacing (25 × 10cm)	0.04	0.29	1.12	0.12
S_3: Crop spacing (35 × 10cm)	0.05	0.30	1.18	0.14
S_4: Crop spacing (45 × 10cm)	0.05	0.32	1.16	0.17
F-test	NS	NS	S	S
SEm(±)	0.006	0.024	0.040	0.015
CD (P=0.05)	0.019	0.081	0.138	0.051
CV (%)	52.31	30.78	14.19	45.83
Nitrogen management approach through urea (N))				
N_0: Control	0.04	0.23	0.76	0.14

N_1: Nitrogen applied 25 kg/ha of RDN	0.05	0.26	0.93	0.10
N_2: Nitrogen applied 50 kg/ha of RDN	0.03	0.30	1.12	0.15
N_3: Nitrogen applied 75 kg/ha of RDN	0.03	0.32	1.25	0.10
N_4: Nitrogen applied 100 kg/ha of RDN	0.05	0.37	1.40	0.12
F-test	NS	S	S	NS
SEm(±)	0.009	0.015	0.033	0.019
CD (P=0.05)	0.025	0.042	0.096	0.054
CV (%)	74.75	17.09	10.54	52.23

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).

Crop growth rate (CGR)

Crop growth rate (CGR) express as the gain in weight of plant per unit of land per unit of time. The data pertaining to crop growth rate computed at periodic intervals as influenced by various treatments displayed in Table 3. It is apparent from the data that the crop stand geometry at initially showed non-significant effect on crop growth rate at 20-40 DAS and 80-at harvest, however at crop geometry quinoa exerted significant influence on crop growth rate at the growth stages except 40–60 DAS and 60-80 DAS. Among the different crop stand geometry, the maximum crop growth rate 17.81, and 60.24 g/m^2/day were recorded by spacing S_1: crop spacing (15 cm x 10 cm). While in nitrogen application the crop growth rate (CGR) obtained during the study under the treatments is the reflection of higher amount of dry matter accumulation in respective periods. The highest crop growth rates (CGR) 14.49 and 53.05 g/m^2/day were recorded with N_4: Nitrogen @ 100 kg/ha application which was closely followed by rest of other nitrogen application at 40-60 DAS and 60-80 DAS. The higher Crop Growth Rate (CGR), may be attributed to more number of plants and higher dry matter production on unit area basis. Followed to this, wider spacing produced significantly lower CGR at all growth stages. Though the individual plant canopy was increased in these spacing, CGR was decreased as the plant population and dry matter production on unit area basis was less Ramesh *et al*., (2017).

Table 3: Influenced by crop stand geometry and nitrogen management approach on crop growth rate (CGR) at different growth interval of quinoa (Two year pooled analysis).

Treatments	Crop Growth Rate (CGR) (g/m^2/day)			
	20-40 DAS	**40-60 DAS**	**60-80 DAS**	**80-at harvest**
Crop stand geometry (S)				
S_1: Crop spacing (15 × 10cm)	1.85	17.81	60.24	3.69
S_2: Crop spacing (25 × 10cm)	1.46	11.61	44.60	3.70
S_3: Crop spacing (35 × 10cm)	1.33	8.62	33.71	3.23
S_4: Crop spacing (45 × 10cm)	1.16	7.22	25.84	3.07
F-test	NS	S	S	NS
SEm±	0.21	1.03	1.73	0.23
CD (P=0.05)	0.72	3.56	6.00	0.79
CV (%)	55.40	35.25	16.34	25.89
Nitrogen management approach through urea (N))				
N_0: Control	1.50	8.64	28.56	4.10
N_1: Nitrogen applied 25 kg/ha of RDN	1.69	9.86	35.07	3.77
N_2: Nitrogen applied 50 kg/ha of RDN	1.40	11.26	41.54	3.25
N_3: Nitrogen applied 75 kg/ha of RDN	1.07	12.32	47.27	3.07
N_4: Nitrogen applied 100 kg/ha of RDN	1.59	14.49	53.05	2.93
F-test	NS	S	S	NS
SEm±	0.27	0.58	1.31	0.47
CD (P=0.05)	0.77	1.69	3.80	1.37
CV (%)	63.47	17.88	11.08	48.04

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).

Relative Growth Rate (RGR)

Relative growth rate (RGR) was influence by various levels of crop geometries different growth periods. The data pertaining to relative growth rate was computed at periodic intervals as influenced by various treatments displayed in Table 4. Perusal of the data revealed that the crop stand geometries exerted non-significant influence on relative growth rate at all the growth stages.

In case of Nitrogen application relative growth rate (RGR) influenced non-significantly at 20-40 DAS and 60-80 DAS. This might be due to better performance of individual plant in terms of dry matter production under wider spacing because of utilization of available resources such as sun light, water, nutrient and space which made higher relative growth rate under wider spacing compared to narrow spacing (Ramesh *et al*., 2017).

Table 4: Influenced by crop stand geometry and nitrogen management approach on relative growth rate (RGR) at different growth interval of quinoa (Two year pooled analysis).

Treatments	Relative Growth Rate (RGR) (g/g/day)			
	20-40 DAS	**40-60 DAS**	**60-80 DAS**	**80-at harvest**
Crop stand geometry (S)				
S_1: Crop spacing (15 × 10cm)	0.111	0.122	0.070	0.0025
S_2: Crop spacing (25 × 10cm)	0.118	0.110	0.073	0.0034

S_3: Crop spacing (35 × 10cm)	0.123	0.112	0.073	0.0039
S_4: Crop spacing (45 × 10cm)	0.121	0.111	0.071	0.0041
F-test	NS	NS	NS	NS
SEm±	0.004	0.008	0.004	0.0004
CD (P=0.05)	0.015	0.027	0.015	0.0014
CV (%)	14.37	26.38	22.90	26.88
Nitrogen management approach through urea (N))				
N_0: Control	0.115	0.110	0.067	0.0030
N_1: Nitrogen applied 25 kg/ha of RDN	0.132	0.101	0.070	0.0043
N_2: Nitrogen applied 50 kg/ha of RDN	0.114	0.111	0.074	0.0032
N_3: Nitrogen applied 75 kg/ha of RDN	0.104	0.132	0.075	0.0026
N_4: Nitrogen applied 100 kg/ha of RDN	0.126	0.115	0.074	0.0024
F-test	NS	S	NS	NS
SEm±	0.010	0.006	0.002	0.0006
CD (P=0.05)	0.028	0.018	0.007	0.0016
CV (%)	28.54	19.23	11.56	52.82

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.

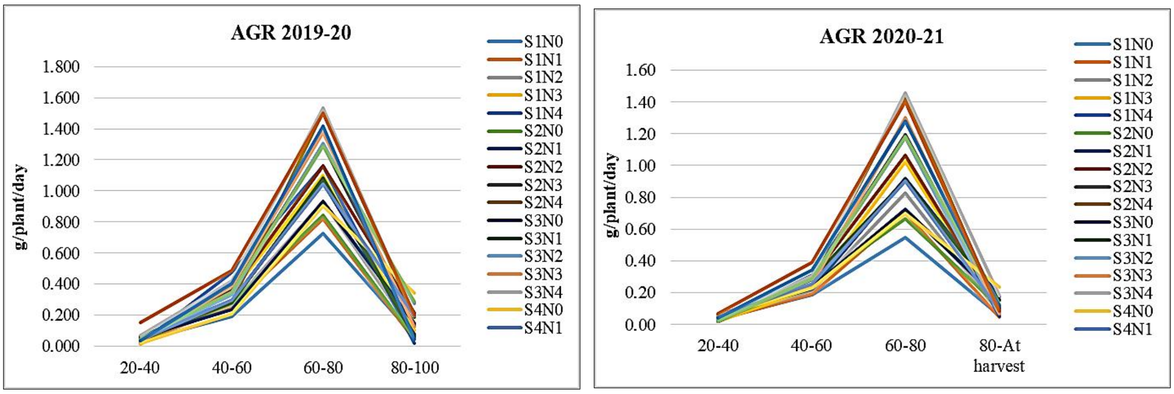

Fig 1: Absolute growth rate as influenced by crop geometry and nitrogen levels on Quinoa during 2019-20 (A) and 2020-21 (B).

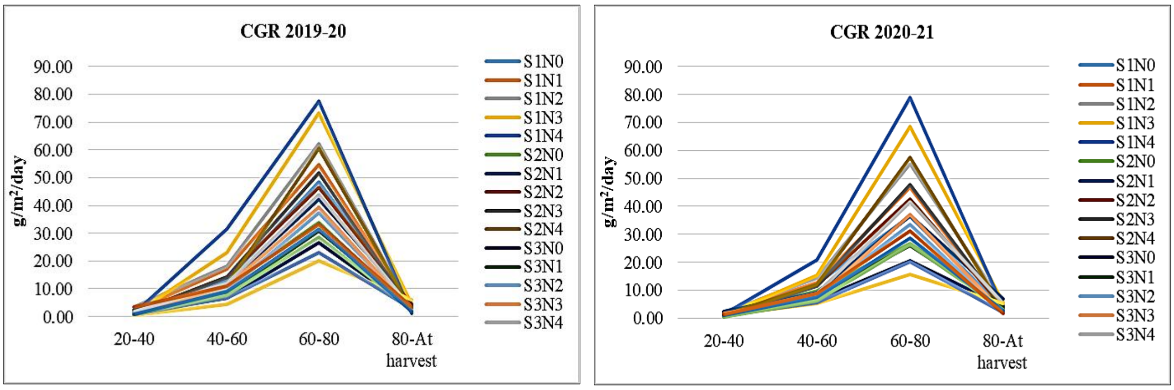

Fig 2: Crop growth rate as influenced by crop geometry and nitrogen levels on Quinoa during 2019-20 (C) and 2020-21 (D).

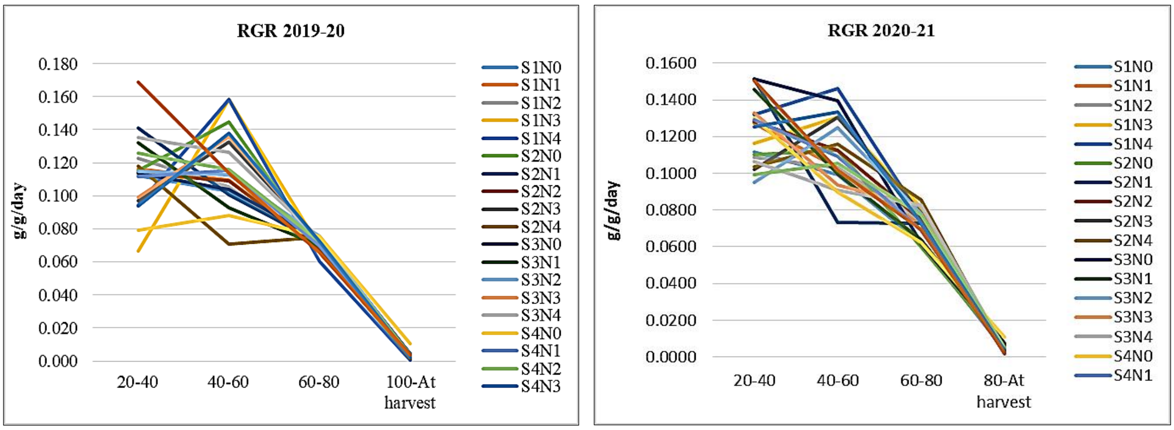

Fig 3: Relative growth rate as influenced by crop geometry and nitrogen levels on Quinoa during 2019-20 (E) and 2020-21 (F).

Conclusion

The research findings on the basis of two years experimentation reveal that the crop stand geometry and nitrogen management have the potential to influence growth and growth indices of quinoa. Hence, it can be concluded from the two year experiment that the crop stand geometry S_4: 15 cm x 10 cm and nitrogen application with N_4: Nitrogen applied 100 kg/ha of RDN concentration significantly affect growth indices and produced maximum vegetative growth.

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