Effect of Nitrogen and Potassium on Growth, Yield, and Seed Quality of Quinoa in Ferralsols and Acrisols under Rainfed Conditions

Nguyen Van Minh¹, Dinh Thai Hoang², Dang Thi Phuong Anh², Nguyen Viet Long²*

¹ Faculty of Agriculture and Forestry, Tay Nguyen University, Dak Lak, 567 Le Duan Street, Buon Ma Thuot City, Dak Lak province, 63100, Vietnam
² Faculty of Agronomy, Vietnam National University of Agriculture, Hanoi, 131000, Vietnam
* Corresponding author’s e-mail: nvlong@vnua.edu.vn

ABSTRACT
The study has investigated the individual and combined effects of nitrogen and potassium on the growth, grain yield, and quality of quinoa in ferralsols and acrisols. The experiments were conducted during the dry season under rainfed conditions in Central Highland, Vietnam. The factorial design was a randomized complete block design with three replications. The results revealed the positive impacts of nitrogen and potassium on the growth and yield of quinoa. However, after the application of an optimum dose of nitrogen, growth, and yield were not significantly changed and even decreased when the dose continued increasing. Higher levels of nitrogen and potassium application resulted in greater protein and fat content, but lower starch and fiber contents, compared to lower levels. The fertilizer practice has to rely on soil fertility. The study shows that the application of 150 kg N and 105 kg K₂O ha⁻¹ could be the optimum rate of nitrogen and potassium for quinoa production in ferralsols and acrisols in Central Highland.

Keywords: acrisols, ferralsols, nitrogen, potassium, quinoa.

INTRODUCTION
Quinoa (Chenopodium quinoa Willd.), an ancient staple food crop, recently has been spread for growing worldwide. It could flourish in various agro-ecological zones with a wide range of adaptation of relative humidities (40–80%), temperatures (-4 to 38°C), being highly tolerant to soil moisture deficiency. In addition, quinoa is considered a high nutritional plant food that provides a high content of protein with all essential amino acids, fats, carbohydrates, minerals, and vitamins, as well as possesses nutraceutical and medicinal properties (FAO, 2011). In order for quinoa to grow and develop well and to reach high yield and high seed quality, it requires sufficient amount of essential nutrients, especially nitrogen (N) and potassium (K) (Alvar-Beltrán et al., 2021). Numerous studies demonstrated the role of N in enhancing the growth, yield, and seed quality of quinoa (Jacobsen et al., 1994; Thanapornpoonpong, 2004; Kaul et al., 2005; Abou-Amer and Kamel, 2011; Gomaa, 2013; Basra et al., 2014; Kakabouki et al., 2014; Geren, 2015; Fawy et al., 2017; Almadini et al., 2019; Owji et al., 2020; Wang et al., 2020; Al-asadi et al., 2021). Meanwhile, limited information has been reported on the effects of K on quinoa growth and yield (Rêgo et al., 2017; Salim et al., 2019; Turcios et al., 2020). Moreover, nutrient balance is a key factor to promote plant growth and yield. Hou et al. (2018) demonstrated that the imbalance between N and K might lead to the yield reduction in a cereal crop. However, the information on the balance of N and K in quinoa has been also not clear.

Climate change with the phenomenon of raising drought status is one of the factors that constrain agricultural production. According to the World Bank’s forecast (2016), agricultural production will be soon less effective because over 70% of the production area is now subject
to rain-fed conditions. Vietnam is ranked in the top of the five most-affected countries by climate risk with extreme droughts continued well and recorded as the worst droughts in the last 100 years (Eckstein et al., 2017). Quinoa was first evaluated to grow well in Vietnam in 1986 with a higher potential yield than those in native regions (Trinh, 2001; Betero et al., 2004). Recently, quinoa adapted to grow in difficult cultivation regions where agricultural production is subjected to drought or salinity stress in the whole country (Nguyen, 2020). Central Highland, with a relatively flat and large topography is considered a favorable region for developing quinoa production. In this region, ferralsols and acrisols soils are two typical soils that account for 24.09 and 64.43% of total natural land. Quinoa was demonstrated to grow well in ferralsols soils in this region (Nguyen et al., 2020). However, this kind of soil is also suitable for perennial crops, such as coffee, rubber, or pepper. Although drought stress constrains the production, these crops still contributed substantially to Vietnam’s agricultural exports. Therefore, the potential for growing quinoa in acrisols soil should be discovered.

Our main objectives were to investigate the individual and combined effects of N and K on the growth, yield, and quality of quinoa under both ferralsols and acrisols soils conditions in rain-fed areas; and to recommend the optimum of N and K doses to fertilize quinoa under such conditions.

MATERIALS AND METHODS

Plant materials

The quinoa variety Atlas introduced from the Netherlands was used in the performed research. This was recommended as drought tolerance (Nguyen et al., 2021) and the best adaptive variety in Central Highland (Nguyen et al., 2020).

Experimental conditions

The experiments were conducted in the dry season from February to May 2021 at two locations in the Central Highland region, Vietnam. The weather conditions were shown in Table 1 with total rainfall of 357.2 mm and 144.4 mm in Dak Lak and Dak Nong province, respectively. The experimental soils were typical soil in

Table 1. Soil physicochemical properties

| Parameters                  | Ferralsols soil in Dak Lak | Acrisols soil in Dak Nong |
|-----------------------------|----------------------------|---------------------------|
| pH                          | 5.08                       | 4.71                      |
| OM (%)                      | 4.36                       | 2.44                      |
| Total N                     | 0.19                       | 0.09                      |
| Total P                     | 0.21                       | 0.11                      |
| Total K                     | 0.15                       | 0.08                      |
| Available P (mg 100g⁻¹)     | 8.07                       | 2.74                      |
| Available K (mg 100g⁻¹)     | 20.84                      | 7.01                      |
| Exchangeable Ca (meq 100g⁻¹)| 2.78                       | 0.56                      |
| Exchangeable Mg (meq 100 g⁻¹)| 2.17                      | 0.11                      |

Table 2. Meteorological Records for Dak Lak and Dak Nong provinces in 2020

| Factors                  | Dak Lak | Dak Nong |
|--------------------------|---------|----------|
|                          | Feb | Mar | Apr | May | Feb | Mar | Apr | May |
| Average temp. (°C)       | 23.5 | 24.1 | 25.0 | 25.7 | 22.7 | 26.3 | 26.7 | 28.0 |
| Max temp. (°C)           | 35.0 | 34.3 | 34.0 | 33.5 | 26.6 | 28.3 | 28.6 | 31.9 |
| Min temp. (°C)           | 18.0 | 18.1 | 18.5 | 21.5 | 20.4 | 24.7 | 23.3 | 25.1 |
| Rainfall (mm)            | 5.0  | 33.1 | 115.0 | 204.1 | 0    | 0    | 34.6 | 109.8 |
| Rain days (day)          | 1    | 2    | 4    | 22   | 0    | 0    | 3    | 11   |
| Humidity (%)             | 68   | 74   | 78   | 83   | 70   | 68   | 70   | 73   |
| Total sunny (hours)      | 280  | 264  | 245  | 206.5 | 266.0 | 298.8 | 265.4 | 241.9 |

Source: Hydrometeorological Center of Dak Lak and Dak Nong Provinces (2020)
Central Highland: a grey soil in Dak Nong with lower pH and poorer soil properties compared to a red basalt soil in Dak Lak (Table 2).

**Experimental design**

The experimental design was a randomized complete block design (RCBD) with three replications. The distance between each replication was 1 m. The plot area was 14 m$^2$ (5×2.8 m). The experimental factors included four N levels (60, 90, 120, and 150 kg N ha$^{-1}$) and four K levels (60, 75, 90, and 105 kg K$_2$O ha$^{-1}$).

**Crop management**

The experimental land was plowed and raked carefully at depth of 20 to 30 cm. Weeds were cleared before sowing. Seeds were sowed in rows with a distance of 50 x 30 cm at 2-3 cm of depths, then thinned to one plant per hill at the 2-3 leaves stage. The basal fertilizer was applied before sowing with an amount of 1 ton Huco microbial organic fertilizer, 500 kg lime, and 60 kg P$_2$O$_5$ (superphosphate). Urea (46% N) and potassium chloride (60% K$_2$O) were used for top dressing at 20 and 40 days after sowing. The quinoa plants grew under rain-fed conditions with water supplements at the sowing date to ensure seed germination. Crop management was regularly practiced to control pests, diseases, and weeds.

**Data collection**

At harvest, the 10 sample plants were randomly selected from each experimental plot to measure plant height, stem diameter, the number of branches, the number of panicles, and the number of seeds per panicle. The harvested seeds were sun-dried for 3 days to determine 1000-seed weight and plot yield. The seed sample then was oven-dried at 60°C until constant weight to determine the contents of protein, starch, fat, fiber, and ash contents according to the methods described in detail by Eisa et al. (2018).

**Data analysis**

The data were subjected to analysis of variance according to a randomized complete block design for a factorial experiment using Minitab 16. Grouping information using the Tukey method was done with a confidence of 95.0%.

**RESULTS**

**Effect of nitrogen and potassium on growth characteristics of quinoa**

Different N and K application levels had significant effects on plant height, plant diameter, and the number of branches at both locations (except for the effect of K on the number of branches in Dak Nong). In general, there were upward trends in all investigated parameters when increasing the N and K application levels (Table 3). In fact, applying N at 150 kg N ha$^{-1}$ resulted in significantly higher plant height and the number of branches compared to the lowest N levels (60 and 90 kg N ha$^{-1}$). At 120 kg N ha$^{-1}$, the number of branches was highest, significantly higher than those at 60 and 90 kg N ha$^{-1}$. The application of K at the rate of 105 kg K$_2$O ha$^{-1}$ achieved better values for all parameters. However, in Dak Lak it resulted in significantly higher values than those at rates of 60 and 75 kg K$_2$O ha$^{-1}$ for plant diameter and 60 kg K$_2$O for the number of branches only. In Dak Nong, it resulted in significantly higher values than those at rates of 60 and 75 kg K$_2$O ha$^{-1}$ for plant height and 60 and 75 kg K$_2$O ha$^{-1}$ for plant diameter only. The interaction of N and K was significant for most parameters, except for plant diameter and the number of branches in Dak Lak (Table 3). Applying N and K at rates of 90 kg K$_2$O combined with 120 and 150 kg N ha$^{-1}$ seemed to be better for quinoa growth than other combinations.

**Effect of nitrogen and potassium on yield components of quinoa**

N application had noticeable impact on yield components including the number of main panicles, the number of seeds per panicle, 1000-seed weight, and seed yield of quinoa, except for the number of seeds per panicle in Dak Nong (Table 4).

In Dak Lak, yield components increased along with the rate of N application, then decreased after reaching a peak at 120 kg N ha$^{-1}$. The clearest trend was observed in seed yield with the highest value of 23.0 ton ha$^{-1}$. However, significant differences were only found among N treatments for seed yield, and between lower (60 and 90 kg N ha$^{-1}$) and higher rate treatments (120 and 150 kg N ha$^{-1}$) for all other traits. In Dak Nong, higher values for yield components were the result of
increasing N application from 60 to 150 kg ha\(^{-1}\). However, significant differences were also found among N treatments for seed yield, and between the highest rate (150 kg N ha\(^{-1}\)) with other treatments for other parameters.

The difference in K application caused variations in the yield components of quinoa for the number of panicles, the number of seeds per panicle, and seed yield in Dak Lak, and for the number of main panicles and seed yield in Dak Nong (Table 5). There were similar trends with increasing yield components by increasing K application rates at both locations. In fact, significant differences were found between lower (60 and 75 kg K\(_2\)O ha\(^{-1}\)) and higher rates (90 and 105 kg K\(_2\)O ha\(^{-1}\)) for the panicle number, and the seed number per panicle in Dak Lak, and between the rate of 105 kg K\(_2\)O ha\(^{-1}\) with other K treatments. Seed yield was highest with 22.9 ton ha\(^{-1}\) in Dak Lak and 17.7 ton ha\(^{-1}\) in Dak Nong when K was applied at the rate of 105 kg K\(_2\)O ha\(^{-1}\).

The interaction of N and K was significant for panicle number, the number of seeds per panicle in Dak Lak, and seed yield in both locations. The better values for yield components traits seemed to be the results of the combination between K at the rate of 105 kg K\(_2\)O ha\(^{-1}\) with N at the rates of 120 and 150 kg N ha\(^{-1}\).

### Table 3. Effects of nitrogen and potassium on plant height (PH), plant diameter (PD), the number of branches (No.B) of quinoa in Dak Lak and Dak Nong provinces

| Treatment | Dak Lak | Dak Nong |
|-----------|---------|----------|
| **PH**    | **PD**  | **No.B** | **PH** | **PD** | **No.B** |
| 60        | 128.8B  | 13.1C    | 26.6B  | 115.7C | 13.6C    | 27.0B  |
| 90        | 129.1B  | 13.3BC   | 26.7B  | 118.8BC| 14.6BC   | 28.6AB |
| 120       | 147.1A  | 15.2A    | 30.2Ab | 120.7AB| 15.8A    | 32.0A  |
| 150       | 151.7A  | 15.8B    | 30.3AB | 123.8AB| 15.8B    | 30.0A  |
| **K**     | **PH**  | **PD**   | **No.B** | **PH** | **PD** | **No.B** |
| 60        | 135.4B  | 13.5B    | 27.6B  | 117.5B | 13.5C    | 28.6A  |
| 90        | 138.1B  | 14.5B    | 29.2AB | 120.7AB| 14.6BC   | 29.1A  |
| 120       | 137.0B  | 15.8AB   | 30.3AB | 123.8AB| 15.8AB   | 30.0A  |
| 150       | 146.1A  | 17.6A    | 31.9A  | 128.8A | 16.9B    | 30.4A  |
| **N x K** | **PH**  | **PD**   | **No.B** | **PH** | **PD** | **No.B** |
| 60:60     | 129.7ef | 12.7b-d  | 23.4b  | 102.4d | 10.3c    | 24.9a  |
| 60:90     | 135.5c-f| 10.4d    | 29.3ab | 121.8a-d| 14.1b    | 25.3a  |
| 60:120    | 129.1f  | 14.6b-d  | 27.2ab | 124.2a-d| 14.8b    | 25.6a  |
| 60:150    | 128.1ef | 14.5b-d  | 26.6ab | 114.5a-d| 15.1b    | 32.1a  |
| 90:60     | 129.1ef | 11.4cd   | 28.0ab | 123.3a-d| 14.1b    | 40.0a  |
| 90:90     | 132.1d-f| 13.9cd   | 28.7ab | 111.0a-d| 14.7b    | 26.8a  |
| 90:120    | 121.0ef | 13.4b-d  | 29.4ab | 119.0a-d| 14.7b    | 27.7a  |
| 90:150    | 134.1d-f| 14.6b-d  | 27.7ab | 122.0a-d| 14.9b    | 30.0a  |
| 120:60    | 133.2d-f| 15.6b-d  | 32.1ab | 119.3a-d| 15.0b    | 30.0a  |
| 120:90    | 141.8b-e| 18.1a-c  | 30.7ab | 123.0a-d| 14.6b    | 32.0a  |
| 120:120   | 150.7a-d| 19.7ab   | 35.7ab | 122.4a-d| 18.5a    | 33.2a  |
| 120:150   | 162.7a  | 23.3a    | 36.4a  | 140.0a  | 18.8a    | 25.7a  |
| 150:60    | 149.7a-d| 14.1b-d  | 27.1ab | 125.1a-d| 14.4b    | 29.4a  |
| 150:90    | 142.9b-e| 15.5b-d  | 28.0ab | 126.9a-d| 14.9b    | 32.4a  |
| 150:120   | 154.5a-c| 15.6b-d  | 29.0ab | 129.7a-c| 15.0b    | 33.3a  |
| 150:150   | 159.6ab | 18.0a-c  | 36.8a  | 138.7ab | 18.9a    | 33.9a  |

### Analysis of variance

| **N** | **K** | **N x K** |
|-------|-------|-----------|
| ***   | **    | ***       |
| **    | ns    | ns        |

Different capital letters show significance among N, and K treatments, different lowercase letters show significance among N combined K treatments at p < 0.05 by Turkey’s test. ns = not significant; *= significant at 0.05; ** = significant at 0.01; *** = significant at 0.001.
Effect of nitrogen and potassium on seed nutrient of quinoa

N application had significant effect on the protein and starch contents in both locations, the fiber content in Dak Lak, lipid content in Dak Nong. Meanwhile, the K application had significant effect on the protein content in both locations, fiber content in Dak Lak, and starch content in Dak Nong. Both N and K had no effects on the carbohydrate contents in quinoa seeds. In both locations, the protein content reached peaks when the N and K application rates increased to 120 kg N ha\(^{-1}\) and 90 kg K\(_2\)O ha\(^{-1}\), respectively; after that, the increases were not significant at higher rates. Similarly, the lipid content increased along with the amount of N and K application, but a significant difference was found between lower N treatments (60 and 90 kg N ha\(^{-1}\)) and 150 kg N ha\(^{-1}\) in Dak Nong only. In contrast, there were downward trends in starch and fiber contents along with the increase of N and K application rates. However, the remarkable variation was just found between treatment 60 kg N ha\(^{-1}\) with higher N treatments (120 and 150 kg N ha\(^{-1}\)) for starch, and between the treatment of 60 kg ha\(^{-1}\) of N and K with treatments of 90 and 105 kg ha\(^{-1}\) in Dak Lak. The interaction of N and K application was significant

| Treatment | Dak Lak | Dak Nong |
|-----------|---------|-----------|
|           | No.P    | No.S      | P1000 | SY   | No.P | No.S | P1000 | SY   |
| N         | 60      | 37.6C     | 267.4B | 3.42B | 17.7D | 31.1B | 249.5A | 2.89B | 14.3C |
|           | 90      | 38.1C     | 267.6B | 3.70AB | 19.7C | 31.9AB | 250.8A | 3.13AB | 15.5B |
|           | 120     | 40.2A     | 270.4A | 3.90A  | 23.0A | 32.7AB | 251.4A | 3.35AB | 16.3B |
|           | 150     | 39.1B     | 268.9AB | 3.84A  | 21.3B | 33.4A  | 253.0A | 3.58A  | 17.9A |
| K         | 60      | 37.7B     | 266.0B | 3.63A  | 17.5C | 30.7C  | 247.2A | 3.29B  | 14.4C |
|           | 90      | 38.2B     | 267.5B | 3.65A  | 19.5C | 31.5BC | 249.8A | 3.19A  | 15.8B |
|           | 120     | 39.3A     | 269.4A | 3.74A  | 21.9B | 32.9AB | 252.3A | 3.33A  | 16.1B |
|           | 150     | 39.8A     | 271.4A | 3.84A  | 22.9A | 33.9A  | 255.3A | 3.43A  | 17.7A |

| N:K       | 60:60   | 35.2f     | 265.7B-d | 3.23B | 15.2f | 29.9B  | 246.6a | 2.86a  | 13.7f |
|           | 60:90   | 38.5b-d   | 265.7od | 3.39ab | 17.5e | 30.4B  | 247.5a | 2.81a  | 14.2ef |
|           | 60:120  | 38.2c-e   | 267.4a-d | 3.59ab | 18.8ed | 32.0A  | 249.3a | 2.98a  | 14.4ef |
|           | 60:150  | 38.2c-e   | 270.7a-c | 3.45ab | 19.4d | 31.9AB | 254.7a | 2.92a  | 14.9d-f |
|           | 90:60   | 38.5b-d   | 262.3d | 4.05a  | 15.2f | 30.3B  | 249.6a | 3.19a  | 14.3ef |
|           | 90:90   | 36.1ef | 268.3a-c | 3.56ab | 17.3e | 30.1B  | 248.7A | 3.09a  | 15.4d-f |
|           | 90:120  | 38.9a-d   | 269.3a-c | 3.42ab | 22.4bc | 33.3B  | 250.3a | 3.29a  | 15.5c-f |
|           | 90:150  | 39.1b-d   | 270.6a-c | 3.76ab | 23.9ab | 33.9B  | 254.5a | 3.42a  | 16.8b-e |
|           | 120:60  | 39.7a-c   | 269.1a-c | 3.80ab | 22.4ab | 32.1B  | 248.3a | 3.00a  | 14.4ef |
|           | 120:90  | 40.0a-c   | 268.8a-c | 3.85ab | 22.6ab | 32.0B  | 249.0a | 3.28a  | 15.6c-f |
|           | 120:120 | 39.8a-c   | 271.4ab | 3.78ab | 23.0ab | 32.6B  | 253.6a | 3.50a  | 16.0b-f |
|           | 120:150 | 41.5a     | 272.3a | 4.15a  | 24.0a | 34.1B  | 254.8a | 3.60a  | 19.0ab |
|           | 150:60  | 37.4d-f   | 267.1a-d | 3.43ab | 17.3e | 30.7B  | 244.4a | 3.37a  | 15.1d-f |
|           | 150:90  | 38.1c-e   | 267.2a-d | 3.79ab | 20.5cd | 33.7B  | 254.2a | 3.59a  | 18.0a-d |
|           | 150:120 | 40.3a-c   | 269.4a-c | 4.14a  | 23.3ab | 33.6B  | 256.1a | 3.57a  | 18.6a-c |
|           | 150:150 | 40.6ab    | 272.1a | 3.98ab | 24.2a | 35.6a  | 257.3a | 3.79a  | 20.0a |

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for the protein content in both locations, the better values resulted from the combinations of K at the rate of 105 kg ha\(^{-1}\) with higher N application rates.

**DISCUSSION**

There was a positive correlation between N application and quinoa yield with an increase of N between 0 to 120 kg ha\(^{-1}\) (Kaul et al. 2005). Under temperate climatic conditions in Denmark, although there was a significant yield increase when the amount of N fertilizer was raised from 40 to 160 kg ha\(^{-1}\), quinoa seems to be well adapted to poor soil (Jacobsen et al., 1994). Similarly, increasing N from 0 to 180 kg N ha\(^{-1}\) resulted in better values for plant height, leaf area, number of seeds per cluster, and total seed yield in quinoa (Al-asadi et al., 2021). Increase N from 120 to 180 kg ha\(^{-1}\) enhanced plant height, leaf area, plant dry weight, panicle length, and grain yield of quinoa (Owji et al., 2020). Higher N application rate (240 kg ha\(^{-1}\)) showed better values for plant height, the number of branches, 1000-seed weight, biomass, and seed yield of quinoa in Ras Sadersinai (Fawy et al., 2017). Under sandy soil conditions in Egypt, Shams (2012) revealed that fertilizing quinoa with 360 kg N ha\(^{-1}\) resulted in maximum plant

**Table 5.** Effects of nitrogen and potassium on contents of protein (Pro.), starch (Sta.), lipid (Lip.), fiber (Fib.), and ash of quinoa in Dak Lak and Dak Nong provinces

| Treatment | Dak Lak | | | | | Dak Nong | | | | |
|-----------|---------|-----|-----|-----|-----|---------|-----|-----|-----|-----|
|           | Pro.    | Sta.| Lip.| Fib.| Ash | Pro.    | Sta.| Lip.| Fib.| Ash |
| N         | 60      | 18.0C| 62.8A| 4.7A| 6.0A| 17.2C  | 64.2A| 4.9B| 7.2A| 3.9A|
|           | 90      | 19.4B| 61.8AB| 4.9A| 5.7AB| 18.4BC | 62.4A| 5.0B| 7.6A| 3.6A|
|           | 120     | 22.0A| 60.2BC| 5.5A| 4.8B| 19.5AB | 59.9B| 5.4AB| 7.7A| 3.7A|
|           | 150     | 20.7AB| 60.0C| 5.4A| 4.7B| 17.9A  | 59.2B| 5.7A| 7.3A| 3.8A|
| K         | 60      | 18.0B| 62.0A| 5.2A| 5.9A| 17.2C  | 62.9A| 5.2A| 7.3A| 3.8A|
|           | 90      | 19.4B| 61.3A| 5.3A| 5.4AB| 18.5BC | 62.4A| 5.2A| 7.4A| 3.6A|
|           | 120     | 20.9A| 60.9A| 5.4A| 5.1B| 19.3AB | 61.2A| 5.3A| 7.5A| 3.7A|
|           | 150     | 21.8A| 60.6A| 4.5A| 4.7B| 17.0A  | 59.3B| 5.4A| 7.7A| 3.9A|
| N:K       | 60:60   | 18.1de | 63.9a| 4.1a| 6.6a| 14.6e  | 67.1a| 4.4ab | 6.6a| 4.0a|
|           | 60:90   | 18.3de | 62.3ab| 4.4a| 6.5a| 16.5de | 66.2a| 4.3b | 7.1a| 3.6a|
|           | 60:120  | 16.5e | 62.8ab| 6.0a| 5.8a| 17.2b-e| 64.7ab| 4.8ab | 7.2a| 3.9a|
|           | 60:150  | 19.1c-e| 62.3ab| 4.2a| 5.3a| 20.3a-d| 58.9cd| 6.0ab | 7.9a| 4.2a|
|           | 90:60   | 16.7e | 63.1ab| 5.3a| 6.2a| 16.3de | 64.7ab| 5.1ab | 7.4a| 3.7a|
|           | 90:90   | 20.1b-e| 61.9ab| 5.1a| 5.4a| 17.1c-e| 63.9a-c| 5.0ab | 7.4a| 3.6a|
|           | 90:120  | 21.9a-d| 61.1ab| 4.2a| 4.7a| 18.7a-e| 60.8b-d| 5.1ab | 8.2a| 3.4a|
|           | 90:150  | 19.0de | 61.1ab| 4.8a| 6.5a| 21.4a-c| 60.2b-d| 4.9ab | 7.6a| 3.5a|
|           | 120:60  | 19.5b-e| 60.6ab| 5.3a| 5.9a| 18.9a-e| 60.8b-d| 5.1ab | 7.1a| 3.5a|
|           | 120:90  | 20.7b-e| 60.2ab| 5.9a| 4.9a| 19.6a-d| 59.6b-d| 5.4ab | 7.6a| 3.6a|
|           | 120:120 | 22.3a-d| 60.2ab| 5.8a| 4.1a| 19.3a-e| 59.7b-d| 5.7a | 7.6a| 3.9a|
|           | 120:150 | 25.9a | 58.9b| 4.9a| 4.1a| 20.3a-d| 59.7b-d| 5.3ab | 8.3a| 4.0a|
|           | 150:60  | 17.8de | 60.2ab| 6.0a| 5.1a| 18.9a-e| 59.1cd| 6.2a | 8.0a| 3.9a|
|           | 150:90  | 18.5de | 61.0ab| 5.8a| 4.9a| 20.9a-d| 59.4cd| 5.9ab | 7.4a| 3.5a|
|           | 150:120 | 23.1a-c| 59.3ab| 5.5a| 4.2a| 21.9a-b| 59.8b-d| 5.4ab | 6.9a| 3.4a|
|           | 150:150 | 23.4ab | 60.3ab| 4.1a| 4.6a| 22.0a | 58.4d| 5.3ab | 6.9a| 3.8a|

Analysis of anova

| N           | *** | *** | ns  | ** | ns  | *** | *** | *  | ns  | ns  |
|-------------|-----|-----|-----|----|-----|-----|-----|----|-----|-----|
| K           | *** | ns  | ns  | *  | ns  | *** | *** | ns | ns  | ns  |
| N x K       | *** | ns  | ns  | ns | ns  | ns  | Ns  | ns | ns  | ns  |

Different capital letters show significance among N, and K treatments, different lowercase letters show significance among N combined K treatments at p < 0.05 by Turkey’s test. ns = not significant; * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001.
height, grain yield, and biological yield. From the obtained study results, the positive impacts of N and K application on the growth and yield of quinoa, but after an optimum dose, growth and yield were not significantly changed even decreased when the dose continues increasing. The result is similar to the previous studies. Wang et al. (2020) reported that applying N at the rate of 240 kg ha\(^{-1}\) had a significantly greater 1000-seed weight than 80 and 160 kg ha\(^{-1}\). Moreover, plant height, leaf area index, dry matter, 1000-seed weight all increased along with N, whereas seed yield did not further increase when the N rate was beyond 160 kg ha\(^{-1}\). Under Mediterranean climatic conditions, among seven N levels ranging from 0 to 175 kg ha\(^{-1}\), the level of 150 kg ha\(^{-1}\) was proven to be the best level for N supplementation for grain yield of quinoa (Geren, 2015). Basra (2014) reported that soil application of N at 75 kg ha\(^{-1}\) and higher improved plant height, stem diameter, main panicle length, yield components, but 75 kg ha\(^{-1}\) was found to be the best level of N to attain maximum economic harvest in quinoa. In the red river delta in Vietnam, under normal and saline stress conditions of an alluvium soil, the growth parameters, and yield components increased according to the increase of the N application rates from 0 to 90 kg N ha\(^{-1}\), then decreased when the nitrogen rates were higher (Dinh et al., 2015, 2021). Conducting a greenhouse experiment, Rêgo et al. (2017) found linear correlations of K application rate with the shoot and root dry mass, but polynomial correlations with the number of grain and grain production in quinoa. The grain yield of quinoa increased significantly when the K application rate was raised up to 120 kg ha\(^{-1}\), then slightly decreased by the application at the rate of 180 kg ha\(^{-1}\) (Salim et al., 2019). Turcios et al. (2020) reported that an adequate supply of K promoted the growth of quinoa for biomass and leaf area under both non-stress and saline-stress conditions.

In a recent study, higher levels of N and K application resulted in greater protein and fat content, but lower starch and fiber contents, compared to lower levels. Abou-Amer and Kamel (2011), Wang et al. (2020) agreed that the protein content in quinoa seeds further increased with a higher N rate. Geren (2015) also found upward trends in crude protein content in quinoa seed by increasing N application rates from 0 to 175 kg ha\(^{-1}\). Similarly, Kakabouki et al. (2014) stated that crude protein content was higher in the treatment of 200 kg N ha\(^{-1}\) compared to 100 kg N ha\(^{-1}\). Gomaa et al. (2013) revealed that the crude protein percentage in quinoa seed increased as a result of the increasing rate of ammonium nitrate. Almadini et al. (2019) reported that increased N rate from 0 to 160 kg N ha\(^{-1}\) promoted the contents of protein, fat, starch, and ash. Thapanompoonpong (2004) agreed that the protein and starch contents increased, but the fat content decreased by increasing N levels.

Fertilizer supplements should be practiced to satisfy the crop nutrient requirement. In quinoa, Moreale (1993) recorded that producing one ton of stover plant requires 5.0, 1.8, and 32.5 kg N, P, and K, respectively, and to produce seed yield of about 4 ton ha\(^{-1}\), quinoa uptake 95 kg N, 27 kg P, and 185 kg K. Therefore, supply of 100 to 150 kg N ha\(^{-1}\), 30 kg P (corresponding to 70 kg P\(_{2}O_{5}\)) and 100 to 200 kg K (corresponding to 125 to 250 kg K\(_{2}O\)) is recommended in Netherland and Denmark. Alvar-Beltrán et al. (2021) reported that while N and K are required at medium to fairly high amounts, P is needed in lower amounts. They also suggested that 12.7, 1.6, and 35.5 kg ha\(^{-1}\) of N, P, and K, respectively, should be added into the soil to produce one ton of total biomass (including seeds, stem, and leaves). In this study, with a base dose of P at 60 kg ha\(^{-1}\), the combinations of K at the rate of 150 kg ha\(^{-1}\) with N at higher rates (120 and 150 kg ha\(^{-1}\)) achieved better growth, yield components, and protein contents. Abdolahpour et al. (2020) agreed that the higher amounts of N, P, and K application showed greater plant height, the number of branches, 1000-seed weight, seed yield, and protein content in quinoa seed.

In the conducted study, the quinoa grown in ferralsol soil in Dak Lak seemed to be better in acrisols soil in Dak Nong for growth, yield traits as well as seed quality in terms of protein content. The dry season in Central Highland is often from October to May. In this study, quinoa was grown for half end of the dry season and rainfall came sooner in Dak Lak. Total rainfall during quinoa growing in this location was also 2.5 times higher than that in Dak Nong. However, rainfall seemed to be not the main factor that affected the growth and yield in this region. In the same location in Dak Lak province, Nguyen et al. (2020) observed that compensating for lower plant height and panicle numbers, quinoa in the dry season had a greater panicle length, seed number per panicle, 1000-seed weight, and seed yield compared to it in the rainy season. The reason may be from soil fertility. The ferralsols soil is the most fertile soil, whereas acrisols
soil is a poor fertility one in the Central Highland. Richer soil nutrients may lead the plant to reach the saturation points for growth, yield, and quality sooner. In fact, plant diameter, the number of branches, yield components, and protein content of quinoa in Dak Lak decreased when the supply of N was over the optimum dose of 120 kg N ha\(^{-1}\) in Dak Lak but continuously increased by raising N application from 60 to 150 kg ha\(^{-1}\). Kansomjet et al. (2017) also found greater growth and yield of two quinoa varieties Moradas and Verdes in Pang-Da which had richer soil fertility, compared to Phabadhuaytom. The highest seed yield and 1000-seed weight were achieved at a rate of 93.75 kg N ha\(^{-1}\) in Pang-Da and 187.50 kg N ha\(^{-1}\) in Phabadhuaytom, respectively.

**CONCLUSIONS**

The resulted showed positive effects of N and K application on growth, yield, and seed nutrients. It was also shown that the quinoa grown in ferralsols soil in Dak Lak seemed to be better in acrisols soil in Dak Nong for growth, yield traits as well as seed quality in terms of protein content. The optimum doses to suggest for quinoa culture should be based on soil fertility. In terms of ferralsols and acrisols soils in Central Highland, the recommended dose of fertilizer was 150 kg N, 60 kg P\(_2\)O\(_5\), and 105 kg K\(_2\)O per hectare.

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