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Impact of Plant Spacing and Fertilization Dose on the Growth and Yield Traits of Okra (*Abelmoschus esculentus* (L.) Moench) in Sudan

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Abstract

This study examines the impact of plant spacing and nitrogen fertilization doses on the growth and yield traits of okra (*Abelmoschus esculentus* (L.) Moench) in Sudan. Using a factorial experiment within a completely randomized block design, the research explored four spacing levels within raw, S1, S2, S3, and S4 (20, 25, 30, and 35 cm, respectively) and four nitrogen fertilizer doses, Ur1, Ur2, Ur3 and Ur4 (60, 80, 100, and 120 kg.ha^{-1} , respectively). Key metrics were measured: plant height, number of leaves, number of nodes, pod length, fresh weight, and seed count per pod. The results, analyzed via OPSTAT statistical software and ANOVA, indicated that a 60 cm × 30 cm spacing combined with a nitrogen dose of 60 kg.ha^{-1} significantly optimized growth parameters and yield components. Specifically, this combination resulted in the tallest plants (15.50 cm), the highest number of leaves (7.30), nodes (7.30), and greater fresh pod weight (7.69 g) and length (5.50 cm). Significant interaction effects between spacing and fertilizer doses were observed across all parameters at a 5% confidence level. The study recommends a 60 cm × 30 cm spacing with a nitrogen dose of 60 kg.ha^{-1} to maximize okra growth, yield, and quality in Sudan's agroecological zones, supporting sustainable agricultural practices and enhanced productivity. These findings can be directly applied to optimize okra production in Sudan, contributing to the country's agricultural sustainability.

Keywords*:* Interaction, nitrogen fertilization, plant density, within row spacing, yield optimization

Introduction

Okra, scientifically known as *Abelmoschus esculentus* (L.), Moench is a highly popular vegetable crop in tropical and subtropical regions worldwide. Its origins can be traced back to Africa, specifically the Abyssinian Center of Origin, which includes Ethiopia, mountainous areas of Eritrea, and Sudan's plains as described by (Yılmaz et al., 2021) and (El Tahir, 2023). Historical evidence suggests that the ancient Egyptians cultivated okra as early as 1216 (Blench, 2013). The vegetable then spread from Egypt to North Africa, the Mediterranean, Asia, and India. Through the transatlantic slave trade, okra travelled from West Africa to Spain, France, England, and the Americas (Sousa and Raizada, 2020).

The plant has acquired various names across different regions. In the Middle East, it is referred to as Bamiya or Bamiyah. Quiabo in Brazil, Jiao Dou in China, Bhindi in India, and Kacang Bendi in Malaysia. The English term okra originates from the Igbo language of Nigeria, where it is known as Okwuru, which evolved into Ochra and Okra. The first recorded use of the word "okra" in English dates back to 1679 in the Colony of Virginia. Additionally, the term "Gumbo," often used interchangeably with okra in the United States, comes from the Kimbundu word "Ki ngombo" and was introduced through the Louisiana Creole dialect (Cresswell, 2010).

Okra, the 'perfect villager's vegetable' in Africa, showcases remarkable resilience. It flourishes in backyard gardens and displacement camps, adapting to various climates and soil types (Sousa and Raizada, 2020). Its rich dietary fibre content and versatility in culinary applications make it a staple in local diets (Lamont, 1999). In Sudan, okra is consumed either

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fresh as green pods in a stew or its dried form, ground into a powder known as 'Waika' for use in several dishes. The plant has spread naturally across Sudan, in the regions of Kordofan, West Darfur, the White Nile, the Blue Nile, and along the River Nile towards the north (Geneif, 1984; Adlan, et al., 2017).

Okra in Sudan is mainly grown for subsistence farming in rain-fed areas. However, the crop has recently gained economic importance, leading farmers to cultivate okra under irrigation in marginal areas with low soil fertility. Small-scale farmers generally practice wide plant spacing, which is often determined by the availability of land and manual practices in the agriculture system in Sudan. However, improper inter- and intra-row spacing can lead to sub-optimal plant density, making plants susceptible to weed competition and pest infestations, resulting in low yield and suboptimal use of resources (Singla, et al. 2018). Limited research exists on the interaction between plant spacing and nitrogen application, particularly in varying agro-climatic conditions (Ahirwar et al., 2021), more comprehensive studies are needed to determine the precise nitrogen and space requirements for different okra cultivars. Proper plant spacing and suitable fertilisation doses are required to achieve maximum yield and quality, as both factors may influence crop production, quality, and economy (Khanal et al., 2020). Our study aims to investigate more efficient planting arrangements that can increase okra yield by maximizing resource utilization and improving canopy coverage. This approach challenges traditional practices by introducing scientifically validated spacing and fertilization strategies, which could lead to better economic returns and provide okra growers with actionable insights aligning with sustainable agricultural practices. The findings will be valuable for farmers facing similar climatic and soil conditions. The research specifically explores the effects of interplant spacing, fertilization, and their interaction on okra production under Khartoum soil and agro-climatic.

Materials and Methods

The experiment was carried out at the Al Zaeim Al Azhari University Demonstration farm at Khartoum North during the monsoon/Kharief season, October 2019, in Khartoum State near Shambat locality. The field experiment was conducted at the Agricultural Research Station in Khartoum, Sudan. Seeds of okra (*Abelmoschus esculentus* (L.) Moench) were planted on June 15, 2019, in a soil that had been standardly enriched with 50 cubic meters per hectare of organic manure two weeks before seeding, ploughed, levelled, and ridged. Furrow irrigation was scheduled every ten days to maintain optimal soil moisture. Fields were monitored weekly for pests and diseases, and preventive measures such as fungicide treatment and the application of insecticides were taken as needed. Harvesting was carried out in stages 45 days from sowing and continued for 100 days. Considering the market demand present in Sudan for tender smaller to medium-sized okra, which typically ranges from 5 to 8 cm, the pods are harvested 5-10 days post-anthesis, and the field is examined at intervals of 2 to 3 days (Adetuyi et al. 2008). Shambat soil belongs to the Central Clay Plain of the Sudan, which has been formed by alluvial deposits of the Nile, primarily of basaltic origin, and it is considered largely as Vertisols. Moderately affected by saline and sodic subsoil. The soil texture is clayey throughout the experimental farm (Ali et al., 2016). The climate of Shambat and its surroundings is a semi-arid climate, characterized by high temperatures and limited rainfall. The mean annual temperatures in this region typically range from 26°C to 32°C, with summer temperatures often exceeding 43°C. Rainfall is generally low and erratic, concentrated mainly between June and September, with annual totals ranging from 200 mm to 700 mm in central Sudan. The main metrological data for rainfall precipitation, minimum, maximum, and ambient temperature, during the experiment, is presented in Figures 1 and 2.

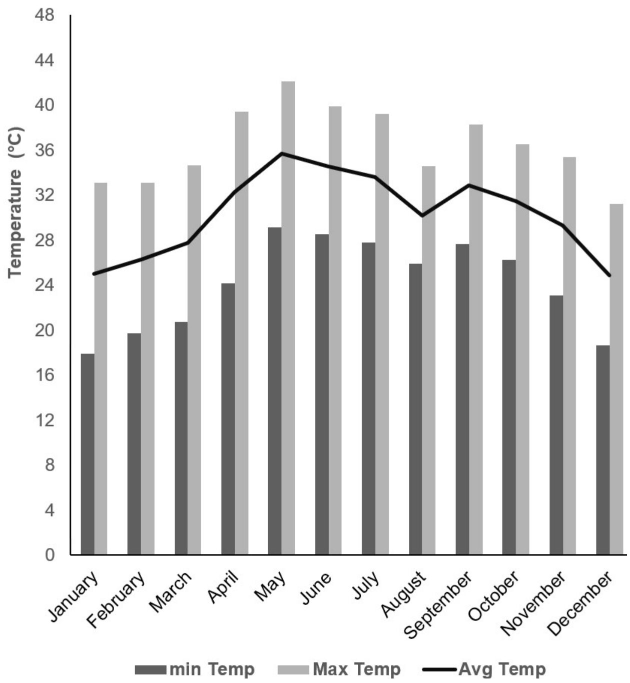

Figure 1. The average minimum, maximum, and mean temperatures during 2019.

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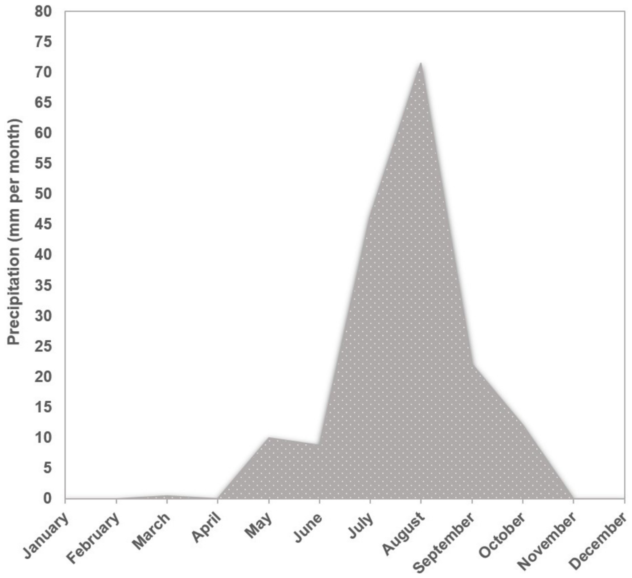

Figure 2. Average rain precipitation (mm) during monsoon season (*Kharif*) 2019

Experimental Design

The study uses a factorial experiment in a completely randomized block design with two factors, plant spacing (A) and fertilizer (B). Plant spacing had four levels, S1, S2, S3, and S4 (20, 25, 30, and 35 cm, respectively), while fertilizer had four levels, Ur1, Ur2, Ur3 and Ur4 (60, 80, 100, and 120 $kg.ha^{-1}$, respectively). The primary aim of this experiment was to systematically investigate the impact of plant spacing and fertilization dose on the growth and yield traits of okra (*Abelmoschus esculentus*) in Sudan. Each experimental plot, measuring 2 meters by 2 meters, contained three rows of okra plants spaced 60 cm apart. The data collected focused on key growth and yield components. The experimental area was divided into three blocks to account for variations in field conditions. Treatments were randomly assigned to plots within each block to minimize the influence of uncontrolled variables. The following data were recorded:

Plant Growth Measurements

Plant height (cm) and the number of nodes and leaves per plant were counted as an average of five plants, randomly selected from each plot 40 days from sowing. Using a ruler, plant height was measured from the soil level to the tip of the main stem. The number of nodes on the main stem and the number of leaves per plant were counted. The number of nodes to the first flower was recorded in the field at the onset of flowering, which was visually identified when the first flower bud was fully formed.
Yield and its components.

To evaluate yield and its components, pod length (cm) and fresh weight were measured from an average of ten pods randomly collected from each plot, five days post-flowering. The pod length was taken from the base to the tip with a digital caliper. Pod fresh weight (g) was determined using an electronic scale. The number of seeds per pod was counted manually from the pods that remained on the plant for 25-30 days after flowering, achieving physiological maturity and displaying changes in pod colour along with early signs of cracking. The pods were then harvested and allowed to dry in the shade for ten days, after which the seeds were counted manually. The total number of pods per plant was calculated by averaging the counts from five randomly chosen plants in each plot, which were tagged at the flowering stage and harvested over 100 days.

Statistical Analysis

The data collected from each plot were analyzed using the OPSTAT statistical software developed by Sheoran et al. (1998). An Analysis of Variance (ANOVA) was employed to evaluate the main effects of spacing (A) and fertilizer (B), as well as their interaction effects on the dependent variables. The F-test, proposed by Fisher (1928), was used to test the significance between the means of the groups at a 5% significance level ($\alpha = 0.05$). The Critical Difference (CD) test was used for post-hoc comparisons between the treatment means (Gomez and Gomez, 1984). According to the CD test, the means within a column followed by different lowercase letters were considered significantly different. Critical difference values were provided alongside each group's mean in Tables 1 and 2 to indicate the significance level between means.

Results and Discussion

Okra Vegetative Growth

Tables 1 and 2 present the analysis results for the main effects of each factor and their interactions for growth and yield traits, respectively.

Plant height (cm)

The main effect of spacing and fertilization on plant height was significant at a 5% confidence level, as per Table 1. A spacing of (60 cm × 30 cm) resulted in significantly taller plants with a mean length of 15.1 cm. Nitrogen fertilization doses in urea (46% N) at 60, 80, and 100 $kg.ha^{1}$ resulted in significantly taller plants, recording a length of 14.0, 13.8, and 13.9 cm., respectively. The interaction effects of spacing

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with urea fertilization dose varied significantly at a 5% confidence level. The most significant interaction for plant height was observed in the combination of a spacing of (60 cm × 30 cm) with 60, 80, and 100 kg.ha^{-1} fertilizing doses, recording a length of 14.0, 13.8, and 13.9 cm, respectively. This suggests moderate plant density reduces competition for light and nutrients, while a sufficient nitrogen supply promotes vegetative growth. Similar findings were reported by Brar and Singh (2016), Adlan et al. (2017), Singh et al. (2020), and Anim (2022), indicating that optimal spacing and nitrogen levels enhance stem elongation in okra.

Number of leaves per plant

The main effect of spacing revealed that a spacing of (60 cm × 30 cm) significantly gives more leaves per plant, recording a mean of 6.15. Nitrogen fertilization dose at 60 kg.ha^{-1} recorded the highest significant number of leaves per plant at a 5% confidence level, recording a mean of 6.15. Analysis of the interaction effect was significant at a 5% confidence level, as per Table 1. The highest significant interaction for the number of leaves was observed in the combination of the spacing of (60 cm × 30 cm) with 60 kg.ha^{-1} of urea, recording a mean of 7.3. This revealed that this combination produces the highest number of leaves. This is consistent with the findings of Adlan et al. (2017), Fatima et al. (2019). and Guo et al. (2020), who reported that adequate nitrogen enhances vegetative growth and leaf production, which are crucial for maximizing photosynthetic capacity and yield.

Number of nodes to the first flower

The independent effect of fertilizer doses and spacing between plants on the number of nodes to the first flower was significant at a 5% confidence level, as per Table 1. A spacing of (60 cm × 20 cm) significantly produces plants bearing flowers at lower nodes closer to the base of the plant, recording a mean of 5.8 nodes. The fertilization doses at 120 kg.ha^{-1} were found to significantly encourage lower node bearing, recording a mean of 6.2. The interaction effect between plant spacing and urea fertilization dose varies significantly at a 5% confidence level. The interaction of (60 cm × 20 cm) spacing with any of the three urea doses (80, 100, and 120 kg.ha^{-1}) led to significantly lower node bearing, recording a mean of 5.5, 5.6, and 5.8, respectively. This result indicates that denser planting and higher nitrogen levels accelerate the vegetative phase, leading to an earlier reproductive phase. Such findings are essential for predicting harvest times and optimizing crop cycles. The literature has limited information about the relationship between nitrogen application and the number of nodes to the first flower in okra. While some researchers have reported the effect of nitrogen on flowering time and delay in flowering in okra, they do not directly address its impact on the number of nodes in the first flower (Changade et al., 2023; Meena et al., 2024).

Number of nodes on the main stem

The main effect of spacing revealed that a spacing of (60 cm × 30 cm) significantly increases the number of nodes per plant, recording a mean of 7.8 nodes. The main effect of nitrogen fertilization in the form of urea (46% N) at 80 and 100 (kg.ha^{-1}) significantly increases the number of nodes per plant at a 5% confidence level, recording a mean of 7.6 each, respectively. The interaction effect between plant spacing and urea fertilization dose is significant at a 5% confidence level, as per Table 1. The interaction of (60 cm × 30 cm) spacing with urea doses of 100 kg.ha^{-1} recorded a significantly higher mean of 8.4 nodes. These findings conform with the results of Brar and Singh (2016).

Okra Yields

Fruit fresh weight (g)

Fertiliser doses, spacing, and interaction were significant at a 5% confidence level, as per Table 2. The main effect of spacing revealed that a spacing of (60 cm × 30 cm) recorded a significant and high mean of 7.1 (g) for fruit weight. The main effect of nitrogen fertilization doses in the form of urea (46% N) at 60 (kg.ha^{-1}) significantly produced heavier fruits, recording a mean of 6.9 (g) for fruit weight. The interaction effect revealed that the combination of (60 cm × 30 cm) x (60 kg.ha^{-1}) and (60 cm × 25 cm) x (60 kg.ha^{-1}) produced significantly higher values for fruit fresh weight, recording a mean of 7.7 and 7.6 (g), respectively. This finding aligns with Parmar et al. (2016) and Singh et al. (2020), who observed that moderate plant density and adequate nitrogen supply enhance fruit development by ensuring sufficient nutrient availability and reducing competition.

Fruit length (cm)

Fertiliser doses, spacing, and interaction were significant at a 5% confidence level, as per Table 2. The main effect of spacing revealed that a spacing of (60 cm × 30 cm) recorded a significant and high mean value of 5.1 (cm) for fruit length. The main effect for nitrogen fertilization in the form of urea (46% N) at 60 (kg.ha^{-1}) recorded significantly higher values for fruit length at a 5% confidence level, recording a mean of 4.8 (cm). The interaction effect of fertilization doses

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Table 1. Main and interaction effect of plant spacing and urea fertilization doses on growth traits of okra

Source of variation	Plant height (cm)	Number of leaves per plant	Number of nodes to the first flower	Number of nodes per plant
The main effect of spacing				
S1 (60cm×20cm)	14.4 b	5.2 d	5.8 d	7.3 c
S2 (60cm×25cm)	14.1 c	5.8 b	6.7 b	7.6 b
S3 (60cm×30cm)	15.1 a	6.2 a	7.1 a	7.8 a
S4 (60cm×35cm)	11.5 d	5.4 c	6.5 c	7.2 c
CD (α=0.05)	**0.28**	**0.16**	**0.20**	**0.15**
The main effect of the Urea rate				
Ur1 (60 kg.ha-1)	14.0 a	6.2 a	6.8 a	7.3 b
Ur2 (80 kg.ha-1)	13.8 a	5.7 b	6.6 b	7.6 a
Ur3 (100 kg.ha-1)	13.9 a	5.4 c	6.5 b	7.6 a
Ur4 (120 kg.ha-1)	13.3 b	5.4 c	6.2 c	7.4 b
CD (α=0.05)	**0.28**	**0.16**	**0.20**	**0.15**
Interaction effect (spacing × urea rate)				
S1 × Ur1	14.7 b	5.5 de	6.3 d	7.3 de
S1 × Ur2	14.4 bc	5.7 cd	5.5 e	8.0 bc
S1 × Ur3	14.8 b	5.2 e	5.6 e	6.9 f
S1 × Ur4	13.5 d	4.5 f	5.8 e	7.1 ef
S2 × Ur1	14.8 b	6.4 b	6.8 c	7.8 c
S2 × Ur2	14.1 c	5.9 cd	7.1 bc	7.4 de
S2 × Ur3	14.0 c	5.4 de	6.7 cd	7.6 cd
S2 × Ur4	13.4 d	5.6 d	6.1 de	7.6 cd
S3 × Ur1	15.5 a	7.3 a	7.7 a	7.3 de
S3 × Ur2	15.1 ab	6.0 c	7.3 b	8.1 b
S3 × Ur3	15.4 a	5.6 d	6.8 c	8.4 a
S3 × Ur4	14.3 c	5.7 cd	6.6 cd	7.2 e
S4 × Ur1	11.1 f	5.4 de	6.4 d	6.6 g
S4 × Ur2	11.4 f	5.3 de	6.4 d	7.0 ef
S4 × Ur3	11.4 f	5.3 de	6.7 cd	7.5 d
S4 × Ur4	12.1 e	5.6 d	6.4 d	7.6 cd
CD (α=0.05)	**0.56**	**0.33**	**0.40**	**0.30**

Note: Means within a column followed by different lowercase letters are significantly different at the 5% significance level (α=0.05) according to the Critical Difference (CD) test.

and spacing was significant at a 5% confidence level. The interaction effect between the spacing of (60 cm × 30 cm) with 60 (kg.ha^{-1}), and 80 (kg.ha^{-1}), recorded significantly higher values of 5.5 (cm) each. This finding suggests that moderate plant density and adequate nitrogen supply enhance pod development and give longer fruits by ensuring sufficient nutrient availability and reducing competition (Ahirwar et al., 2021).

Number of fruits per plant

Fertiliser doses, spacing, and interaction were significant at a 5% confidence level, as per Table 2. The main effect of spacing revealed that a spacing of (60 cm × 30 cm) recorded a significantly higher mean value of 6.5 fruits per plant. The main effect of nitrogen fertilization is urea at 60, 80, and 100 kg.ha^{-1}, recorded significantly higher values for the number of fruits per plant at a 5% confidence level, recording a mean of 5.8, 5.9, and 6.0, respectively. The interaction effect revealed several combinations

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of significantly higher means, including (60 cm × 25 cm) × 60 (kg.ha^{-1}) and the combinations between (60 cm × 30 cm) with 60, 80, and 100 (kg.ha^{-1}), recording a mean value of 6.2, 7.2, 6.4 and 6.2 respectively. This finding is consistent with research by Brar and Singh (2016); Adetula and Denton (2003), indicating that optimal nitrogen levels enhance reproductive success and yield potential in okra.

Number of seeds per fruit

Fertiliser doses, spacing, and their interaction were significant at a 5% confidence level (Table 2). The main effect of spacing revealed that a spacing of (60 cm × 30 cm) recorded a significantly higher mean value of 14.0 seeds per fruit. Nitrogen fertilization in the form of urea (46% N) at 60 (kg.ha^{-1}) recorded a significantly higher mean value of 12.9 seeds at a 5% confidence level. The interaction of fertilization doses and spacing was significant at a 5% confidence level. The combination of (60 cm × 30 cm) with 60 (kg.ha^{-1}), and 80 (kg.ha^{-1}) recorded significantly higher mean values of 15.1 and 14.5 seeds per pod, respectively. This supports the findings by Adelabu and Franke

Table 2. Main and interaction effect of plant spacing and urea fertilization doses on yield traits of okra

Source of variation	Fruit fresh weight (g)	Fruit length (cm)	Number of fruits per plant	Number of seeds per fruit
The main effect of spacing				
S1 (60cm×20cm)	5.7 c	3.5 d	4.9 c	10.9 c
S2 (60cm×25cm)	6.6 b	4.4 b	5.9 b	12.1 b
S3 (60cm×30cm)	7.1 a	5.1 a	6.5 a	14.0 a
S4 (60cm×35cm)	5.6 d	4.1 c	5.8 b	9.3 d
CD (α=0.05)	**0.09**	**0.08**	**0.51**	**0.62**
The main effect of the Urea rate				
Ur1 (60 kg.ha-1)	6.9 a	4.8 a	5.8 a	12.9 a
Ur2 (80 kg.ha-1)	6.6 c	4.3 b	5.9 a	11.0 b
Ur3 (100 kg.ha-1)	5.8 d	3.3 d	6.0 a	11.2 b
Ur4 (120 kg.ha-1)	6.7 b	3.8 c	5.3 b	11.2 b
CD (α=0.05)	**0.09**	**0.08**	**0.51**	**0.62**
Interaction effect (spacing × urea rate)				
S1 × Ur1	6.3 e	4.2 d	5.1 bc	12.6 b
S1 × Ur2	5.8 g	3.4 g	5.4 bc	11.1 c
S1 × Ur3	5.1 j	3.7 f	5.3 bc	9.4 d
S1 × Ur4	5.8 g	2.7 h	3.8 d	10.4 cd
S2 × Ur1	7.6 a	4.8 b	6.2 ab	13.5 b
S2 × Ur2	7.1 c	4.0 e	6.1 b	9.9 cd
S2 × Ur3	6.0 f	4.6 c	6.0 bc	12.5 b
S2 × Ur4	5.6 h	4.2 d	5.1 bc	12.4 b
S3 × Ur1	7.7 a	5.5 a	7.2 a	15.1 a
S3 × Ur2	7.5 b	5.5 a	6.4 ab	14.5 a
S3 × Ur3	6.8 d	4.8 b	6.2 ab	13.3 b
S3 × Ur4	6.3 e	4.6 c	6.1 b	13.1 b
S4 × Ur1	5.9 fg	4.6 c	4.8 c	10.3 cd
S4 × Ur2	5.9 fg	4.3 d	5.5 bc	8.4 d
S4 × Ur3	5.3 i	3.9 ef	6.6 ab	9.5 d
S4 × Ur4	5.3 i	3.8 f	6.1 b	9.1 d
CD (α=0.05)	**0.18**	**0.16**	**1.03**	**1.24**

Note: Means within a column followed by different lowercase letters are significantly different at the 5% significance level (α=0.05) according to the Critical Difference (CD) test.

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(2023), who demonstrated that adequate nitrogen is crucial for seed development, weight, and pod set in okra.

The spacing of okra plants significantly impacts their growth and yield. When okra plants are closely spaced, they may compete for essential resources such as light, moisture, and nutrients, leading to suboptimal growth, reduced yield, and lower-quality fruits (Padhiyar, 2023) and (Adesina and Wiro, 2020). On the other hand, when plants are widely spaced, they may struggle to utilize natural resources, including sunlight and soil moisture efficiently. Increased spacing allows a more significant amount of sunlight to reach the soil surface rather than being absorbed by leaves for photosynthesis; moreover, it promotes the evaporation of soil water, thereby reducing the amount of moisture available to plants, potentially leading to water stress, especially in arid or semi-arid regions. Both factors result in lower yields (Chapepa et al., 2020; Mellouli et al., 2000). Therefore, plant spacing plays a crucial role in influencing the growth and yield of okra by affecting light interception, air circulation, and nutrient availability. Recent studies have shown that plant spacing significantly affects various growth factors. Optimum spacing improves light penetration and reduces resource competition, enhancing growth and higher yields. A study by Norman, et al. (2019). found that optimal plant spacing improved okra yields by reducing pest infestation and enhancing air circulation. Similarly, Khanal et al. (2020); Padhiyar et al. (2023) reported that a wider spacing of 60 cm × 30 cm resulted in higher pod yield and better quality due to improved light interception and nutrient uptake.

Fertilization is crucial for okra cultivation, as it directly affects nutrient availability and uptake, influencing vegetative growth and pod development. Nitrogen is essential, as it promotes vegetative growth and increases leaf area, which is critical for photosynthesis, (Ahirwar et al., 2021). Similarly, Adelabu and Franke (2023) found that balanced fertilization improved okra yield and quality, highlighting the importance of optimizing nutrient management. Although nitrogen is a crucial input, it is also essential to use it efficiently by manipulating doses with another fertilization source, such as farmyard manure (Nurmas et al., 2021; Rafee et al., 2024).

Several findings underline the importance of considering multiple factors beyond plant spacing when optimizing okra production. Factors such as nitrogen dose, okra variety, soil type, and environmental conditions can all influence the effectiveness of a particular plant spacing. The significant interactions between spacing and fertilization underscore the necessity of considering both factors together for optimal okra cultivation. The results align with existing research emphasizing the synergistic effects of these variables. The studies by Danmaigoro et al. (2022) highlighted the combined application of optimal spacing and fertilization in improving okra's physiological parameters and yield. Furthermore, Khanal, et al. (2020) found that appropriate spacing and nutrient management reduced competition for light and nutrients, enhancing overall plant performance.

The integration of results shows a clear pattern where the 60 cm × 30 cm plant spacing, in combination with a nitrogen fertilization dose of 60 kg.ha^{-1}, consistently optimized both the growth and yield parameters of okra. This combination reduced competition for resources and provided sufficient nitrogen to promote vegetative growth, leading to taller plants, more leaves, and higher yield components.

Plant spacing and fertilizer doses significantly affected the yield components, including pod length, pod fresh weight, and number of seeds per pod. The 60 cm × 30 cm spacing, combined with 60 kg.ha^{-1} nitrogen, optimized these yield parameters, significantly increasing pod length, fresh weight, and seed number per pod. Plant spacing and fertilizer doses significantly affected the yield components, including pod length, pod fresh weight, and number of seeds per pod. The 60 cm × 30 cm spacing, combined with 60 kg.ha^{-1} nitrogen, optimized these yield parameters, significantly increasing pod length, fresh weight, and seed number per pod. Specifically, this combination produced pods with a mean size of 5.5 cm, fresh weight of 7.7 g, and 15.1 seeds per pod. These results highlight the importance of optimal plant density and nitrogen fertilization for enhancing okra yield.

Conclusion and Recommendations

The study concludes that a plant spacing of 60 cm × 30 cm and a nitrogen fertilization level of 60 kg.ha-1 generally optimize growth and yield parameters in okra. It also recorded a significant interaction between nitrogen fertilization doses and spacing on growth and yield traits. The results are consistent with previous research, underscoring the importance of optimizing agronomic practices for improved productivity. These findings provide a valuable guideline for enhancing okra production in Sudan and similar agroecological zones. It will benefit local farmers by improving crop yields, enhancing produce quality, and promoting sustainable farming practices. These outcomes can contribute to food security, economic growth, and environmental sustainability in Sudan's agricultural

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sector. Future research should explore the long-term effects of these practices on soil health and crop sustainability over multiple growing seasons. It will be beneficial if the applicability of these recommendations is tested in different agro-climatic zones within Sudan, especially in Kordofan, Darfur, and the rain-fed sector in Qadarif and the Blue Nile States.

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