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Effect of nitrogen fertilizer level and application method on some growth traits and total yield of okra (*Abelmoschus esculentus*) under different irrigation systems

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Abstract

This study aimed to evaluate the effect of different nitrogen fertilizer levels and application methods, in combination with surface and subsurface drip irrigation systems, on some growth characteristics and productivity of okra (*Abelmoschus esculentus* L.). A field experiment was conducted inside a plastic greenhouse at the Agricultural Research Station, College of Agriculture, University of Basrah, during the 2024-2025 growing season. A factorial experimental design was used, including four nitrogen fertilizer levels (0, 50, 75, and 100% of the recommended rate), two fertilizer application methods (band application and fertigation), and two irrigation systems (surface drip and subsurface drip). Measurements included number of flowers, total leaf chlorophyll content, and total fruit yield. The results showed significant effects of nitrogen fertilizer levels, application methods, and irrigation systems on all studied traits. The 75% nitrogen level recorded the highest number of flowers (40.42 flowers plant⁻¹) and chlorophyll content (0.0250 mg 100 g⁻¹ fresh weight), whereas the 100% level achieved the highest total fruit yield (6.0760 t ha⁻¹). Fertilizer application via irrigation water (fertigation), particularly under subsurface drip irrigation, outperformed the other treatments in improving the studied traits. The results indicate that integrated management of nitrogen fertilization and subsurface drip irrigation is an effective strategy to enhance okra productivity and improve fertilizer and water use efficiency.

Keywords: Okra, nitrogen fertilizer, fertigation, drip irrigation, chlorophyll, total yield

Introduction

Nitrogen is one of the essential macronutrients for plant growth, as it is a key component of proteins, nucleic acids, and chlorophyll, and plays a pivotal role in physiological processes associated with vegetative, flowering, and fruiting growth. Nitrogen is primarily absorbed by plants in the form of nitrate or ammonium, constituting approximately 2-5% of the plant's dry weight (Watson, 2000) [21]. More than 70% of leaf nitrogen is concentrated in the chloroplasts responsible for photosynthesis (Mendoza-Tafolla *et al.*, 2019) [13]. Consequently, the availability of nitrogen at optimal levels positively reflects on flower formation, increased chlorophyll content, and improvement of the total crop yield.

Urea (46% N) is one of the most widely used nitrogen fertilizers globally due to its high nitrogen content and low cost (Watson, 2000) [21]. However, its efficiency in calcareous soils, which are common in Iraq, is often limited due to losses through ammonia volatilization or leaching, particularly when broadcast-applied on the soil surface (Rochette *et al.*, 2009) [16]. Numerous studies have demonstrated that the method of fertilizer application is no less important than the application rate itself, as it directly affects nitrogen availability and uptake by the roots.

Okra (*Abelmoschus esculentus* L.) is one of the economically and nutritionally important summer vegetable

crops in tropical and subtropical regions, particularly in Iraq, due to the high nutritional value of its fruits, which are rich in fiber, vitamins, and minerals. The productivity of this crop largely depends on balanced fertilization and irrigation management, given its sensitivity to nutrient availability—especially nitrogen—during different growth stages (Gemede *et al.*, 2015) [8].

Fertilizer application through irrigation water (fertigation) is considered a modern technique that enhances fertilizer use efficiency by delivering dissolved nutrients directly to the active root zone and reducing losses through volatilization and leaching, in addition to improving the spatial uniformity of nutrient distribution (Hagin *et al.*, 2002; Shukla *et al.*, 2018) [9, 18]. Moreover, integrating fertigation with drip irrigation systems, particularly subsurface drip irrigation, provides a stable moisture and nutrient environment around the roots, reduces water evaporation and weed growth, and improves water and fertilizer use efficiency compared with surface irrigation (Roddy, 2006) [17].

Despite the availability of numerous studies addressing the effect of nitrogen fertilization on okra growth and yield, studies combining different nitrogen levels, application methods, and surface and subsurface drip irrigation systems remain limited, particularly under the environmental conditions of calcareous soils in southern Iraq. Therefore,

this study aims to evaluate the effect of nitrogen fertilizer levels and application methods on flower number, chlorophyll content, and total yield of okra under surface and subsurface drip irrigation systems, with the goal of identifying optimal fertilizer and water management practices that enhance productivity and resource use efficiency.

Materials and Methods

A field experiment was conducted inside a plastic greenhouse at the Agricultural Research and Experiment Station, College of Agriculture, University of Basrah, Karma Ali location, during the 2024-2025 growing season. The experiment investigated the effect of nitrogen fertilizer levels and application methods under surface and subsurface drip irrigation systems on the growth and productivity of okra (*Abelmoschus esculentus* L.). Soil properties: Composite soil samples were collected from a depth of 0-30 cm before planting, air-dried, sieved through a 2 mm mesh, and subjected to standard physical and chemical analyses. The results showed that the soil had a silty clay texture, a pH of 7.8, electrical conductivity of 5.8 dS m⁻¹, organic matter content of 3.3%, and dominant calcareous conditions, as shown in Table 1.

Table 1: Some chemical and physical properties of the study soil.

Unit	Value	Trait
	8.13	pH
dS m ⁻¹	5.84	EC
cmol (+) kg ⁻¹	11.71	CEC
Ppm	839.16	Available nitrogen
Ppm	82.21	Available phosphorus
Ppm	27.2	Available potassium
%	3.3	Organic matter
µg m ⁻³	2.74	Particle density
µg m ⁻³	1.49	Bulk density
%	45.8	Total porosity
g kg ⁻¹	105	Sand
	429	Silt
	448	Clay
	Clay loam	soil texture

Land preparation: The experimental field was prepared by perpendicular plowing, followed by opening furrows at a spacing of 60 cm. Organic manure (cattle manure) was applied at a rate of 5 t ha⁻¹ to all treatments, in addition to phosphorus and potassium fertilizers according to recommended rates. Okra seeds (cv. Hinnawi) were planted on 1/6/2024, with five seeds per hill and a spacing of 40 cm between hills. Plants were thinned one month after emergence to three plants per hill.

Experimental Design and Treatments

The experiment was conducted using a factorial design with three main factors

1. Nitrogen fertilizer levels (N)

- **N0:** 0% (control)
- **N1:** 50% of the recommended rate.
- **N2:** 75% of the recommended rate.
- **N3:** 100% of the recommended rate.

Urea fertilizer (46% N) was used as the nitrogen source and applied in three splits: one before planting and two after planting.

2. Fertilizer application methods (M)

- **M1:** Band application (fertilizer placed in a whole 5 cm away from the plant and at a depth of 5 cm).
- **M2:** Fertigation (fertilizer dissolved in irrigation water and injected into the irrigation system during the last hour of irrigation).

3. Irrigation systems (I)

- **I1:** Surface drip irrigation.
- **I2:** Subsurface drip irrigation, with laterals buried at a depth of 10-15 cm below the soil surface.

Studied Traits

Measurements were taken on three randomly selected plants from each experimental unit and included:

1. **Number of flowers (flowers plant⁻¹):** The total number of flowers was recorded during February, March, and April 2025.
2. **Total leaf chlorophyll content (mg 100 g⁻¹ fresh weight):** Determined 60 days after emergence using the 80% acetone extraction method and measuring absorbance at wavelengths of 645 and 663 nm, according to standard equations.
3. **Total yield (t ha⁻¹):** Calculated by summing the weights of pods harvested during all picking periods and converting them to a per-hectare basis based on plant density.

Statistical Analysis

Data were statistically analyzed using analysis of variance (ANOVA) for a factorial design, and means were compared using the least significant difference (LSD) test at the 0.05 probability level.

Results and Discussion

First: Effect of Nitrogen Fertilizer Levels, Application Methods, and Irrigation System on the Number of Flowers

The results presented in Table 2 and Appendix 2 showed significant effects of nitrogen fertilizer level, application method, and irrigation system on increasing the number of flowers in okra plants compared with the control treatment at different measurement stages. No flowers were recorded in January for all treatments; flowering began in February, reached its maximum in March, and generally declined in April. This pattern is attributed to the gradual plant response to nitrogen fertilization and the association of flowering with phenological growth stages, in which nutritional effects interact with environmental conditions. Similar findings were reported by FAO (2010) and Hegazy *et al.* (2023), who indicated that adequate nitrogen availability enhances flower bud formation, whereas nitrogen deficiency or excess disrupts the balance between vegetative and reproductive growth.

Data in Table 2 indicated a significant effect of nitrogen level on flower number, with a gradual increase as nitrogen level increased compared with the control. The 75%

nitrogen level recorded the highest number of flowers at the third measurement (March), reaching 40.42 flowers plant⁻¹, significantly surpassing the 50% and 100% levels, which recorded 28.33 and 36.48 flowers plant⁻¹, respectively, while the control recorded 34.42 flowers plant⁻¹. These results indicate that moderate nitrogen levels represent an optimal point for balancing vegetative and reproductive growth.

Fertigation significantly outperformed band application

under both surface and subsurface drip irrigation systems. Subsurface fertigation achieved the highest number of flowers in March, with an average of 42.62 flowers experimental unit⁻¹, compared with values ranging from 23.00 to 28.08 flowers experimental unit⁻¹ for the other methods. This superiority is attributed to improved nitrogen availability and uptake efficiency in the rhizosphere (Brar & Singh, 2015; Pokhrel *et al.*, 2024) ^[5, 15].

Table 2: Effect of nitrogen fertilizer application level and irrigation method on number of flowers (flower•plant⁻¹) in okra plants

Month	Application Method	Irrigation Method	100%	75%	50%	0%	Mean M	Mean I
January 2025	Fertigation	Surface irrigation	0.00	0.00	0.00	0.00	0.00	0.00
January 2025	Fertilization	Surface irrigation	0.00	0.00	0.00	0.00	0.00	
January 2025	Fertigation	Subsurface irrigation	0.00	0.00	0.00	0.00	0.00	0.00
January 2025	Fertilization	Subsurface irrigation	0.00	0.00	0.00	0.00	0.00	
February 2025	Fertigation	Surface irrigation	12.00	14.67	12.00	5.00	10.92	10.13
February 2025	Fertilization	Surface irrigation	12.00	10.00	5.00		10.33	
February 2025	Fertigation	Subsurface irrigation	14.67	16.00	15.00	6.00	12.92	12.04
February 2025	Fertilization	Subsurface irrigation	13.00	12.00	6.00		13.67	
March 2025	Fertigation	Surface irrigation	4.33	7.00	1.33	1.00	3.42	2.71
March 2025	Fertilization	Surface irrigation	2.33	2.00	1.00		2.67	
March 2025	Fertigation	Subsurface irrigation	7.33	4.00	1.33	2.00	3.67	3.88
March 2025	Fertilization	Subsurface irrigation	8.00	2.33	2.00		4.00	
April 2025	Fertigation	Surface irrigation	30.00	39.00	37.33	6.00	28.08	25.54
April 2025	Fertilization	Surface irrigation	37.67	23.33	6.00		25.00	
April 2025	Fertigation	Subsurface irrigation	50.33	43.00	21.33	3.00	29.42	28.29
April 2025	Fertilization	Subsurface irrigation	42.00	31.33	3.00		32.33	
Overall	Fertigation	Surface irrigation	15.44	20.22	16.89	4.00	14.14	12.79
Overall	Fertilization	Surface irrigation	17.33	11.78	4.00		12.67	
Overall	Fertigation	Subsurface irrigation	24.11	21.00	12.56	3.67	15.33	14.74
Overall	Fertilization	Subsurface irrigation	21.00	15.22	3.67		16.67	

A significant interaction was observed between nitrogen level and application method, with the 100% nitrogen level combined with subsurface fertigation producing the highest number of flowers (42.11 flowers experimental unit⁻¹). Subsurface drip irrigation also significantly outperformed surface drip irrigation in flower number due to better moisture conservation and reduced water stress (FAO, 2010; Pokhrel *et al.*, 2024) ^[15].

Second: Effect of Treatments on Total Chlorophyll Content

Table 3 results showed a significant effect of nitrogen fertilizer application level and method on total chlorophyll content in okra plants at mid-growth season (April).

The Table 3 clearly indicates that the factor of application level had a significant effect by increasing the total chlorophyll content compared to the control treatment. The total chlorophyll content in okra plants increased with increasing levels of nitrogen fertilizer application. The highest content was achieved at the second level of fertilizer application (75%), recording a value of 0.0250 mg·100 g⁻¹ fresh weight, without significant difference from the first

and third levels, but with significant differences compared to the control treatment which recorded 0.0090 mg·100 g⁻¹ fresh weight. Similarly, the first and third levels did not differ significantly from each other, but both significantly outperformed the control treatment.

The reason for this may be attributed to the response of okra plants to nitrogen from the fertilizer additions, its absorption by the roots, and since it is mobile within the plant, it is rapidly translocated from the roots to the upper part of the plant (vegetative growth). There, it is assimilated and incorporated into protein synthesis, leading to the achievement of a large biomass, which in turn resulted in recording a high total chlorophyll content (Marschner, 2012; Taiz *et al.*, 2015) ^[12, 19].

The variation in total chlorophyll content among plants with increasing levels of nitrogen fertilizer application compared to the control is due to the plants' response in absorbing nitrogen and its contribution to photosynthesis processes, as well as increasing their protein content and number of chloroplasts. The plant stores the largest portion of protein and cellular contents of the leaves in the chloroplasts, which constitute about 80% of the protein in the leaf cell.

Table 3: Effect of nitrogen fertilizer application level and irrigation on total chlorophyll content (mg·100 g⁻¹ fresh weight) in okra plants at mid-growth season.

Mean I	Mean M	Application rate N				Application method M	Irrigation method I
		0	50%	75%	100%		
0.0184	0.0199	0.0083	0.0244	0.026	0.0208	Fertigation	Surface irrigation
	0.0169	0.0083	0.0227	0.0188	0.0178	Fertilization	
0.0200	0.0222	0.0095	0.0237	0.0285	0.0278	Fertigation	Subsurface irrigation
	0.0178	0.0095	0.0191	0.0266	0.0195	Fertilization	
		0.0090	0.0223	0.0250	0.0215	mean	
	RLSD	N = 0.0012 N*M = 0.0016 N*D = 0.0018 N*M*D = 0.0028					

The control treatment recorded the lowest value of 0.0090 mg·100 g⁻¹ fresh weight. Regarding the method of nitrogen fertilizer application, the above Table indicates a significant effect on total chlorophyll content. The fertigation method (application through irrigation water) achieved the highest total chlorophyll content with a value of 0.0222 mg·100 g⁻¹ fresh weight, representing percentage increases of 18.71%, 11.55%, and 31.36% compared to the other application methods: side-dressing, fertigation combined with subsurface drip irrigation, and surface drip irrigation, respectively.

This was followed by the fertigation method using surface drip irrigation, recording a value of 0.0199 mg·100 g⁻¹ fresh weight.

The reason for this is attributed to the high efficiency of nutrient use or absorption under the fertigation method, where the nutrient element (nitrogen) is delivered directly to the absorption site in the plant (root hairs), allowing rapid and easy uptake, and consequently achieving higher levels of total chlorophyll content in the vegetative tissues (tender leaves) of the plant (Havlin *et al.*, 2014) ^[10].

As for the interaction effect between the level and method of nitrogen fertilizer application, the results in Table 3 show that the general trend of the interaction was towards an increase in total chlorophyll content in okra plants with increasing application level, particularly at the second application level (75%) when combined with the fertigation method using subsurface drip irrigation, which recorded the highest value of total chlorophyll content at 0.0285 mg·100 g⁻¹ fresh weight, significantly outperforming all other levels across all other application methods.

The lowest values were recorded in the control treatment under both the fertigation and side-dressing methods through surface-applied drip irrigation pipes placed on the soil surface, with a value of 0.0083 mg·100 g⁻¹ fresh weight. This may be attributed to the compatibility of the semi-high (75%) dissolved nitrogen fertilizer application through or with subsurface irrigation water, which supplies nitrogen to okra plants in dissolved form, allowing rapid root absorption, fast translocation to the upper part of the plant, assimilation within the cell, and a positive reflection on total

chlorophyll content (Brar & Singh, 2015; Taiz *et al.*, 2015) ^[5, 19].

When comparing the two irrigation methods, Table 3 shows the total chlorophyll content in okra plants, revealing significant differences for the subsurface drip fertigation method, through which the various dissolved nitrogen fertilizer applications are delivered via buried irrigation laterals at depths ranging between 10-15 cm below the soil surface. This method achieved a value of 0.0200 mg·100 g⁻¹ fresh weight, with significant superiority over the surface drip irrigation method, which recorded a lower value of 0.0184 mg·100 g⁻¹ fresh weight, lagging behind the subsurface drip irrigation method by a reduction percentage of 8%.

This may be due to the efficiency of subsurface drip irrigation, which maintains constant adequate soil moisture content in the study area, enabling the plant to absorb irrigation water without high effort or stress as a result of minimal evaporation or water loss, since the water source (drippers or drip lines) is located very close to the root hairs, with the drippers or drip lines positioned below the soil surface at a depth of 10-15 cm.

These results are largely consistent with those reported by (Ayars *et al.*, 2015; Pokhrel *et al.*, 2024) ^[4, 15], indicating that delivering water to plants subsurface near the roots or root hairs achieves a regulated water sufficiency for okra plants to avoid drought stress, thereby positively reflecting on the vegetative part of the plant and some of its morphological characteristics, including total chlorophyll content.

Third: Effect of Treatments on Total Yield of Okra

Results in Table 4 indicated significant effects of nitrogen level and application method on total yield. The 100% nitrogen level achieved the highest total yield (6.076 t ha⁻¹), significantly exceeding the 50% and 75% levels, which recorded 5.0763 and 5.4432 t ha⁻¹, respectively, while the control recorded only 0.396 t ha⁻¹. This reflects the strong response of okra to nitrogen fertilization (FAO, 2010; Uko *et al.*, 2018; Abdelrahman *et al.*, 2019) ^[20, 1].

Table 4: Effect of nitrogen fertilizer application level and irrigation method on total yield (t·ha⁻¹) of okra plants.

Mean	Mean	Application rate N				Application method M	Irrigation method I
		100%	75%	50%	0%		
3.58	3.8535	5.638	4.928	4.506	0.342	Fertigation	Surface irrigation
	3.3015	4.797	4.288	3.779	0.342	Fertilization	
4.41	4.6818	7.48	5.862	4.935	0.450	Fertigation	Subsurface irrigation
	4.1435	6.389	5.227	4.508	0.450	Fertilization	
	3.9951	6.0760	5.0763	4.4320	0.3960	Mean	
		N = 0.0602 N*M = 0.0875 N*D = 0.0851 N*M*D = 0.131				RLSD = 0.05	

Fertigation significantly increased total yield compared with band application, due to improved nutrient delivery and uptake efficiency (Brar & Singh, 2015) ^[5]. The interaction between nitrogen level and application method showed that 100% nitrogen applied via fertigation achieved the highest yield. Subsurface drip irrigation significantly outperformed surface drip irrigation, increasing total yield by 18.23%, due to reduced water and nutrient losses (Pokhrel *et al.*, 2024; Al-Amiri & Talib, 2025) ^[15, 3].

Conclusion

The results of this study indicate that nitrogen fertilization is a critical factor in improving flowering traits, chlorophyll content, and total yield of okra, with plant response strongly dependent on fertilizer level, application method, and irrigation system. Moderate nitrogen levels (75% of the recommended rate) were superior in enhancing flower number and chlorophyll content, reflecting an optimal balance between vegetative and reproductive growth, while the full nitrogen rate (100%) produced the highest total yield by meeting plant nutritional requirements during critical growth stages.

Fertilizer application via irrigation water (fertigation) significantly outperformed band application in all studied traits, due to increased nitrogen uptake efficiency and reduced losses. Subsurface drip irrigation also proved superior to surface drip irrigation in improving flowering, chlorophyll content, and total yield, as a result of improved soil moisture conservation and nutrient availability.

The interaction results suggest that combining a high nitrogen level (100%) with fertigation under subsurface drip irrigation is among the most efficient treatments for achieving maximum okra productivity, while moderate nitrogen levels represent a suitable option for improving resource use efficiency without negatively affecting physiological plant traits.

Recommendations

1. The use of nitrogen fertilization via fertigation, particularly under subsurface drip irrigation, is recommended to enhance fertilizer and water use efficiency and improve okra productivity.
2. A moderate nitrogen level (approximately 75% of the recommended rate) is preferred when the objective is to improve physiological traits and flowering, whereas the full rate (100%) is recommended when targeting maximum total yield.
3. Future studies are suggested to investigate the interaction of nitrogen fertilization with other nutrients or the use of slow-release fertilizers under modern irrigation systems to enhance agricultural sustainability.

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