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RESEARCH ARTICLE

Impact of drip irrigation scheduling and nitrogen levels on nitrogen use efficiency, phenology and soil nitrogen dynamics of okra (*Abelmoschus esculentus* L.)

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Abstract

A field experiment was conducted at the Water Technology Centre, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, during *summer* of 2020-21 on "Optimization of irrigation and nitrogen levels under drip fertigation in okra (*Abelmoschus esculentus* L.) during *summer*" 2020-21. The experiment was laid out in a split-plot design with a Radhika hybrid (40 cm x 45 cm) and replicated thrice. The treatments comprised of three irrigation levels through drip scheduled at 0.75 Epan, 1.0 Epan and 1.25 Epan as main plots and four nitrogen levels *viz.,* 75% RDN (112.5 kg N ha^{-1}), 100% RDN (150 kg N ha^{-1}), 125% RDN (187.5 kg N ha^{-1}) and 150% RDN (225 kg N ha^{-1}) as sub-plots. The experimental soil was sandy clay in texture, alkaline in reaction, medium in organic carbon content, low in available nitrogen, and high in available phosphorus and potassium. The results indicated that optimized drip irrigation scheduling significantly improved NUE, with the highest efficiency observed at an Epan (I2) irrigation scheduling of 1.00 and a 75% RDN (N1) nitrogen level. Phenological development, including days to first flowering, days to 50% flowering, and days to first and final picking, was not influenced by irrigation scheduling and nitrogen supply. The number of branches per plant increased with 1.00 Epan (I2) and 100% RDN (N2) nitrogen application, contributing to higher biomass and potential yield. Soil nitrogen content varied across treatments, with initial and final measurements providing insights into nitrogen uptake and residual soil fertility.

Keywords: Drip irrigation, Nitrogen levels, Phenology, Fertigation, Okra.

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Introduction

Okra (*Abelmoschus esculentus* L.) is an important vegetable in India, occupying a 5.90 lakh hectare area with a total production of 69.49 lakh tons and a productivity of 12.0 t ha^{-1} (Horticultural Statistics at a glance, 2018). It is grown throughout the country for its tender green fruits during spring-summer and rainy seasons. It is a good source of vitamins A, B, and C, and is also rich in protein, carbohydrates, and fats (Adiroubane and Letachoumanane, 1992). It is one of the popular vegetable crops grown in Telangana, occupying a total of 13,006 hectares, with an area of 810 hectares during the summer (Horticulture Department, Telangana State, 2019). The overall production is 2.60 lakh tons, yielding a productivity of 20.49 t ha^{-1}. Okra is a warm-season vegetable crop that requires warm, humid conditions for optimal growth. Bhendi can be grown in a wide range of soils. However, it grows best in loose, friable, well-drained sandy loam soils rich in organic matter. It also gives good yield in heavy soils with good drainage. A pH range of 6.0 to 6.8 is considered optimum. Alkaline, saline soils, and soils with poor drainage are not suitable for this crop. It also requires a high amount of organic fertilization

(Akanbi et al., 2010; Akande et al., 2010). It is susceptible to low temperatures. Seeds of okra fail to germinate below 20˚C temperature. For optimal growth, flowering, and fruit initiation, okra requires an average temperature of 25 to 30°C. The okra plants grow taller in the rainy season than in the warm summer. Okra requires well-distributed moderate rainfall (80–100 cm) for the production of its young, edible fruits. Increased vigor and high productivity were observed when the crop was grown in the rainy season than in the summer season. Increasing differences between day and night temperatures can reduce seed yield considerably, especially during the summer season (Dhankhar et al., 2012). Therefore, appropriate agronomic management needs to be envisaged to improve yield during the summer season.

For yield enhancement of okra, a suitable water supply is essential to maintain a sufficient moisture condition in the soil throughout the crop growth period, especially during the summer season. The influence of water deficit on yield in this span is more pronounced under conditions of high temperature and low humidity (Vadar et al., 2019), which is more common during the summer season. To meet these optimal conditions, drip irrigation has been proven to be the most effective agronomic management option for enhancing the yield and quality of okra. It was reported that drip irrigation alone enhances crop yield by up to 40% over conventional irrigation (Sivanappan et al., 1987). The use of proper doses of fertilizer is one of the most important ways to produce high-quality green pod yields of okra. Nitrogen is an essential macronutrient that has great significance in the growth, development, and metabolism of plants. Nitrogen application significantly increases pod weight, diameter, number of fruits per plant and number of seeds per pod in okra (Moniruzzaman and Quamruzzaman, 2009) and other crops (Bahadur et al. 2021). Fertilizers applied under traditional methods are generally not utilized efficiently by the crop. In fertigation, nutrients are applied directly through emitters into the zone of maximum root activity, and consequently, fertilizer-use efficiency can be improved over the conventional method of fertilizer application. The drip fertigation in okra offers increased pod yield, pod weight, pod length, maximum root penetration depth, and better pod quality (Hari and Ramesh, 2017). It also reduces the cost of weeding and irrigation management, thereby enhancing economic returns (Sreeja and Satasiya, 2015). The integration of drip irrigation and nitrogen fertilization presents a synergistic approach to optimizing okra production. Drip irrigation not only ensures efficient water use but also facilitates the precise application of fertilizers, thereby enhancing nutrient availability and uptake by the plant roots. This targeted approach helps minimize nutrient losses through leaching and volatilization, common issues associated with conventional fertilization methods. Despite the recognized benefits of drip irrigation and nitrogen management, limited research has been conducted on their combined impact on okra. Understanding the interaction between irrigation scheduling and nitrogen application is crucial for optimizing nitrogen use efficiency (NUE), phenological development, branching patterns, and soil nitrogen dynamics in okra cultivation. Keeping in view the opportunity and research gap in the okra crop, the investigation into the impact of irrigation levels, quantification of water requirements under a drip system, and N levels for fertigation of the summer season okra crop was prioritized.

Materials and Methods

A field experiment was conducted at the Water Technology Centre, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad (17°19'24.7" N, 78°24'34.0" E at an altitude of 542.4 m amsl). The experimental site received 12.6 mm of precipitation overall during the summer growing season for okra. Soil texture is sandy clay soil, which is low in nitrogen, high in phosphorus and potassium that is readily available, medium in organic carbon content, alkaline in reactivity, and non-saline. Irrigation water was neutral (7.20 pH) and classified as C3 class, suggesting that it is suitable for irrigation when following good management practices. Radhika was the variety of okra utilized. With an inline dripper spacing of 40 cm and a 2 L/h discharge rate, the drip irrigation lateral was of the inline kind. A split-plot design was employed to conduct the experiment, with 12 treatments replicated three times. These treatments included drip irrigation scheduled at three different times: 0.75 Epan as I1, 1.0 Epan as I2, and 1.25 Epan as I3 and four different nitrogen concentrations: 75% RDN (N1), 100% RDN (N2), 125% RDN (N3), and 150% RDN (N4). A full dose of P2O5 and K2O was applied in its entirety as basal in the forms of DAP and MOP. Nitrogen was applied as fertigation in 18 splits, with a 4-day gap between each split, starting 15 days after sowing and ending with the final picking.

The number of branches per plant was recorded from five randomly tagged plants from each treatment, and then the average was worked out and expressed as the total number of branches per plant. Days to first flower appearance were observed and recorded at which plants in every treatment had come to flowering. Days to 50% flowering appearance was observed and recorded at which 50% of plants in every treatment had come to flowering**.** However, days to first picking, i.e., the day at which the initial picking of pod begins in plants of every treatment, was observed and recorded. Days to final picking, i.e., the day at which the final picking of pod begins in plants of every treatment, was observed and recorded.

The observed data on crops were subjected to analysis of variance procedures as outlined for a split-plot design (Gomez and Gomez, 1984) to determine the treatment difference wherever the treatment difference was found significant, the critical. Differences were determined at a 5% probability level.

Results and Discussion

Nitrogen use efficiency

The data on nitrogen use efficiency are illustrated in Fig. 1. Nitrogen use efficiency was significantly influenced by drip irrigation scheduling, nitrogen levels, and their interactions. Among the drip irrigation scheduling options, the highest nitrogen use efficiency was observed at 1.0 Epan, with a fresh fruit yield of 155.0 kg per kg N applied. However, the lowest nitrogen use efficiency was recorded at 0.75 Epan (105.4 kg kg^{-1} N), followed by 1.25 Epan (132.6 kg kg^{-1} N) irrigation scheduling. These results are in line with the findings of Kumar *et al.* (2013), who stated that maximum nitrogen use efficiency was observed under drip irrigation scheduled at 1.0 Epan. Whereas the lowest was observed with 0.6 Epan irrigation scheduling.

Among the nitrogen levels, the highest nitrogen use efficiency was observed at 75% RDN (167.7 kg kg^{-1} N) followed by 100% RDN (153.8 kg kg^{-1} N) and 125% RDN (112.4 kg kg^{-1} N). The lowest was observed at 150% RDN (90 kg kg^{-1} N). Similar results were also reported by Kumar *et al.* (2013), who observed maximum nitrogen use efficiency with 60% RDN, compared to 80% RDN and 100% RDN. This result is corroborated with the findings of Singh et al. (2023). The interaction effect of irrigation scheduling and nitrogen levels on nitrogen use efficiency was not significant.

Number of branches

The influence of drip irrigation scheduling, nitrogen levels, and their interaction effect on the number of branches is analyzed statistically, and the data are presented in Table 1. The number of branches $plant^{-1}$ of okra differed significantly with irrigation scheduling at 1st green pod picking and final green pod picking stages. The maximum number of branches (2.0 and 3.6) was recorded with 1.0 Epan, which was on par with 1.25 Epan (1.7 and 3.4) and significantly higher than 0.75 Epan (1.4 and 2.9). While crop irrigation scheduled at 0.75 Epan (I_1) remained significantly inferior to 1.0 Epan (I_2) and 1.25 Epan (I_3) treatments at 1st and final green pod picking stages. The number of branches did not differ significantly with irrigation scheduling at 1st flower appearance stage. The irrigation scheduling at 1.0 Epan (I_2) enabled the crop to absorb and translocate nutrients effectively, along with transpiration pull, resulting in a greater number of new nodes. This enhanced meristematic activity and consequent vertical extension of growth, due to the optimum availability of water and nutrients, increased branching (Sharma *et al.* 2016). These results are in line with the findings of Kamble et al. (2020), who also reported that okra crop irrigation scheduled at 1.0 ETc recorded the

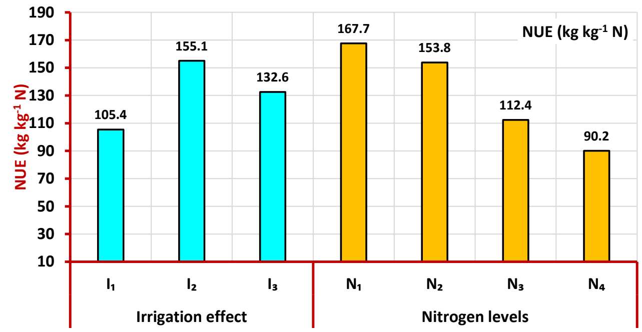

Fig. 1: Nitrogen use efficiency of okra as influenced by drip irrigation scheduling and nitrogen levels

maximum number of branches compared to 0.8 ETc and 1.2 ETc irrigation treatments.

The number of branches $plant^{-1}$ recorded at 1st and final green pod picking stages differed significantly with nitrogen levels. At the 1st green pod picking stage, the crop nurtured with 100% RDN (N2) recorded the maximum number of branches per plant (2.0), which was on par with 125% RDN (1.7) and significantly more than 75% RDN (1.6) and 150% RDN (1.6). However, the number of branches recorded with 75% RDN (N_1), 125% RDN (N_3), and 150% RDN (N3) was found to be comparable to each other. At the final picking stage, the crop treated with 100% RDN (N2) recorded the maximum number of branches (3.5), which was on par with 125 RDN (N3) and 150% RDN (N4), and significantly more than 5%. The number of branches of okra did not differ significantly with nitrogen levels at 1st flower appearance stage. The above results indicated that the okra crop responded positively in terms of the number of branches per plant with added nitrogen levels up to 100% RDN (N_2). This might have reflected on increase in absorption and translocation of assimilates and stimulating apical and lateral meristems. Therefore, for okra crops, 100% RDN under drip fertigation can be considered as the optimum dose. The additional increment over and above the optimal levels of nitrogen decreased the branching and hence, it is proved to be inhibitory to okra. Possibly, the reduction in growth under high nitrogen supply results from its general adaptation to low nitrogen levels. Similar results were reported by Uddin *et al.* (2014). Soni *et al.* (2006) reported that the maximum number of branches (5.48) was recorded with the application of 125 kg N ha^{-1}, followed by 150 kg N ha^{-1} (4.90), and the lowest number of branches (4.38) was recorded with 0 kg N ha^{-1} during the *kharif* season at Akola, Maharashtra. Further, Nagegowda *et al.* (2019) stated that, with increasing nitrogen dose from 0 to 150 kg N ha^{-1}, the number of branches was increased significantly. Khanal *et al.* (2020) stated that, significantly, a greater number of branches (3.0) was recorded with the application of N at 90 kg ha^{-1} , and further increment in nitrogen dose to 120 kg N ha^{-1} did not significantly increase the number of branches under drip

Table 1: Effect of drip irrigation scheduling and nitrogen levels on the number of branches at different stages of okra

Treatments	*First flower appearance*	*First picking*	*Final picking*
Main plot – (Irrigation regimes)			
I1: 0.75 Epan	0.7	1.4	2.9
I2: 1.0 Epan	1.0	2.0	3.6
I3: 1.25 Epan	0.9	1.7	3.4
SEm ±	0.05	0.1	0.1
C.D ($p = 0.05$)	NS	0.4	0.5
Sub plot – (Fertigation levels)			
N1 – 75% RD N (112.5 kg ha^{-1})	0.8	1.6	3.1
N2 – 100% RD N (150 kg N ha^{-1})	1.0	2.0	3.5
N3 – 125% RD N (187.5 kg N ha^{-1})	0.9	1.7	3.3
N4 – 150% RD N (225 kg N ha^{-1})	0.8	1.6	3.3
SEm ±	0.1	0.1	0.1
C.D ($p = 0.05$)	NS	0.3	0.2
Interaction			
Fertigation levels at same level of irrigation regimes			
SEm ±	0.1	0.2	0.3
C.D ($p = 0.05$)	NS	NS	NS
Irrigation regimes at same or different levels of fertigation			
SEm ±	0.1	0.2	0.2
C.D ($p = 0.05$)	NS	NS	NS

fertigation in Nepal. Gayathri & Reddy (2013) stated that nitrogen is a very important constituent of protoplasm and its favorable effect on the chlorophyll content of leaves might have increased the synthesis of carbohydrates, amino acids, etc., from which the phytohormones such as auxins, gibberellins, cytokinins and ethylene have been synthesized resulting in an increased number of branches.

The interaction effect of irrigation scheduling and nitrogen levels on the number of branches is found to be non-significant at all stages of crop growth, ranging from 2.7 to 3.8. The highest was noticed in 1.0 Epan (I_2) irrigation scheduling. Among the nitrogen levels, the highest number of branches was recorded in 100% RDN (N_2).

Phenology

The phenology of the okra crop, in terms of days to attain different growth stages, is recorded, analyzed statistically, and presented in Table 2. The effect of irrigation scheduling, nitrogen levels, and their interactions on achieving different growth stages was not significant. The crop needed 39 to 43 days to attain 50% flowering, 51 to 52 days for 1st green pod picking and 87 to 90 days for final green pod picking.

Table 2: Effect of drip irrigation scheduling and nitrogen levels on number of days to attain different phenophases of okra crop

Treatments	*First flower appearance*	*50% flower appearance*	*First picking*	*Final picking*
Main plot – (Irrigation regimes)				
I_1: 0.75 Epan	40.7	47.0	53.2	88.1
I_2: 1.0 Epan	41.9	47.5	53.9	88.7
I_3: 1.25 Epan	41.7	48.2	54.0	87.8
SEm ±	1.07	1.05	1.11	1.96
C.D ($p = 0.05$)	NS	NS	NS	NS
Sub plot – (Fertigation levels)				
N_1 – 75% RD N (112.5 kg ha^{-1})	40.2	46.1	53.2	87.3
N_2 – 100% RD N (150 kg N ha^{-1})	41.3	47.5	53.6	89.2
N_3 – 125% RD N (187.5 kg N ha^{-1})	42.2	47.8	54.0	88.2
N_4 – 150% RD N (225 kg N ha^{-1})	42.1	48.8	54.0	88.0
SEm ±	1.03	0.95	1.10	1.88
C.D ($p = 0.05$)	NS	NS	NS	NS
Interaction				
Fertigation levels at same level of irrigation regimes				
SEm ±	2.14	2.10	2.22	3.92
C.D ($p = 0.05$)	NS	NS	NS	NS
Irrigation regimes at same or different levels of fertigation				
SEm ±	1.88	1.78	1.99	3.43
C.D ($p = 0.05$)	NS	NS	NS	NS

These results indicated that the okra crop is non-sensitive to irrigation levels and nitrogen doses in terms of attaining different phenophases. The outcomes concur with those of the study conducted by Ibrahim et al. (2015), who reported that Flower bud initiation was significantly delayed with increasing levels of fertilizer application, regardless of the source.

Available soil nitrogen at crop harvest

The final available soil nitrogen after crop harvest was analyzed statistically and presented in Table 3. The effect of irrigation scheduling on final soil 'N' was statistically not significant. However, the plots irrigated with 0.75 Epan (I_1) recorded 281.3 kg N ha^{-1}, which was followed by 1.0 Epan (I2) and 1.25 Epan (I3) irrigation scheduling. This investigation clearly indicates that the plots in which the crop was grown under optimum moisture conditions (1.0 Epan) lost more available soil nitrogen (initial N), whereas the plots in which the crop was grown under moisture stress conditions (0.75 Epan) and excess moisture condition (1.25 Epan) lost less

Table 3: Initial and Final soil nitrogen availability as influenced by irrigation scheduling and nitrogen levels (kg ha-1)

Treatments	*Final Soil Nitrogen*				
	N1	*N2*	*N3*	*N4*	*Mean A*
I1	231	263	299	331	281
I2	192	212	243	298	236
I3	210	233	281	316	260
Mean B	211	236	275	315	
Factors		S.Em +		CD (p=0.05)	
Main (I)		11.2		NS	
Sub (N)		9.9		30	
Sub (N)at same main (I)		22		NS	
Main (I) at same or different sub (N)		19		NS	
Initial Soil N		253.6			

available soil nitrogen (initial N). The more depletion of available nitrogen from I_2 (1.0 Epan) plots might be due to increased demand from healthy canopies because of ideal soil moisture conditions prevailing in root zone of crop. These results are in line with the findings of Sabata and Masan (1992).

The influence of nitrogen levels on final soil 'N' was significant. The crop nurtured with 150% RDN recorded 315.4 kg soil "N" which was followed by 125% RDN and 100% RDN and more than 75% RDN (211.1 kg N ha^{-1}). The above results indicated that the plots nurtured at 75% RDN, 100% RDN, and 125% RDN lost more native available soil N, whereas the plots in which the crop was applied with 150% RDN lost less native available soil N, respectively. The lower depletion in N4 treatment evidences the sufficiency of externally added nitrogen fertilizers. Similar results were also reported by several researchers (Krishnan and Christopher, 1997; Bansal et al., 1980; Venkatesh, 1999). The interaction effect of irrigation scheduling and nitrogen levels on Final soil nitrogen was not significant.

Conclusion

The present study demonstrated that optimized drip irrigation scheduling significantly enhanced nitrogen use efficiency (NUE), with the highest efficiency observed at an irrigation scheduling of 1.00 Epan (I2) and a 75% recommended nitrogen dose (RDN) (N1). Interestingly, phenological stages such as days to first flowering, days to 50% flowering, and days to first and final picking were not significantly influenced by variations in irrigation scheduling or nitrogen levels. However, the number of branches per plant increased notably with the 1.00 Epan (I2) irrigation scheduling and 100% RDN (N2) nitrogen application, leading to higher biomass and potential yield. The soil nitrogen content varied across treatments, providing valuable insights into nitrogen uptake and residual soil fertility, indicating effective nitrogen management.

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सारांश

ग्रीष्म 2020-21 के दौरान जल प्रौद्योगिकी केंद्र, कृषि महाविद्यालय, पीजेटीएसएयू, राजेंद्रनगर, हैदराबाद में “ग्रीष्म 2020-21 के दौरान भिंडी (एबेलमोसस एस्कुलेंटस एल.) में ड्रिप फर्टिगेशन के तहत सिंचाई और नाइट्रोजन के स्तर का अनुकूलन” पर एक क्षेत्र प्रयोग किया गया। प्रयोग को राधिका हाइब्रिड (40 cm x 45 cm) के साथ स्प्लिट-प्लॉट डिज़ाइन में रखा गया था और तीन बार दोहराया गया था। उपचार में ड्रिप के माध्यम से तीन सिंचाई स्तर शामिल हैं, जिन्हें मुख्य भूखंडों के रूप में 0.75 एपैन, 1.0 एपैन और 1.25 एपैन पर और चार नाइट्रोजन स्तर अर्थात 75% RDN (112.5 kg ha^{-1}), 100% RDN (150 kg ha^{-1}), 125% RDN (187.5 kg ha^{-1}) और 150% RDN (225 kg ha^{-1}) उप-भूखंडों के रूप में निर्धारित किया गया है। प्रायोगिक मिट्टी बनावट में रेतीली चिकनी, प्रतिक्रिया में क्षारीय, कार्बनिक कार्बन सामग्री में मध्यम, उपलब्ध नाइट्रोजन में कम, उपलब्ध फॉस्फोरस और उपलब्ध पोटेशियम में क्रमशः उच्च थी। परिणामों से संकेत मिलता है कि अनुकूलित ड्रिप सिंचाई समय-निर्धारण ने एनयूई में महत्वपूर्ण रूप से सुधार किया है, जिसमें 1.00 एपैन (I2) सिंचाई समय-निर्धारण और 75% RDN (N1) नाइट्रोजन स्तर पर उच्चतम दक्षता देखी गई फेनोलॉजिकल विकास, जिसमें पहले फूल आने के दिन, 50% फूल आने के दिन, पहली और अंतिम पिकिंग के दिन शामिल हैं, सिंचाई शेड्यूलिंग और नाइट्रोजन आपूर्ति से प्रभावित नहीं थे। 1.00 एपैन (I2) और 100% RDN (N2) नाइट्रोजन अनुप्रयोग के साथ प्रति पौधे शाखाओं की संख्या में वृद्धि हुई, जिससे उच्च बायोमास और संभावित उपज में योगदान मिला। मिट्टी में नाइट्रोजन की मात्रा उपचार के दौरान भिन्न होती है, प्रारंभिक और अंतिम माप नाइट्रोजन अवशोषण और अवशिष्ट मिट्टी की उर्वरता के बारे में जानकारी प्रदान करते हैं।