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Impact of Drip Fertigation on Leaf Area Index, Root Biomass and Quality Parameters of Lady's Finger (*Abelmoschus esculentus* L.)

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ABSTRACT

Background: The integration of drip irrigation and nitrogen fertilization presents a synergistic approach to optimize okra production. Drip irrigation not only ensures efficient water use but also facilitates the precise application of fertilizers, thereby enhancing nutrient availability and nutrient uptake. This targeted approach helps in minimizing nutrient losses through leaching and volatilization, issues commonly associated with conventional fertilization application.

Methods: A field experiment was conducted at Water Technology Centre, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad during *summer,* 2021 on "Optimization of irrigation and nitrogen levels under drip fertigation in okra (*Abelmoschus esculentus* L). The experiment was laid out in a split-plot with three replications Bhendi crop (Radhika hybrid) was sown at a spacing of 40 cm × 45 cm. The treatments comprised of three irrigation levels scheduled through drip scheduledat 0.75 Epan, 1.0 Epan and 1.25 Epanin 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}) in sub-plots. Experimental soil was sandy clay in texture, alkaline in reaction, medium in organic carbon content, low in available nitrogen, high in available phosphorous and available potassium, respectively.

Result: The results indicated that, the highest leaf area index, root biomass, pod chlorophyll content and crude fibre content were highest under drip irrigation scheduled at 1.0 Epan treatment. Among the nitrogen levels the highest leaf area index, root biomass, pod chlorophyll content and crude fibre content were recorded with 100% RDN (N_2) treat. Among the interaction of treatment combinations, the crop irrigation scheduled at 1.0 Epan in conjunction with 100% RDN (I_2N_2) recorded maximum leaf area index, root biomass, pod chlorophyll content and crude fibre content.

Key words: Drip irrigation, Nitrogen levels, Quality, Root biomass.

INTRODUCTION

Okra (*Abelmoschus esculentus* L.) is an important vegetable of India occupies 5.90 lakh hectare area with total production of 69.49 lakh tons and 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. okra podsconsist of 81.9 g/100 g water, 8.2 g/100 g total dietary fibre (of which 4.7 g/100 g insoluble fibre and 3.4 g/100 g solublefibre), 4.9 g/100 g carbohydrates, 3.6 g/100 g crude proteins,1.5 g/100 g ash, 0.07 g/100 g fat and 50.6 kcal/ 100 g ofenergy (Tufaro, 2022). It is one of the popular vegetable crops grown in Telangana with total 13,006-hectare area while, in summer it occupies an area of 810 hectares (Horticulture Department, Telangana State, 2019) with an overall production of 2.60 lakh tons and 20.49 t ha^{-1} productivity. Okra is a warm-season vegetable crop requires warm and humid conditions for good 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 6.0-6.8 is considered as optimum. Alkaline, saline soils and soils with poor drainage are not good for this crop, it also requires high amount of organic fertilization (Akanbi *et al.,* 2010 and Akande *et al.,* 2010). It is susceptible to low temperature. Seeds of okra fail to germinate below 20°C temperature. For optimal growth, flowering and fruit initiation, okra requires an average temperature ranging between 25-30°C. The okra plants grow taller in the rainy season than in the warm

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summer. Okra requires a well distributed moderate rainfall (80-100 cm) for production of its young edible fruits. Increased vigour and high productivity were observed when the crop was grown in rainy season than summer season. Increasing differences between day and night temperatures can reduces seed yield considerably especially during summer season (Dhankhar *et al*., 2012).

For yield enhancement of okra, suitable water supply to maintain sufficient moisture condition in soil throughout the crop growth period is essential especially during summer season. The influence of water deficit on yield in this span is more under surroundings of high temperature and low humidity (Vadar *et al.,* 2019) which is more common during *summer* season. To meet these optimal conditions, drip irrigation proved to be most effective agronomic management option for enhancement of yield and quality of okra. It was reported that, the drip irrigation alone enhances the crop yield up 40% over conventional irrigation (Lokesh *et al*., 2024).

Use of optimum doses of fertilizer is one of the most important ways to ensure quality of green pod yield production of okra. Nitrogen is an essential macro nutrient which plays crucial role on growth, development and metabolism. Nitrogen application significantly increases pod weight, pod diameter, number of fruits per plant and number of seeds per pod in okra (Moniruzzaman and Quamruzzaman, 2009). Fertilizers applied by traditional methods are generally not effective. In fertigation, nutrients are applied through emitters directly into the zone of maximum root activity and consequently fertilizer-use efficiency can be improved over conventional method of fertilizer application. The drip fertigation in okra offers increased pod yield, pod weight, pod length, root penetration depth and pod quality (Hari and Ramesh, 2017) apart from reducing thecost of weeding and irrigation management and enhances economic returns (Sreeja and Satasiya, 2015). A synergistic method for maximising okra output is the combination of nitrogen fertilization with drip watering. In addition to guarantee effective water management, drip irrigation makes it easier to apply fertilisers precisely.

Keeping in view the opportunity and research gap in okra crop, the investigation on impact of irrigation levels, quantification of water requirement under drip system and N levels for fertigation of summer season okra crop was under the present study.

MATERIALS AND METHODS

A field experiment was conducted at Water Technology Centre, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad during 2021-22 (17°19′24.7″N, 78°24′34.0″E) at an altitude of 542.4 m amsl). A total of 12.6 mm of precipitation was received during the crop growing season. The texture of the experimental soil is sandy clay soil and it was low in nitrogen, high in phosphorus and potassium, medium in organic carbon content, alkaline in reactivity and non-saline. Irrigation water was neutral (7.20 pH) and classified as C3 class.Radhika variety was usedfor the experiment. Inline drip system with spacing of 40 cm and discharge rate of 2 L/h was installed. Split-plot design was used to set up the experiment, with 12 treatments and replicated thrice. Thetreatments included drip irrigation scheduled at: 0.75 Epan as I_1, 1.0 Epan as I_2 and 1.25 Epan as I_3 in main plots and four different nitrogen concentrations: 75% RDN (N_1), 100% RDN (N_2), 125% RDN (N_3) and 150% RDN (N_4) in sub plots. Full dose of P_2O5 and K_2O were applied totally as basal in the form of DAP and MOP. Nitrogen was applied through fertigation in 18 equal, with at 4 days interval gap between each split, starting from 15 days after sowing and ending with the final picking (90 DAS).

Leaf area index (LAI)

Leaf area index was estimated by taking five randomly selected tagged plants in every treatment at 15 days from sowing to final picking using LI 3100 leaf area meter (LI-COR, INC. Linocoln, Nebraska, U.S.A.).

The leaf area index was calculated by dividing the total leaf area with the corresponding ground area as suggested by Watson (1952). Leaf area index was calculated by using the following formula.

$$\text{LAI} = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Unit ground area (cm}^2\text{)}}$$

Root biomass studies

The effect of irrigation and nitrogen levels on root biomass investigated using a 15 cm^3 core sampler at final picking in the wetted zone up to 45 cm depth from surface and from dripper point at 45 cm radial distance was to be active root zone.

Quality parameters

Total chlorophyll content

Total chlorophyll content (mg 100^{-1} g F.W.) of pods was recorded by using Delta Absorbance (DA) meter at first picking, fifth picking and final picking.

Crude fibre content

Crude fibre content was determined by the method suggested by A.O.A.C. (1960). A representative ground fruit sample of 2 g was refluxed with 1.25 per cent H_2SO_4, washed and again refluxed with 1.25 per cent NaOH for 30 minutes, respectively. The sample was dried out, weighed and ignited in a muffle furnace. Loss in weight was considered as crude fibre content and expressed based on using following relationship:

$$\text{Crude fiber (\%)} = \frac{W_2 - W_3}{W_1} \times 100$$

Where,

W_1 = Initial weight of sample.

W_2 = Weight of refluxed sample.

W_3 = Weight of ignited sample.

RESULTS AND DISCUSSION

Leaf area index

The Leaf Area Index (LAI) of okra as influenced by drip irrigation scheduling, nitrogen levels and their interaction is presented (Table 1). The effect of irrigation scheduling recorded at 15 days interval is depicted in Fig 1 and 2.

Irrigation scheduling

The influence of irrigation scheduling on Leaf Area Index (LAI) trend of okra recorded at 15 days interval from 15 days after sowing to final green pod picking is illustrated in Fig 1. Perusal of Leaf Area index indicated that, irrespective of irrigation levels the leaf area index was continuously increasing up to 60 days after sowing and there after decreased gradually towards the final green pod picking stage. The reduction in LAI towards final picking stage was due to leaf detachment (abscission) from plants as the crop reached senescence. Formation of abscisic acid (ABA) in roots and its consequent translocation from root to shoot might have caused reduced stomatal conductance and transpiration rate and there by detachment from the plant at senescence stage of okra (Ahmadi *et al.*, 2010).

Among the irrigation levels, the crop irrigated at 1.0 Epan (I_2) maintained maximum Leaf Area Index (LAI) followed by 1.25 Epan (I_3) and the lowest was at 0.75 Epan (I_1) levels throughout the crop growth period. The higher LAI in I_2 blocks might be due to optimal soil moisture conditions maintained in the rhizosphere throughout the crop growth period. While, the reduced LAI in I_1 and I_3 treatments might be due to deficit and excess soil moisture conditions, respectively prevailed in root zone although the crop growth period.

The influence of irrigation levels on Leaf Area Index of okra recorded at 1st flower appearance, 1st green pod picking and final green pod picking stages is analyzed statistically and presented in Table 1. Higher leaf area index of 0.17, 1.10 and 0.51 was recorded with 1.0 Epan (I_2) which was significantly more over 1.25 Epan (I_3) with LAI of 0.16, 0.94 and 0.44 and 0.75 Epan (I_1) with LAI of 0.16, 0.74 and 0.32 at first flower appearance, 1st picking and final picking stages, respectively. Irrigation scheduled at

Table 1: Effect of drip irrigation scheduling and nitrogen levels on leaf area index (LAI) at different stages of okra.

Growth stages	First flower appearance					First picking					Final picking				
Treatments	N_1	N_2	N_3	N_4	Mean	N_1	N_2	N_3	N_4	Mean	N_1	N_2	N_3	N_4	Mean
I_1	0.15	0.16	0.15	0.15	0.15	0.72	0.74	0.73	0.73	0.73	0.31	0.33	0.32	0.32	0.32
I_2	0.16	0.17	0.17	0.16	0.16	1.08	1.15	1.09	1.08	1.10	0.52	0.54	0.49	0.49	0.51
I_3	0.16	0.16	0.16	0.15	0.16	0.92	0.95	0.93	0.93	0.93	0.43	0.45	0.44	0.43	0.44
Mean	0.16	0.16	0.16	0.16		0.91	0.949	0.92	0.91		0.42	0.44	0.42	0.41	
Factors	S.Em+		CD (p=0.05)			S.Em+		CD (p=0.05)			S.Em+		CD (p=0.05)		
Main (I)	0.001		0.003			0.006		0.023			0.006		0.026		
Sub (N)	0.001		0.003			0.005		0.014			0.005		0.014		
Sub (N) at same main (I)	0.001		NS			0.012		0.028			0.013		0.027		
Main (I) at same or different sub (N)	0.002		NS			0.009		0.031			0.009		0.033		

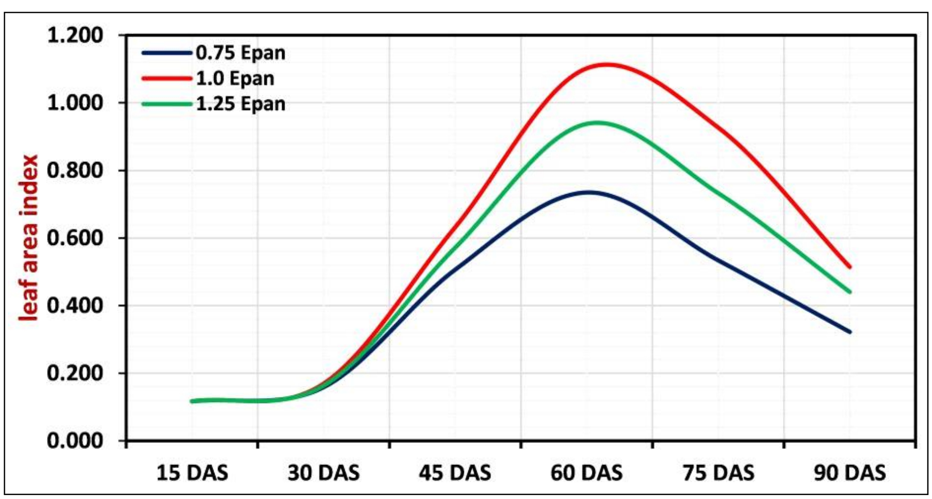


Fig 1: Effect of drip irrigation scheduling on leaf area index of okra at 15 days interval.

0.75 Epan (I_1) remained significantly inferior to I_2 (1.0 Epan) and I_3 (1.25 Epan) treatment irrespective of the crop growth stages.

The reduction in LAI of okra above and below 1.0 Epan levels might be due to deficit and excess soil moisture conditions in the rhizosphere. Similar trend was also reported by Shivaraj *et al*. (2018). Limited water supply to Okra in deficit irrigation scheduling treatment (I_1) affected the physiological development of the crop, due to sub-optimal supply of required amount of water to the root zone from the pod formation stage to maturity stage of the crop when the crop actually needed sufficient quantity of water to meet its evapotranspiration demand (Konyeha and Alatise, 2013).

Nitrogen levels

The effect of nitrogen levels on Leaf Area Index of okra is depicted in Fig 2. The data indicated that the crop fertilized with 100% RDN (N_2) produced maximum leaf are index and the lowest underand 75% RDN (N_1) produced throughout the crop growth period respectively. Barring these two extremes the crop fertilized with 125% RDN (N_3) and 150% RDN (N_4) remained in intermediate to 100% RDN (N_2) and 75% RDN (N_1).

The Leaf area Index of okra recorded at 1st flower appearance, 1st pod picking and final pod picking stages as influenced by nitrogen levels is analyzed statistically and presented in Table 1. At 1st flower stage the crop nurtured with 100% RDN (N_2) recorded maximum Leaf Area Index (0.17) which was significantly more over its succeeding higher doses of N_3 (125% RDN) and N_4 (150% RDN) and preceding lower dose of N_1 (75% RDN) treatments. However, the N_1 (75% RDN) treatment found significantly inferior to N_2 (100% RDN), N_3 (125% RDN) and N_4 (150% RDN) treatments. Similar trend was also reflected at 1st green pod picking and final green pod picking stages.

The reduction in LAI under high and low nitrogen levels might be due to general adaptation of okra crop at certain level of nitrogen dose. However, the symptoms of toxicity due to excess of nitrogen (125% RDN or 150% RDN) or symptoms of nitrogen deficiency due to lower dose (75% RDN) with reference to 100% RDN were not observed in plants. These results are in line with the finding of Bhatti *et al.* (2011) and Chawla *et al*. (2018) who stated that maximum leaf area index was recorded with 100% RDN significantly enhanced the growth of okra (91.64 q ha^{-1}) over control and 75 per cent RDN.

Interaction effect

The interaction effect of irrigation scheduling and nitrogen levels on leaf area index of okra is found significant at first and final picking stages.

At 1st flower appearance stage under I_2 (1.0 Epan) irrigation scheduling, significantly more LAI of 1.15 was recorded with 100% RDN (N_2) when compared to its preceding lower does [75% RDN (N_1)] and succeeding higher doses [125% RDN(N_3) and 150% RDN(N_4)]. However, the N_1, N_3 and N_4 levels recorded the LAI of 1.08, 1.09 and 1.09 were comparable to each other. At I_1 and I_3 irrigation scheduling, the LAI was not differed significantly with nitrogen levels. Similar trend is also reflected at final picking stage.

Among the different treatment combinations, I_2N_2 recorded more LAI of 1.15 and 0.54 at 1st and final green pod picking stages, respectively. However, it was significantly more over rest of the treatment combinations at 1st green pod picking stage and comparable with I_2 N_2 (0.52) and significantly more over the rest of the treatment combinations at final green pods picking stage.

Irrigation scheduled at 1.0 Epan had led to efficient use of additional food material synthesized with 100% RDN which clearly indicated that expansion in leaf area responded positively to N availability up to 100% RDN. This could be due to the significant role of N availability in assimilation of photo-assimilates enhancing the period of leaf area expansion by plant. Lower values of leaf area in the N limiting environments were recorded with 75% RDN

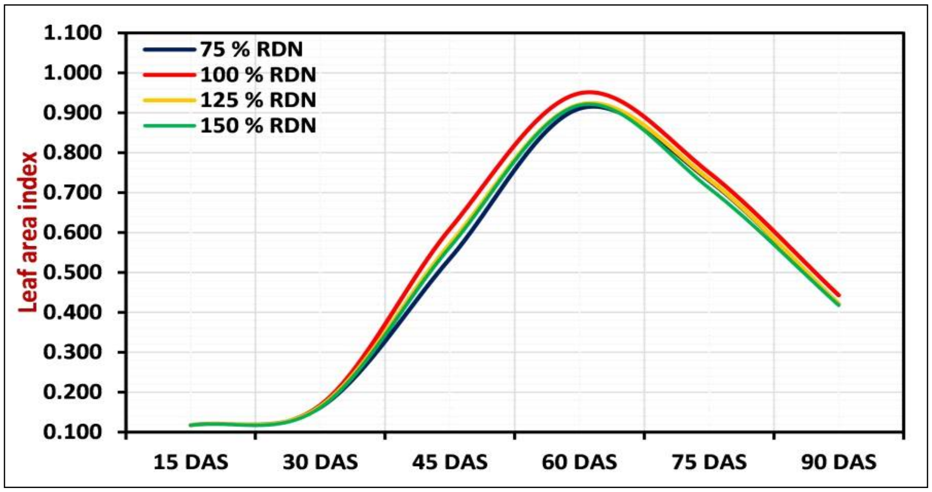


Fig 2: Effect of nitrogen levels on leaf area index of okra at 15 days interval.

indicated that depletion and or shortage of N might have adversely affected the ability of N to the crop to sustain its leaf area expansion for longer periods resulting in reduced interception of photosynthetic active radiation (PAR) with overall negative effects on crop growth and yield. Similarly, Venkadeswaran and Sundaram (2016) also documented optimum optimal moisture in the root zone under drip fertigation that reduces the variation in nutrient concentration, thereby enhancing their availability to plantsand reducing the leaching of nutrients beneath the root zone.

Root biomass studies

The influence of irrigation scheduling and nitrogen levels on root biomass of okra (mg/1cm^2) is depicted in Fig 3. Among the irrigation schedules the maximum root biomass (1.41 mg/1cm^2) was recordedat 1.0 Epan (I_2) followed by1.25 Epan (I_3). The lowestroot biomass (1.12 mg/1cm^2) was recorded under 0.75 Epan and it was inferior to 1.0 Epan and 1.25 Epan treatments.

Among the nitrogen levels, the maximum root biomass (1.43 mg/1cm^2) was recorded with 100% RDN (N_2) which was followed by succeeding higher dose of 125% RDN (N_3) and 150% RDN (N_4) and preceding lower dose of 75% RDN (N_1). The interaction effect of irrigation scheduling and nitrogen levels on root biomass is depicted in Fig 4. The maximum root biomass (1.57 mg/1cm^2) was recorded under 1.0 Epan in conjunction with 100 % RDN (I_2F_2)

Whereas, minimum root biomass was recorded (1.24 mg/1cm^2) under 0.75 Epan in conjunction with 75% RDN (I_1F_1). Similar results were also reported by Pokhrel *et al.* (2024) who stated that highest yield which correlates root biomass was obtained with T_6 (100 kg N ha^{-1}) which was comparable with T_7 (115 kg N ha^{-1}) against the minimum was recorded with T_1 (0 kg N ha^{-1}) in okra. Therefore, it is suggested that root elongation wasinhibited by either excess of deficit N levels. N deficiency can leadto low root activity and water consumption (Zhang *et al.,* 2017) and decrease the production of reactive oxygen species (ROS)

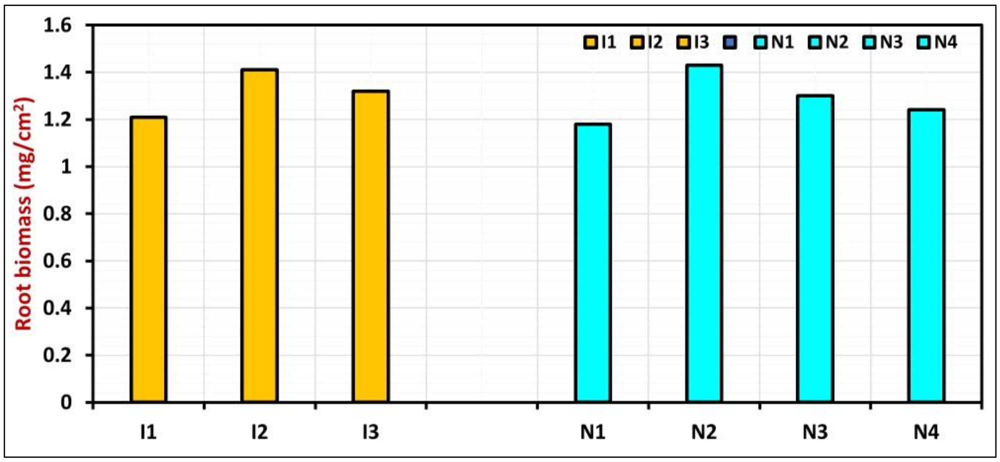
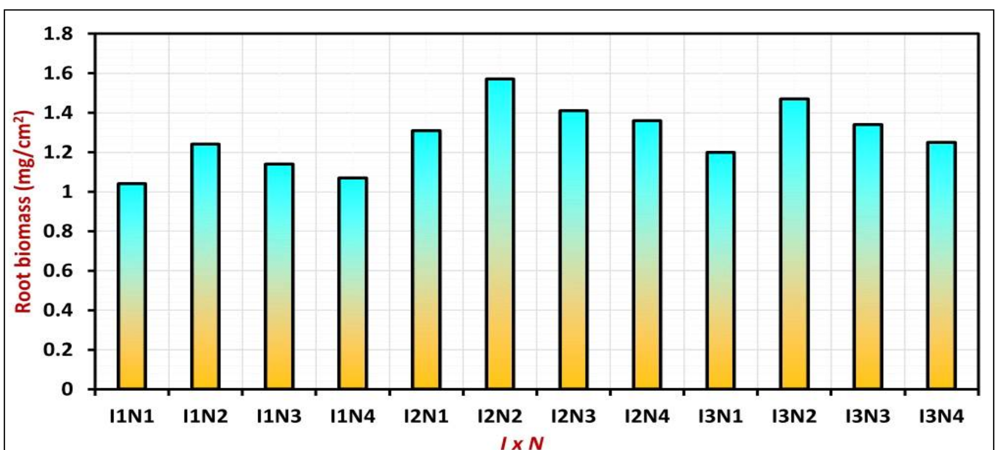


Fig 3: Root dry biomass of summer okra as influenced by irrigation scheduling through drip and nitrogen levels supplied through fertigation.



Note: I_1: 0.75 Epan: I_2: 1.0 Epan and: I_3: 1.25 Epan; F_1: 75% RDN, F_1: 100% RDN, F_1: 125% RDN and F_1: 150% RDN; RDN: Recommended dose of nitrogen (150 kg N ha^{-1}).

Fig 4: Interaction effect of irrigation scheduling and nitrogen levels on root dry biomass of summer okra.

in roots, resulting in low root biomassaccumulation. Excess N can increase aboveground organ growth and decrease root growth. Similar results were also reported by Nagegowda and Senthivel, (2021) who recorded higher moisture and nutrient availability in the vicinity of the roots owing to the higher root biomass in okra.

Quality parameters

Total chlorophyll content of pod (mg 100^{-1} g FW)

The total chlorophyll content of okra pod was not influenced by drip irrigation scheduling, nitrogen levels and their interactions (Fig 5). However, at first picking the maximum chlorophyll content was recorded under drip irrigation scheduled at 1.0 Epan (I_2) which was followed by 1.25 Epan (I_3) and 0.75 Epan (I1). While drip irrigation scheduled at 0.75 Epan (I_1) remained inferior to I_2 and I_3 irrigation treatments. Similar trend was also reflected in fifth and final picking. Among the nitrogen levelsmaximum chlorophyll content was recorded under 100% RDN while, the minimum chlorophyll content was recorded under 75% RDN. Similar trend was also reflected in fifth and final picking also.

Crude fibre content (%)

The crude fibre content of okra as influenced by drip irrigation scheduling, nitrogen levels and their interactions were statistically analysed and presented in Table 2.

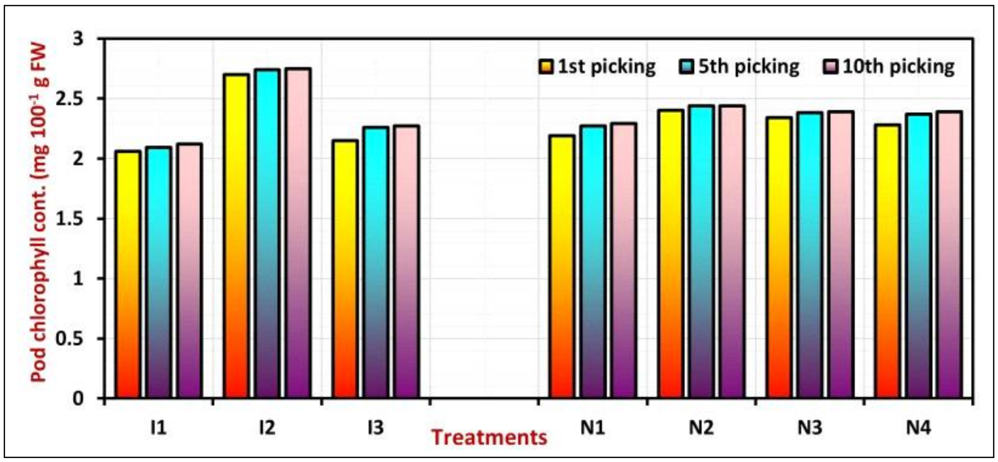


Fig 5: Effect of irrigation scheduling and nitrogen levels on pod chlorophyll content of summer okra.

Table 2: Effect of drip irrigation scheduling and nitrogen levels on crude fiber content (%) of okra.

	Crude fiber content (%)		
	1st picking	5th picking	10th picking
Main plot- (Irrigation regimes)			
I_1: Surface drip irrigation at 0.75 Epan	12.58	12.33	12.77
I_2: Surface drip irrigation at 1.0 Epan	13.41	13.61	13.53
I_3: Surface drip irrigation at 1.25 Epan	13.12	13.26	13.13
SEm±	0.13	0.16	0.13
C.D (P=0.05)	0.53	0.53	0.52
Sub plot- (Fertigation levels)			
N_1 - 75% RD N (112.5 kg ha^{-1})	12.37	12.40	12.30
N_2 - 100% RD N (150 kg N ha^{-1})	13.94	13.92	14.07
N_3 - 125% RD N (187.5 kg N ha^{-1})	12.99	13.02	13.25
N_4 - 150% RD N (225 kg N ha^{-1})	12.84	12.93	12.94
SEm±	0.09	0.09	0.21
C.D (P=0.05)	0.29	0.29	0.63
Interaction			
Fertigation levels at same level of irrigation regimes			
SEm±	0.26	0.26	0.25
C.D (P=0.05)	NS	NS	NS
Irrigation regimes at same or different levels of fertigation			
SEm±	0.19	0.10	0.34
C.D (P=0.05)	NS	NS	NS

Irrigation scheduling

The influence of irrigation scheduling on crude fibre content of okra pod was significant. Maximum crude fibre content (13.41%) was recorded at 1.0 Epan (I_2) which was comparable with 1.25 Epan (13.12%) and significantly higher over 0.75 Epan (I_1). Whereas, the lowest crude fibre was recorded with 0.75 Epan treatment. Similar trend was also reflected at fifth andfinal (10^{th}) picking stages of the okra crop. Rani and Mariappan, (2019) stated that the crop irrigation scheduled at 1.0 Epan has provided optimum soil moisture condition in rhizospherewhich in turn provided higher nutrient uptake by crop. Similar results were also reported by Dhotre *et al.* (2017) in bell pepper.

Nitrogen levels

The influence of nitrogen levels on crude fibre content (%) of okra pod was significant. The crop supplied with 100% RDN (N_2) recorded more crude fibre content of 13.94% which was significantly higher with its succeeding higher dose of 125% RDN (N_3) and 150% RDN (N_4) and significantly more over preceding lower dose (75% RDN). The crop nurtured with 75% RDN (12.37%) remained inferior to N_2, N_3, N_4 treatments. While the crop supplied with 125% RDN and 150% RDN remained on par with each other. Similar trend was also reflected in fifth and final picking. Crude fibre content (%) decreased due to the increase in succulence by the increased application of nitrogen (kg ha^{-1}) and with higher levels of potassium due to the involvement of K in strengthening the thickness of the cell wall.Similar results were reported by Kumar *et al.* (2017) who that maximum crude fibre content was recorded with crop nurtured with 180 kg N ha^{-1} which was followed by 120 kg N ha^{-1} in okra crop.

Interaction effect

The interaction effect of irrigation scheduling and nitrogen levels on crude fibre content (%) of okra pod was not significant.

CONCLUSION

The experiment study concluded that, the crop irrigation scheduled at 1.0 Epan was found outranking in terms of recording maximum LAI across the stages of observations as compared to 0.75 Epan and 1.25 Epan treatments. Among the nitrogen levels, the crop fertilized with 100% RDN recorded maximum LAI, throughout the crop growth period as compared to its preceding lower and succeeding higher levels. The interaction between irrigation scheduling and nitrogen levels was significant in terms of LAI at first and final picking stages. Among the different treatment combinations 1.0 Epan (I2) in conjunction with 100% RDN (N2) recorded maximum LAI at first and final green pod picking stages, respectively. The maximum root biomass, pod chlorophyll content and crude fibre was recorded with 1.0 Epan (I2) treatment. Among the nitrogen levels, the maximum root biomass pod chlorophyll content and crude fibre was recorded with 100% RDN (N_2) were performed better than others.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect lossesresulting from the use of this content.

Informed consent

All procedures for experiments were approved by the Professor Jayashankar Telangana State Agricultural University, Hyderabad.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. Nofunding or sponsorship influenced the design of the study, data collection, analysis, decision to publish,or preparation of the manuscript.

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