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Influence of drip irrigation, crop geometry and mulching on morphological and nutritional traits of okra (*Abelmoschus esculentus*)

ATMA RAM MEENA[1], RAJEEV KUMAR NAROLIA[2]*, LOKESH KUMAR[3] and SIYARAM MEENA[4]

College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan 334 006, India

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ABSTRACT

The experiment was conducted during rainy (*kharif*) seasons of 2019 and 2020 at College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan to study the effect of crop geometry, mulching and different irrigation levels on the morphological and nutritional traits of okra [*Abelmoschus esculentus* (L.) Moench]. The experiment was conducted in a split plot design (SPD) comprised of 4 irrigation levels in the main plot (40%, 60%, 80% and 100% pan evaporation) and 2 different crop geometry (paired row sowing and normal sowing) and 3 types of mulches (no mulch, plastic mulch and straw mulch) were employed in the subplots and sub-subplots, respectively. Results indicated that 100% potential evapotranspiration (PE), drip irrigation (DI) and paired row sowing at 30 cm × 70 cm significantly increased the number of branches/plant, plant height (cm), length of fruit (cm), diameter of fruit (cm) and chlorophyll content of leaves compared to lower irrigation levels and normal sowing. Additionally, straw mulch positively influenced the above-mentioned parameters in the okra fruits as compared to without mulch. Drip irrigation, paired row sowing, and straw mulching also resulted in a significant increase in net returns per hectare. The study demonstrated that combining paired row sowing with straw mulch and irrigating at 100% potential evapotranspiration (PE) yielded the best growth attributes, highest fruit quality, and maximum net returns for okra.

Keywords: Chlorophyll, Crop geometry, Drip irrigation, Mulching, Okra

Okra [*Abelmoschus esculentus* (L.) Moench] also known as bhendi or lady's finger is a crucial vegetable crop cultivated widely across subtropical and tropical regions (Magar *et al*. 2023). The soft green pods are consumed as a tasty vegetable and can be found fresh, canned, or dried in markets (Patra *et al*. 2023). Okra is a nutrient rich food offering several benefits. It is high in dietary fiber (8.2%), protein (3.5%) and carbohydrates (4.9%), with low energy (33 kcal/100 g) and fat (0.2%). Okra seeds provide a rich supply of unsaturated fatty acids, vitamin E (α-tocopherol), and crucial minerals such as calcium, potassium, copper, iron, phosphorus, manganese, and zinc (Dantas *et al*. 2021). Additionally, it has medicinal uses in treating conditions like goiter, inflammation, and dysentery (Sarkar *et al*. 2022).

In the arid zones of Rajasthan, where water scarcity, elevated temperatures, poor soil moisture retention, and erratic rainfall are prevalent, efficient water management is essential. Drip Irrigation (DI) is particularly advantageous in these areas due to its ability to conserve water, enhance the scope of irrigation, improve crop yield and optimize water use efficiency (Yang *et al*. 2023). Optimizing the arrangement of crops around drip lines is critical for reaping maximum advantages (Putti *et al*. 2023), as DI systems can reach up to 90% efficiency, outperforming conventional irrigation methods. In okra farming, DI has proven beneficial, enhancing plant growth, yield, water use efficiency, and profitability for farmers (Karki *et al*. 2020). Mulching is commonly used in irrigated agriculture and, when integrated with DI, significantly enhances crop growth and fruit quality. Plastic mulching aids in increasing soil temperature and maintaining moisture levels, which benefits plant development. For okra, different mulching strategies are implemented to control weed growth and maintain moisture in the root zone. Straw mulching, an organic method that uses natural materials to cover the soil, provides multiple advantages (Busari *et al*. 2023). In semi-arid and arid area of the globe, okra cultivation is usually timed with the monsoon season to mitigate the adverse effects of high temperatures and winds in spring and summer, which can cause plant damage and reduce fruit yield.

Based on these considerations, we developed a hypothesis to investigate if implementing a combination of

[1]College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan; [2]College of Agriculture, Sri Karan Narendra Agriculture University, Jobner, Jaipur, Rajasthan; [3]College of Agriculture, Agriculture University, Jodhpur, Rajasthan; [4]ICAR-Indian Agricultural Research Institute, New Delhi. *Corresponding author email: rknarolia.horti@sknau.ac.in

effective management strategies, including advanced crop establishment techniques like different crop geometries, irrigation levels and mulching, could act as innovative solutions. These methods have demonstrated potential as effective approaches to enhance the profitability of okra farming, especially in regions facing water scarcity.

MATERIALS AND METHODS

The experiments were conducted in rainy (*kharif*) seasons of 2019 and 2020 at College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan. The total recorded rainfall for the 1st crop season was 230 mm, while the second crop season received 214 mm of rainfall. In 1st year, the temperature fluctuated from 35.0–39.5°C (maximum) and 16.7–26.9°C (minimum), whereas in 2nd year, it ranged from 32.6–40.7°C (maximum) and 15.8–28.0°C (minimum). The soil type was loamy with 0.13 (g/100 g soil) soil organic carbon content (Walkley and Black 1947), 93 kg/ha of easily mineralizable nitrogen (Subbiah and Asija 1956), 14.3 kg/ha of available phosphorus (Olsen *et al*. 1954), 203 kg/ha of available potassium (Richards 1954), an electrical conductivity (EC) of 0.16 dS/m, and a *p*H of 8.5 (Metson 1957).

The experiment was conducted in a split plot design (SPD) having 4 different irrigation levels (40%, 60%, 80% and 100% of PE) in main plot. In the sub-plots, 2 crop geometry configurations were tested; normal sowing (row spacing-50 cm), and paired row sowing (30 cm × 70 cm). The sub-sub plots evaluated different mulching options, viz. no mulch, plastic mulch (black) and straw mulch with three replications for each treatment. The water requirements were calculated based on the evaporative demand exerted on the plants. Two different crop arrangements were compared under identical plant densities: one featured two rows spaced 50 cm apart around lateral lines, with 50 cm gaps among groups of rows, while the other had two rows spaced 30 cm apart around lateral lines, with 70 cm gaps between groups of rows. Mustard straw mulch at the rate of 10 t/ha or plastic mulch (25 micron) was used between rows at 20 days after sowing (DAS) in marked plots. Well-rotted FYM at the rate of 220 q/ha was applied during field preparation. Basal fertilizer doses included uniform quantities of 60 kg/ha P_2O_5, 50 kg/ha K_2O, and half doses of 50 kg/ha each of single superphosphate (SSP), muriate of potash (MOP) and urea at sowing. The remaining half dose of nitrogen was top dressed at 30 DAS.

Various parameters were measured and recorded during the data collection process, including plant height (cm), number of branches/plant, diameter of fruit (cm), length of fruit (cm) and chlorophyll content in the leaves. The data underwent an analysis of variance (ANOVA), and statistical analysis was conducted using Microsoft Excel software packages (Meena *et al*. 2024).

RESULTS AND DISCUSSION

Effect of different irrigation levels, crop geometry and mulches on okra yield attributes: The study shows that DI with 100% PE significantly increased the diameter of fruit (cm), length of fruit (cm), number of fruits and branches/plant at 50 DAS in both the years, as compared to 40% PE and 60% PE (Table 1, 2). However, this was comparable to 80% PE irrigation. The number of branches /plant is a significant morphological characteristic that influences canopy spread and fruit diameter (cm), length of fruit (cm) and fruits/plant. The branch count varies based on the volume of water the plant receives (Karki *et al*. 2020, Sedara *et al*. 2021, Karaer *et al*. 2023). Maintaining a higher water level in the soil and enhancing moisture availability to plants under DI promotes rapid growth at 80 and 100% PE. This increases turgor in leaf cells, facilitates tissue multiplication and consequently leads to a greater number of branches. Paired row sowing (30 cm × 70 cm) led to a notable increment in branches/plant at 50 DAS as compared to the normal sowing method with 50 cm row spacing, over both the years. This enhancement could be attributed to the optimal watering received by crops sown in paired rows, as they were situated closer to drip lines, thereby facilitating healthier growth and development of the plant.

The research revealed that straw mulches had a notable positive impact on length of fruit (cm), diameter of fruit (cm), the number of fruits and branches/plant at 50 DAS in both the years, as well as on an aggregated basis (Table 1, 2). Among the different mulching treatments, straw mulch led to superior results in terms of length of fruits (cm), diameter of fruit (cm), and both the number of fruits and branches/plant, outperforming plastic mulch and the no-mulch control. These results are in accordance with Kamble *et al*. (2020) and Patra *et al*. (2023) which reported similar patterns.

The results showed (Fig. 1) that the tallest plants were observed with straw mulch (69.1 cm), followed by plastic mulch (66 cm) and no mulch (63.3 cm). Plant height significantly improved under paired row sowing, reaching 68.4 cm, as opposed to the 63.8 cm observed with conventional sowing methods. Among different irrigation

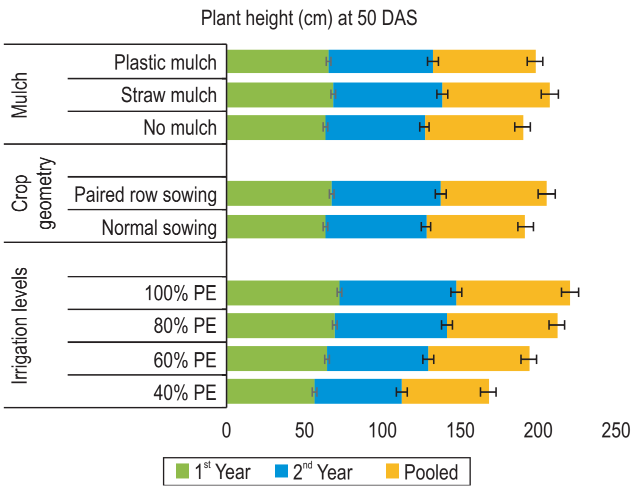

Fig. 1 Effect of different irrigation levels, mulches and crop geometry on plant height of okra at 50 days after sowing (DAS).
PE, Potential evapotranspiration.

Table 1 Effect of different irrigation levels, mulches and crop geometry on fruit diameter, fruit length and number of fruits/plant of okra

Treatment	Length of fruit (cm)			Diameter of fruit (cm)			Number of fruits/plant		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
Irrigation level									
40% PE	11.8	11.9	11.8	3.2	3.3	3.2	14.1	14.1	14.1
60% PE	12.5	12.5	12.5	3.5	3.6	3.6	19.6	21.8	20.7
80% PE	13.1	13.2	13.2	3.7	3.8	3.7	24.8	25.1	25.0
100% PE	13.6	13.7	13.6	3.8	3.8	3.8	26.5	26.2	26.3
SEm(±)	0.19	0.18	0.13	0.07	0.09	0.06	0.66	0.72	0.49
CD (*P*=0.05)	0.64	0.62	0.40	0.26	0.30	0.18	2.30	2.50	1.51
Crop geometry									
Normal sowing	12.57	12.78	12.67	3.51	3.59	3.55	19.98	20.78	20.38
Paired row sowing	12.89	12.87	12.88	3.63	3.61	3.62	22.53	22.84	22.68
SEm(±)	0.15	0.17	0.11	0.05	0.06	0.04	0.33	0.29	0.22
CD (*P*=0.05)	NS	NS	NS	NS	NS	NS	1.07	0.94	0.65
Mulch									
No mulch	12.17	12.34	12.25	3.37	3.43	3.4	19.7	20.79	20.25
Straw mulch	13.13	13.17	13.15	3.72	3.72	3.72	22.38	22.72	22.55
Plastic mulch	12.89	12.98	12.93	3.63	3.64	3.64	21.68	21.91	21.8
SEm(±)	0.16	0.17	0.12	0.06	0.07	0.04	0.38	0.44	0.29
CD (*P*=0.05)	0.46	0.49	0.33	0.17	0.19	0.13	1.09	1.27	0.82

PE, Potential evapotranspiration.

levels, the highest plant height was observed with 100% PE followed by 80%, 60%, and 40% PE.

Effect of different irrigation levels, mulches and crop geometry on chlorophyll content: Chlorophyll is a key factor in plant productivity due to important photosynthetic pigment that absorbs light energy for carbohydrate synthesis and direct impact on fruit production. The study found that increasing irrigation levels at 50 DAS increased the total chlorophyll content in okra leaves, with 100% PE (2.04 mg/g) irrigation resulting in the highest total chlorophyll content, comparable to 80% PE (1.97 mg/g) at 50 DAS but superior to 40% (1.77 mg/g) and 60% PE (1.52 mg/g). When watering was reduced, plants had smaller leaves, less chlorophyll, struggled to make food through photosynthesis, and didn't grow well (Dash *et al*. 2022, Simkin *et al*. 2022).

The arrangement of crops didn't showed a significant effect on the chlorophyll levels in leaves at 50 DAS. However, when crops were sown in paired rows (30 cm × 70 cm), there was an increment in the total chlorophyll content by 1.87 mg/g. Among the mulches tested, straw mulch resulted in the highest chlorophyll content, beating both plastic mulch and having no mulch at all (Khan *et al*. 2023). Specifically, at the 50-day mark, leaves under straw mulch had 1.91 mg of chlorophyll per gram of leaf, compared to 1.85 mg/g under plastic mulch and 1.72 mg/g with control.

Effect of different irrigation levels, crop geometry and mulches on nutrients content in fruit: The detailed analysis of the nutrient content in okra fruits under various agricultural treatments over two consecutive years demonstrates a clear relationship between cultivation practices and the nutritional quality of the produce. The study revealed that DI significantly impacts the nutrient composition of okra fruits, with a clear trend indicating higher levels of N, P and K as irrigation levels increase from 40–100% PE (Table 3). Nitrogen levels in okra fruit rose with increased DI amounts, notably peaking with 100% PE. Similarly, the highest phosphorus (0.22%) and potassium (1.49%) content was found in okra fruits irrigated with 100% PE DI, surpassing levels seen with 40% and 60% PE, though it was similar to levels under 80% PE. Proper and sustained soil moisture not only enhances the availability of nutrients but also their movement within the soil, which in turn accelerates the vegetative growth of plants. This moisture facilitates the dissolution of nutrients in the rhizosphere, leading to an increase in the nutrient uptake as plants are able to extract these nutrients more efficiently due to enhanced root growth. The opening of stomata is fully promoted by adequate soil moisture, allowing for greater nutrient absorption and incorporation into the fruits. The increased uptake of nutrients likely plays a role in boosting fruit yield (Zhu *et al*. 2022, Putti *et al*. 2023, Talpur *et al*. 2023).

Additionally, the impact of crop geometry was evaluated, revealing that while normal sowing practices yielded consistent nutrient levels with a pooled average of 1.38% for nitrogen, 0.21% for phosphorus, and 1.34% for potassium, transitioning to paired row sowing produced a marginal but noteworthy increase in the pooled averages of nitrogen to 1.40% and potassium to 1.38%, with phosphorus levels holding steady (Table 3).

Table 2 Effect of different irrigation levels, mulches and crop geometry on chlorophyll in leaves and number of branches

Treatment	Number of branches/plant at 50 DAS			Chlorophyll content in leaves at 50 DAS (mg/g)		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
Irrigation level						
40% PE	2.51	2.52	2.52	1.54	1.51	1.52
60% PE	2.97	3.06	3.02	1.75	1.80	1.77
80% PE	3.36	3.38	3.37	1.96	1.98	1.97
100% PE	3.50	3.55	3.53	2.03	2.04	2.04
SEm(±)	0.08	0.08	0.06	0.03	0.05	0.03
CD (P=0.05)	0.26	0.29	0.17	0.12	0.16	0.09
Crop geometry						
Normal sowing	2.91	2.99	2.95	1.78	1.79	1.78
Paired row sowing	3.26	3.26	3.26	1.86	1.87	1.87
SEm(±)	0.04	0.04	0.03	0.03	0.03	0.02
CD (P=0.05)	0.13	0.12	0.08	NS	NS	NS
Mulch						
No mulch	2.88	2.97	2.92	1.70	1.75	1.72
Straw mulch	3.25	3.25	3.25	1.91	1.90	1.91
Plastic mulch	3.13	3.16	3.15	1.85	1.85	1.85
SEm(±)	0.05	0.05	0.04	0.03	0.04	0.02
CD (P=0.05)	0.15	0.15	0.11	0.09	0.10	0.07

DAS, Days of sowing; PE, Potential evapotranspiration.

Table 3 Effect of different irrigation levels, mulches and crop geometry on nutrient quantity in okra fruits

Treatment	Nutrient content (%) in fruit								
	Nitrogen			Phosphorus			Potassium		
	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled	1st Year	2nd Year	Pooled
Irrigation level									
40% PE	1.19	1.26	1.22	0.19	0.19	0.19	1.18	1.18	1.18
60% PE	1.33	1.43	1.38	0.20	0.21	0.21	1.30	1.34	1.32
80% PE	1.45	1.48	1.46	0.22	0.22	0.22	1.48	1.43	1.45
100% PE	1.48	1.49	1.48	0.22	0.23	0.22	1.51	1.47	1.49
SEm(±)	0.03	0.02	0.02	0.01	0.00	0.00	0.03	0.03	0.02
CD (P=0.05)	0.09	0.08	0.05	0.02	0.01	0.01	1.18	1.18	0.06
Crop geometry									
Normal sowing	1.35	1.40	1.38	0.20	0.21	0.21	1.35	1.33	1.34
Paired row sowing	1.37	1.42	1.40	0.21	0.21	0.21	1.38	1.38	1.38
SEm(±)	0.02	0.03	0.02	0.00	0.00	0.00	0.03	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mulch									
No mulch	1.23	1.33	1.28	0.19	0.19	0.19	1.25	1.23	1.24
Straw mulch	1.46	1.49	1.47	0.22	0.23	0.22	1.47	1.44	1.45
Plastic mulch	1.40	1.42	1.41	0.21	0.22	0.21	1.39	1.39	1.39
SEm(±)	0.02	0.02	0.02	0.00	0.00	0.00	0.03	0.02	0.02
CD (P=0.05)	0.07	0.07	0.05	0.01	0.01	0.01	0.08	0.07	0.05

PE, Potential evapotranspiration.

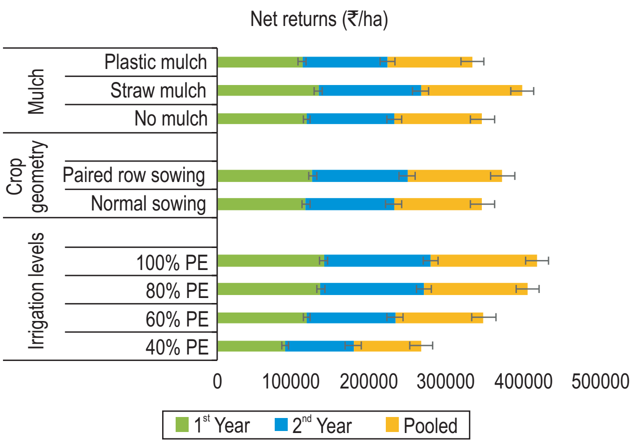

Fig. 2 Effect of different irrigation levels, mulches and crop geometry on net returns.
PE, Potential evapotranspiration.

Mulching, a critical variable in the study, markedly influenced nutrient uptake. The absence of mulch was associated with the lowest nutrient content, with pooled averages reflecting this at 1.28% for nitrogen, 0.19% for phosphorus, and 1.24% for potassium (Table 3). In contrast, the introduction of straw mulch considerably enhanced the absorption of nutrients, with the pooled averages climbing to 1.47% for nitrogen, 0.22% for phosphorus, and 1.45% for potassium. This nuanced understanding underscores the complex interplay between agricultural practices and crop nutrition, providing valuable insights for optimizing cultivation strategies to enhance the quality of okra (Tanveer *et al*. 2022, Meena *et al*. 2024).

Fig. 2, illustrates the net returns in ₹/ha for different treatments including irrigation levels, crop geometry, and mulching. Net returns increase with higher irrigation levels. In the 1st year, returns ranged from 87,306 ₹/ha at 40% PE to 137,292 ₹/ha at 100% PE. The 2nd season showed a similar trend with 88,087 ₹/ha at 40% PE and 138,466 ₹/ha at 100% PE. The pooled data reflects a consistent increase from 87,696 ₹/ha at 40% PE to 137,879 ₹/ha at 100% PE. Paired row sowing produced higher returns than normal sowing, with pooled returns of 122,816 ₹/ha and 114,118 ₹/ha, respectively. Straw mulch also resulted in high returns at 133,144 ₹/ha pooled. Across both seasons and the pooled average, the results indicate that the most profitable outcomes were achieved with 100% PE irrigation, paired row sowing, and the use of straw mulch. The findings of our study align closely with those reported by Patra *et al*. (2023), further corroborating the significance of tailored irrigation levels, crop geometry, and mulching practices in improving the plants overall growth, yield and nutrient profile of okra plants.

The results showed the interactions between irrigation levels and mulches on net returns (per ha) of okra (Supplementary Table 1). For the no mulch, the net returns varied across different irrigation levels, with the highest returns observed at 100% PE irrigation in both years and the pooled data. Straw mulch showed varying net returns, with the highest returns at 80% PE irrigation in 1st season and 100% PE irrigation in 2nd season and pooled data. These results highlight the importance of considering both irrigation levels and mulching techniques for optimizing net returns in okra cultivation.

The study clearly demonstrates the significant impact of different irrigation levels, crop geometry, and mulching on the growth, yield, and nutrient content of okra plants. Optimal irrigation at 100% PE significantly enhances plant height, fruit size, number of branches and fruits/plant, as well as chlorophyll and nutrient content, underscoring the importance of maintaining adequate soil moisture. Paired row sowing, particularly with a 30 cm × 70 cm spacing, led to increased chlorophyll content (1.87 mg/g) and branch development, suggesting that precise crop geometry enhances water and nutrient absorption. The straw mulch was superior in improving plant growth and yield, with the highest chlorophyll content (1.91 mg/g) and nutrient uptake, including nitrogen (1.47%), phosphorus (0.22%), and potassium (1.45%). Economically, these practices proved beneficial, with 100% PE irrigation, paired row sowing, and straw mulching yielding the highest net returns, peaking at 137,879 ₹/ha. These results could play a crucial role in optimizing okra cultivation in areas facing water scarcity.

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