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Optimizing Okra Yield: The Synergistic Effects of Land Configuration, Mulching and Fertilizer Management

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The field experiment was carried out during *rabi* seasons of 2022-23 and 2023-24 at Instructional Farm, Department of Agronomy, College of Agriculture, Dapoli. Dist. Ratnagiri (M.S.). The soil of the experimental plot was sandy clay loam in texture, low in available nitrogen and very low in phosphorus, medium in potassium, very high in organic carbon and acidic in reaction. The field experiments were laid out in a strip plot design comprising of twelve treatment combinations replicated thrice. The vertical strips consist of four land configurations with or without mulch treatment *viz.,* M_1: Raised bed with mulch, M_2: Raised bed without mulch, M_3: Flatbed with mulch and M_4: Flatbed without mulch similarly horizontal strips comprised three fertilizer management practices *viz.,* F_1: RDF through straight fertilizer, F_2: Konkan Annapurna Briquettes (KAB) + Remaining N, P_2O_5 and K_2O through fertigation and F_3: RDF through fertigation. The results revealed that the among the varying land configuration with or without mulch, the treatment raised bed with mulch (M_1) significantly enhanced growth, fruit and stalk yield and it was found comparable to each other with the treatment flat bed with mulch (M_3). Regarding the different fertilizer management practices, the combination of Konkan Annapurna Briquettes with the remaining RDF applied through fertigation (F_2) achieved significantly higher growth parameters, fruit and stalk yield during both the years of experiment and in pooled data. This result was found to be comparable to each other to the treatment involving application of the entire RDF through fertigation (F_3) in the okra crop. Evaluating the interaction of treatment combinations, raised bed with mulch including Konkan Annapurna Briquettes plus remaining RDF through fertigation (M_1F_2) recorded a significant increase in growth, fruit and stalk yield of *rabi* okra during both the years of experiment and in pooled data.

Keywords: Okra; fertigation; Konkan Annapurna Briquettes; growth and yield.

1. INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench) is extensively grown vegetable crop all over India. It is an enormous challenge to fulfil the vegetable requirement for the world's second largest and ever-increasing Indian population, putting immense stress on utilization of natural resources. Drip fertigation optimizes water and land use while boosting yield and water productivity. Optimizing okra yield is crucial for the agricultural sector due to its significant role in enhancing food security and contributing to economic growth. Okra is a nutrient-rich crop, providing essential vitamins, minerals, and dietary fiber, making it a vital food source for communities, particularly in regions with limited access to diverse diets. Improved yields can help address food shortages and ensure a stable supply to meet growing population demands. Economically, okra is a cash crop for many small-scale and commercial farmers, providing income and supporting rural livelihoods. Increased productivity reduces production costs and enhances profitability, fostering economic stability in agricultural regions. Additionally, higher yields can bolster export opportunities, contributing to national economies.

India is the second largest producer of vegetables after China in the world and is a leader in the production of vegetables like peas and okra (Kaur et al*.,* 2019). In India, it is grown over an area of 1.01 M ha with a production of 18588 MT having productivity 11600 kg ha^{-1}. It contributes 5.8 per cent of the total vegetable area and 3.9 per cent of total country's vegetable production (Anonymous, 2019-20). In India, okra is commercially grown in West Bengal, Bihar, Gujarat, Telangana, Maharashtra and other states having tropical and subtropical agro-climatic conditions. Among all states West Bengal ranked 1st in production with 1.490 MT from 2.954 M ha. However, Maharashtra ranked 13th in okra with annual production of 0.649 MT from 1.128 M ha area (Anonymous, 2019-20). Though, okra is cultivated throughout the country, concentrated pockets are there in several districts *i.e.* Kurnool district in Andhra Pradesh, Vaishali, Nalanda, Muzzafarpur and Begu sarai district in Bihar, Surat, Vadodara and Junagarh districts in Gujrat, Bagalkot, Mandya, Belgaum, Haveri, Bangalore and Bijapur districts in Karnataka, Keonjhar, Sundergarh, Mayurbhanj, Bolangir, Ganjem and Kalahandi districts in Orrisa and Nasik, Pune, Thane districts in Maharashtra. In Konkan region okra is mainly grown in Raigad, Palghar and Thane district, it is also grown on smaller scale in Ratnagiri and Sindhudurg district.

Efficient use of water and fertilizers is essential for enhancing agricultural productivity. Precision farming techniques like fertigation and polyethylene mulching significantly improve crop yields, profitability, and nutrient use efficiency. Raised beds enhance drainage, reduce waterlogging, and support sensitive crops, while permanent raised beds further boost efficiency through minimal tillage and rapid crop turnover. Mulching, especially with silver-black polyethylene, conserves soil moisture, suppresses weeds, and improves soil temperature, enhancing crop performance. Fertilizer strategies, including fertigation and briquette application, maximize nutrient efficiency, reduce losses, and increase yields by up to 30%, saving time and costs. This manuscript findings contribute to the broader understanding of resource-efficient farming, which is critical for addressing food security and environmental conservation. This research offers a practical framework for improving crop productivity while reducing input costs, making it relevant for scientists, agronomists, and policymakers aiming to advance sustainable agricultural innovations.

2. MATERIALS AND METHODS

A field experiment was conducted at the Instructional Farm, Department of Agronomy, College of Agriculture, Dapoli, Ratnagiri, during the *rabi* 2022-23 and 2023-24 season using the Konkan Bhendi variety of okra. The experiment was arranged in a strip plot design with twelve treatment combinations replicated three times, four vertical strips of land configurations with or without mulch treatment *viz.,* M_1: Raised bed with mulch, M_2: Raised bed without mulch, M_3: Flatbed with mulch and M_4: Flatbed without mulch and horizontal strips comprised three fertilizer management practices *viz.,* F_1: RDF through straight fertilizer, F_2: Konkan Annapurna Briquettes (KAB) + Remaining N, P_2O_5 and K_2O through fertigation and F_3: RDF through fertigation. The field had flat topography and sandy clay loam soil with low nitrogen and phosphorus, medium potassium and an acidic reaction. During year 2022-23 *rabi* okra crop season, the benefit of 28.6 mm post monsoon rain was occurred with 1 numbers of rainy days. However, in year 2023-24, only 1.9 mm post-monsoon rainfall was received. Okra was sown at a spacing of 45 cm × 30 cm and the recommended dose of straight fertilizer (100:50:25 NPK kg ha^{-1}) was applied using urea, single superphosphate and Muriate of Potash (MOP) similarly fertigation by Sujla (19:19:19), Mono Ammonium Phosphate (MAP) also briquette through Konkan Annapurna Briquette (KAB) as nutrient sources. Fertigation was provided in 10 equal splits at 7 day's intervals starting after 30 DAS to treatment F_3, while briquettes were applied at 15 DAS for the treatment F_2. Because of precise nutrient availability and timely fulfilment of crop requirements. Growth parameters such as plant height (cm), number of functional leaves and dry matter production plant^{-1} (g) were recorded at 30, 60, 90 DAS and at harvest. Where, the fruit and stalk yield (kg ha^{-1}) were assessed at harvest.

3. RESULTS AND DISCUSSION

3.1 Effect of Varying Land Configuration with or Without Mulch

3.1.1 Growth attributes

The growth of *rabi* okra in terms of plant height (cm), number of functional leaves plant^{-1} and dry matter production plant^{-1} (g) at periodic intervals is reported in Table 1, respectively and revealed that almost all the crop growth characters of *rabi* okra showed a significant improvement with the use of different land configuration with or without mulch.

The data presented in the Table 1 clearly indicate that land configuration with or without mulch, had a significant impact on the growth characteristics of okra throughout its crop growth and development. The sowing of okra on a raised bed with mulch consistently led to a significantly higher plant height, number of functional leaves and dry matter production plant^{-1} from the initial growth stage up to harvest. However, the treatment involving a flat bed with mulch found at par with the treatment raised bed with mulch during both years of the study and in pooled data.

The polyethylene mulch has been associated with increased plant height, likely due to improved aeration in the root zone, which promotes greater plant growth. This effect may also be attributed to the higher moisture content retained in the root zone of okra plants under polyethylene mulch, enhancing the plant metabolic activity and resulting in a greater number of leaves (Das et al*.,* 2018 in okra crop). Similarly, the more favourable soil environment provided by the polyethylene mulch, particularly in the early stages of the growing season, led to increased dry matter production (Mohammed et al*.,* 2009 in okra crop).

3.1.2 Fruits and stalk yield

The results revealed that used of raised bed with mulch remained comparable to each other with flat bed with mulch and both the treatments significantly increased almost all the yield attributes (Table 2) as compared to remaining practices of land configuration with or without mulch during both the years of experiment and in pooled data.

The increase in yield due to silver black polyethelene mulch may further be attributed to the retention of higher soil temperature, improved soil moisture and enhanced activity of soil microorganisms, leading to greater nutrient availability. Similar findings were reported by Bhutia et al*.,* (2017) in okra crop. The enhancement in yield attributes with mulching may also be due to increased photosynthesis and other metabolic activities (Bhatt et al*.,* 2011 in summer squash crop). The fruits yield was higher in raised bed planting, likely due to the availability of sufficient nutrients and a favourable growth environment, which allowed plants to store more resources for both vegetative and reproductive growth. These results are consistent with findings by Kadari et al*.,* (2019) in onion crop (See the Figs. 1 & 2)

3.2 Effect of Different Fertilizer Management Practices

3.2.1 Growth attributes

It is evident from the data presented in Table 1 that the remarkable influence of different fertilizer management practices on growth characters of okra was coincided with grand growth period. During grand growth phase, growth parameters of okra crop such as plant height (cm), number of functional leaves plant^{-1} and dry matter production plant^{-1} (g) recorded significantly maximum under the application of Konkan Annapurna Briquettes plus remaining N, P_2O_5 and K_2O through fertigation over rest of the fertilizer management practices and it was comparable to each other with treatment RDF through fertigation during both the years of study and in pooled data.

In this study, the overall performance of the okra crop was significantly influenced by the scheduling of chemical fertilizer, as also reported by Nair et al*.,* (2017) in okra crop. The results indicated that treatment involving the application of Konkan Annapurna Briquettes plus remaining N, P_2O_5 and K_2O through fertigation led to greater plant height with a greater number of functional leaves plant^{-1}. Growth parameter values were higher in these treatments, likely due to the continuous supply and availability of nutrients in the root zone during the developmental, mid and late stages of growth. The nutrient stress was not observed throughout the crop growth period. The fertilizer use efficiency was also higher in these treatments, possibly due to reduced leaching from frequent, need-based irrigation. These findings correspond closely with those obtained by Sharma et al*.,* (2019) in okra crop.

3.2.2 Fruits and stalk yield

Results indicated that the application of Konkan Annapurna Briquettes along with the remaining N, P_2O_5 and K_2O through fertigation significantly increased fruit and stalk yields as well as the number and weight of fruits per plant furthermore remained comparable to each other with RDF through fertigation during both the years of experiment (Table 2). In contrast, the treatment using RDF through straight fertilizers recorded lower values for the same parameters. The higher yield in okra with 100 per cent fertigation of the recommended dose also observed by Varughese et al*.,* (2014) in okra crop. These higher yields were due to better growth and yield parameters like plant height (cm), number of fruits per plant and fruit length (cm). Nagegowda et al*.,* (2020) in okra crop found that the application of water-soluble fertilizer through fertigation recorded significantly higher fruit yield than fertilization through soil application (See the Figs. 3 & 4)

3.3 Interaction Effect Between land Configuration with or Without Mulch and Fertilizer Management Practices on Growth Parameters, Fruit and Stalk Yield

The interaction effect was found to be significant (Table 3) between the varying land configuration with or without mulch and different fertilizer management practices with respect growth parameters and in both fruit and stalk yield.

The interaction between raised bed with mulch and the application of Konkan Annapurna Briquettes along with the remaining N, P_2O_5 and K_2O through fertigation (M_1F_2) resulted in the higher growth parameters such as plant height (cm), number of functional leaves plant^{-1} and dry matter production plant^{-1} (g) similarly significantly increased fruit and stalk yield of okra during both years of study and in the pooled data. This treatment was comparable to each other with the combination of flat bed with mulch including Konkan Annapurna Briquettes and remaining N, P_2O_5 and K_2O through fertigation (M_3F_2) See the Figs. 5 & 6. Nagegowda et al., (2020) in okra crop, reported that application of nitrogen and potassium through fertigation resulted in increase of 36 percent in nutrient use efficiency compared to conventional method of fertilizer application. Hence, higher nutrient use efficiency contributed to reduction in the requirement of fertilizers and cost of cultivation.

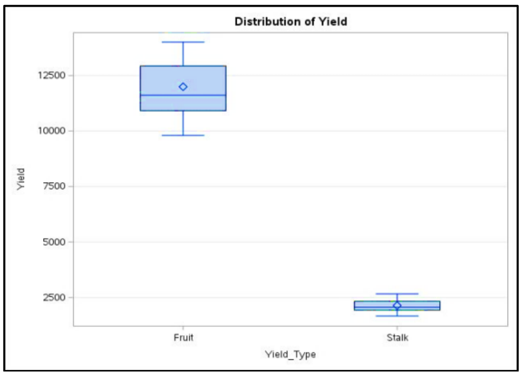

Fig. 1. Distribution of fruits and stalk yield in kg ha-1

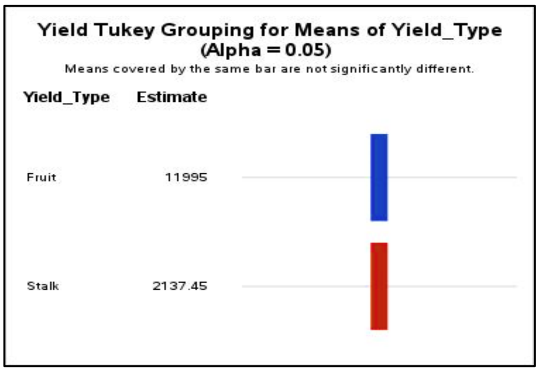

Fig. 2. Mean yield covered by fruits and stalk kg ha-1

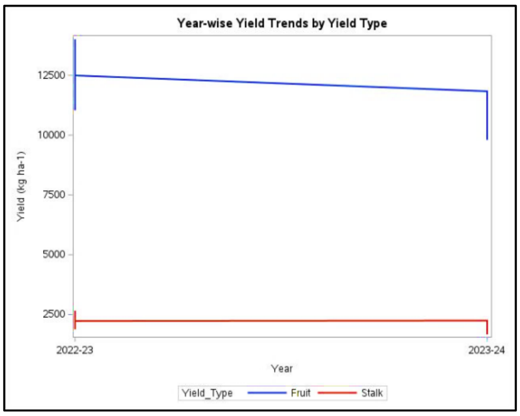

Fig. 3. Trending yield of okra

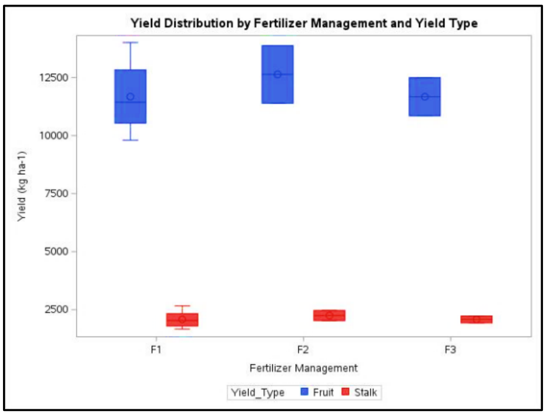

Fig. 4. Yield distribution by fertilizer management

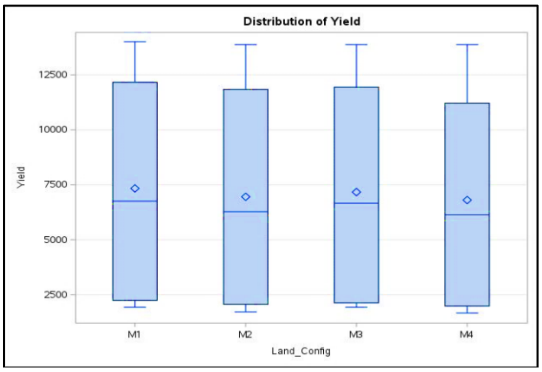

Fig. 5. Yield distribution affected by land configuration with or without mulch treatments

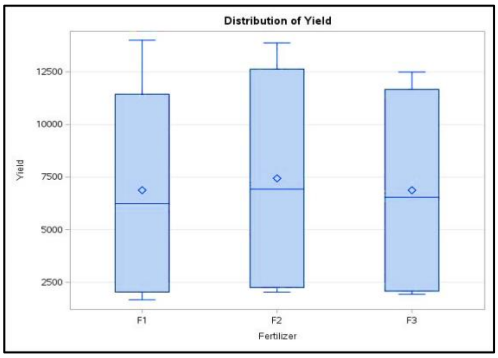

Fig. 6. Yield distribution affected by different fertilizer management treatments

Table 1. Growth parameters of okra as influenced by different treatments during *rabi* 2022-23, 2023-24 and in pooled data

Treatments	Plant height (cm)			Number of Functional Leaves $plant^{-1}$			Dry matter production $plant^{-1}$ (g)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Vertical strips: Land configuration with or without mulch (M)									
M_1: Raised bed with mulch	83.37	83.00	83.19	9.00	9.21	9.10	23.79	25.01	24.40
M_2: Raised bed without mulch	79.65	78.97	79.31	7.98	8.06	8.02	20.54	21.90	21.22
M_3: Flat bed with mulch	82.96	81.87	82.41	8.85	9.19	9.02	22.51	23.58	23.04
M_4: Flat bed without mulch	77.74	77.05	77.40	7.64	7.72	7.68	20.00	21.14	20.57
S.Em.±	0.92	0.65	0.73	0.62	0.71	0.66	0.75	0.60	0.63
C.D. at 5%	3.19	2.23	2.52	N.S.	N.S.	N.S.	2.59	2.09	2.17
Horizontal strips: Fertilizer Management (F)									
F_1: RDF through straight fertilizer	78.49	77.46	77.97	7.43	7.70	7.57	20.43	21.29	20.86
F_2: KAB + Remaining N, P_2O_5 and K_2O through fertigation	83.05	82.67	82.86	9.25	9.35	9.30	22.98	24.29	23.63
F_3: RDF through fertigation	81.25	80.54	80.89	8.41	8.59	8.50	21.71	23.14	22.43
S.Em.±	0.61	0.84	0.65	0.57	0.53	0.54	0.33	0.56	0.32
C.D. at 5%	2.39	3.29	2.56	N.S.	N.S.	N.S.	1.28	2.21	1.27
Interaction (M×F)									
S.Em.±	0.99	0.97	0.95	1.77	1.56	1.66	0.74	0.76	0.73
C.D. at 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 2. Fruit and stalk yield (kg ha^{-1}) of okra as influenced by different treatments during *rabi* 2022-23, 2023-24 and in pooled data

Treatments	Fruit yield (kg ha^{-1})			Stalk yield (kg ha^{-1})		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
Vertical strips: Land configuration with or without mulch (M)						
M_1: Raised bed with mulch	14007.74	11832.00	12919.87	2662.87	2249.26	2456.07
M_2: Raised bed without mulch	12286.32	10087.09	11186.71	2089.90	1715.81	1902.86
M_3: Flat bed with mulch	13375.65	10983.64	12179.64	2408.96	1978.15	2193.55
M_4: Flat bed without mulch	11041.27	9801.28	10421.28	1878.12	1667.20	1772.66
S.Em.±	244.23	419.90	215.27	44.15	76.72	38.00
C.D. at 5%	845.16	1453.05	744.95	152.79	265.50	131.50
Horizontal strips: Fertilizer Management (F)						
F_1: RDF through straight fertilizer	11663.09	9782.59	10722.84	2081.15	1744.44	1912.79
F_2: KAB + Remaining N, P_2O_5 and K_2O through fertigation	13876.79	11394.12	12635.46	2468.15	2029.84	2249.00
F_3: RDF through fertigation	12493.36	10851.29	11672.33	2230.59	1933.54	2082.06
S.Em.±	284.69	290.23	209.64	50.73	51.21	37.36
C.D. at 5%	1117.82	1139.58	823.13	199.19	201.09	146.69
Interaction (M×F)						
S.Em.±	785.63	300.22	488.57	131.44	52.23	81.21
C.D. at 5%	2420.77	925.06	1505.42	N.S.	160.93	250.24

Table 3. Interaction effect between land configuration with or without mulch and fertilizer management on fruit yield (kg ha^{-1}) of *Rabi* okra 2022-23, 2023-24 and in pooled data

Horizontal strips	Fruit yield (kg ha^{-1})											
	2022-23 Vertical strips				2023-24				Pooled			
	M_1	**M_2**	**M_3**	**M_4**	**M_1**	**M_2**	**M_3**	**M_4**	**M_1**	**M_2**	**M_3**	**M_4**
F_1	13207.90	11116.30	12485.93	9842.22	11166.07	9073.01	9836.83	9054.44	12186.99	10094.65	11161.38	9448.33
F_2	14622.12	13681.43	13838.57	13365.04	12540.89	10720.64	11600.00	10714.96	13581.51	12201.04	12719.28	12040.00
F_3	14193.19	12061.23	13802.47	9916.54	11789.04	10467.62	11514.07	9634.44	12991.11	11264.43	12658.27	9775.49
S.Em.±	785.63				300.22				488.57			
C.D. at 5%	2420.77				925.06				1505.42			
Stalk yield (kg ha^{-1})												
F_1	--	--	--	--	2122.67	1543.32	1771.61	1540.16	2316.75	1717.10	2010.16	1607.16
F_2	--	--	--	--	2384.02	1823.58	2089.16	1822.62	2581.84	2075.40	2290.74	2048.00
F_3	--	--	--	--	2241.10	1780.54	2073.68	1638.82	2469.61	1916.08	2279.75	1662.81
S.Em.±	--				52.23				81.21			
C.D. at 5%	--				160.93				250.24			

4. CONCLUSION

The study concluded that land configuration and mulch significantly influenced the growth and yield of *rabi* okra. Raised bed planting with polyethylene mulch consistently enhanced plant height, number of functional leaves, dry matter production also fruit and stalk yield due to improved soil moisture, aeration and nutrient availability. Similarly, fertilizer management practices involving Konkan Annapurna Briquettes with remaining RDF through fertigation significantly improved growth parameters and yield compared to traditional methods, attributed to the continuous nutrient supply and higher fertilizer use efficiency. The combination of raised bed with mulch and Konkan Annapurna Briquettes plus remaining N, P_2O_5 and K_2O through fertigation proved optimal in enhancing growth and yield. Using Konkan Annapurna Briquettes with the remaining nutrients applied through fertigation ensures a continuous nutrient supply, boosting fertilizer efficiency and crop productivity. Promoting these practices through training programs, subsidies for mulch and advanced fertilizers and awareness campaigns can help farmers achieve higher yields while conserving resources, contributing to sustainable agricultural development. Additionally, Policy makers and farmers should adopt integrated strategies to improve *rabi* okra cultivation sustainably. Raised bed planting combined with polyethylene mulch is recommended, as it improves plant growth and yield by enhancing moisture retention, aeration and nutrient availability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declared that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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