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Impact of fertigation schedule on vegetative growth, yield and quality of carambola (*Averrhoa carambola* L.) in lateritic soils of Konkan region

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Abstract
Carambola (*Averrhoa carambola* L.) is also known as star fruit. A field experiment to investigate the effect of fertigation and irrigation levels on vegetative growth and yield of carambola. To assess the influence of fertigation on growth and yield of carambola, investigations were carried out in carambola during 2024 - 2025 at Department of Horticulture, College of Agriculture, Dapoli (MS). The experiment was laid out in a split-plot design with 12 treatments, replicated thrice. The main plots consisted of four fertilizer levels (00:00:00, 100:50:25, 125:75:50 and 200:100:75 g NPK plant^{-1}), while the subplots comprised three irrigation levels (60%, 80% and 100% ETc). The application of 125:75:50 g NPK plant^{-1} + 100% ETc (F_3I_3) treatment combination recorded the highest plant height, stem girth, number of leaves, number of branches, maximum number of fruits and fruit quality. Among the diferent fertigation and irrigation levels, the applications of 125:75:50 g NPK per plant at 100% ETc in seven splits were found to be optimal and eficient fertigation scheduling under lateritic soils of Konkan for growth and yield of carambola, with greater significance after the first year of establishment.

Keywords: Carambola, fertigation, irrigation and growth

Introduction
Carambola (*Averrhoa carambola* L.), native to Asia and belonging to the family Oxalidaceae, is also known as star fruit or five-corner fruit. It is an important minor tropical and subtropical crop, cultivated in countries such as India, China, Thailand, Malaysia, Indonesia, Sri Lanka, Guyana, Brazil and Tobago. In India, it is grown sporadically, often as a dooryard plant, with two fruit types: sweet and sour (Mandal *et al*., 2013) [16]. The west coast of India experiences heavy monsoon rainfall from June to September, followed by water scarcity until April, making adequate irrigation essential. Excessive rainfall leads to nutrient leaching, reducing nutrient use efficiency. Fertigation is one such management option in which any water-soluble fertilizer or chemical can be applied in precise amounts in synchrony with the plant's needs, directly into the crop's root zone (Tayade *et al.,* 2022) [27]. It minimizes nutrient losses, enhances nutrient uptake, save water, labour, fertilizer and is particularly suitable for resource-limited regions (Elhindi *et al*., 2016) [6].

Drip fertigation enables precise delivery of nutrients to the root zone at specific growth stages, reducing cultivation costs while improving yield and quality. Fertigation ensures optimal nutrient levels in the rhizosphere, promoting better crop response compared to conventional broadcasting or band application (Sandal *et al.,* 2015) [21]. It also improves fruit quality, reduces leaching losses and provides targeted nutrition for plant growth, development and yield. Fertigation techniques can promote the efficient use of natural resources, improve fruit quality and yield per unit area, and orchard life, and reduce pollution (Singh *et al.,* 2005) [26]. There is limited information on the effect of the fertigation of NPK fertilizers on carambola. Therefore, there is a need to study the vital aspect of fertigation involving the dosage of fertilizers, frequency of fertigation and levels of irrigation on growth and yield of carambola.

Keeping these points in view, the present study was undertaken to study the "Impact of fertigation Schedule on vegetative growth, yield and quality of carambola (*Averrhoa carambola L.*) in lateritic soils of Konkan region".

Materials and Methods

A field experiment was executed from June 2024 to April 2025 at Nursery No. 14, Department of Horticulture, College of Agriculture, Dapoli, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth Dapoli, District Ratnagiri, Maharashtra. The experiment was laid out in a split-plot design consisting of twelve treatment combinations. The main plots comprised four fertilizer levels (00:00:00, 100:50:25, 125:75:50 and 200:100:75 g NPK per plant), while the subplots consisted of three irrigation levels (60%, 80% and 100% ETc). Each replication included two carambola plants. The experiment was conducted on ten-month-old carambola plants, with a total of 72 plants selected for the study. In the present investigation, 25% of fertilizer dose were applied during the monsoon season in two split doses at 60 day intervals through soil application using ring basin method once at the onset of the monsoon (in the month of July) and again at the retreat of the monsoon (in the month of September), while the remaining 75% were applied through fertigation using drip irrigation in five split doses from November to March at 30 day intervals. Water-soluble fertilizers, including urea, 19:19:19 and 12:61:00, were used for fertigation. Irrigation was supplied daily based on ETc requirements. Crop water requirement is based on reference evapotranspiration which was estimated using FAO Penman-Monteith method (Allen *et al*. 1998) [2].

Observations were recorded on plant height, stem girth, number of leaves, number of branches, number of fruits per plant, fruit weight, fruit girth, protein content, total soluble solids (TSS) and yield per hectare. Plant height was measured from ground level to the tip of the growing point, while stem girth was recorded at the grafting point by using a vernier caliper, with averages expressed in millimeter. Fully developed and newly emerged leaves were counted per plant to determine the number of leaves, excluding dead or dry leaves. Similarly, the total number of branches per plant was recorded. For fruit characteristics, five fruits per observation plant were randomly selected to measure fruit weight and fruit girth using a vernier caliper. The total number of fruits per plant was counted to calculate the average and yield per hectare was estimated by multiplying per plant yield with the number of plants per hectare. Protein content of fruits was calculated based on the total nitrogen content of the fruit, while TSS was measured using a hand refractometer. The experimental data were statistically analyzed following the methods suggested by Panse and Sukhatme (1985) [17].

Result and Discussion

The data presented in Table 1 and Table 2 revealed that the growth and quality parameters of carambola were significantly influenced by different fertigation and irrigation levels respectively.

Growth parameters

Effect of fertigation and Irrigation levels on height (cm) of carambola plant

The data presented in Table 1 reveled that among different levels of fertigations traement F_3 (125:75:50 NPK plant^{-1}) recorded the significantly highest plant height (224.32 cm) which was found to be at par with treatment F_4 (200:100:75 g NPK plant^{-1}) where 219.89 cm plant height was recorded. Regarding the various irrigation levels observed that the highest plant height (210.03 cm) in treatment I_3 (100% ETc) which was at par with treatment I_2 (80% ETc). It was observed that the interaction effect showed significant results. The combined effect of fertilizer and irrigation significantly enhanced the plant height of carambola. The treatment F_3I_3 (125:75:50 NPK plant^{-1} with 100% ETc irrigation) recorded the maximum plant height of 233.80 cm, confirming the effectiveness of balanced fertigation coupled with adequate irrigation. The increase in plant height at higher fertigation levels may be attributed to improved nutrient-use efficiency, minimized leaching losses. The continuous nutrient supply in the root zone through seven splits ensured steady growth throughout the experimental period. As shown in Table 1, additional fertigation did not result in significant improvement, indicating that F_3I_3 was the optimum treatment for plant height.These results are in agreement with the findings of Thakur *et al.* (2020) [7] in apple, reported that optimal soil moisture and nutrient availability enhanced root biomass and nutrient uptake. Similar outcomes were also reported by Jangir *et al.* (2023) [7] in fruit crops, Kumar and Singh (2018) [12] in almond, and Kachwaya and Chandel (2015) [8] in strawberry.

Effect of fertigation and Irrigation levels on stem girth (mm) of carambola plant

From the data, with respect to the application of different levels of fertgations, it was observed that the significantly maximum stem girth 33.70 mm was recorded in the treatment F_3 in which the 125:75:50 g NPK plant^{-1} was applied which found significantly superior over rest of the treatments except treatment F_4 (33.17mm) which was found to be statistically at par. Among the various irrigation levels treatment I_3 (100% ETc) recorded the significantly maximum stem gitrh (30.04 mm) which found significantly superior over rest of the irrigation levels. The interaction effect between fertigation and irrigation on stem girth was statistically non-significant. However, the maximum stem girth of 36.21 mm was recorded under treatment F_3I_3 (125:75:50 g NPK plant^{-1} with 100% ET_c irrigation) in March. Data presented in Table 1 it was reveled that the lowest fertigation level failed to meet the nutrient sufficiency threshold, whereas increasing fertigation beyond this level resulted in no further beneficial effect. indicated that the lowest fertigation level did not meet nutrient sufficiency requirements, while higher fertigation levels produced no additional effect. The increase in stem girth under higher fertigation and irrigation was due to improved nutrient supply and efficient root zone availability. Enhanced photosynthetic efficiency, achieved through increased uptake and deposition of nutrients in leaf tissues, contributed to greater synthesis, translocation, and accumulation of carbohydrates, which in turn improved trunk girth (Sebastian *et al.,* 2025) [23]. This enhanced uptake efficiency, promoting secondary growth and trunk thickening. These findings agree with earlier reports. Sagvekar *et al.* (2019) [20] recorded maximum stem girth with 125% RDF and 120% ET_c irrigation, while Challa *et al.* (2021) [4] reported significant variation in guava under different fertigation levels. Similarly, higher fertigation levels increased trunk girth in cocoa (Krishnamoorthy, C. and Rajamani, K 2013) [10] and apple (Sharma *et al.,* 2024) [25].

Effect of fertigation and Irrigation levels on number of leaves of carambola plant

The data pertaining to the number of leaves traement F_3 (125:75:50 NPK plant^{-1}) recorded the significantly highest number of leaves (585.83) which was found to be at par with treatment F_4 (200:100:75 g NPK plant^{-1}) where 579.72 number of leaves was recorded. Whereas, the effect of various irrigation levels treatment I_3 (100% ETc) recorded the significantly maximum number of leaves (641.58) which found significantly superior over rest of the irrigation levels. It was observed that the interaction effect showed significant results on number of leaves. The significantly highest number of leaves (918.33) was observed in treatment F_3I_3, (125:75:50 g NPK plant^{-1} with 100% ETc) while the lowest (126.33) was observed in F_1I_1. This might be due consistent moisture levels and nutrient reserves developed in the soil through frequent drip fertigation kept the roots active for a longer period, resulting in improved nutrient uptake and movement of food materials within the plant. This continuous supply of moisture further accelerated vegetative growth, as reflected in increased leaf production and overall plant development (Sebastian *et al*., 2025) [23]. These findings are in agreement with Sagvekar *et al.* (2019) [20], who reported that functional leaves in papaya were significantly influenced by 120% ETc combined with 125% RDF fertigation; Kachawaya and Chandel (2015) [9], who observed maximum leaf production with recommended NPK through drip irrigation and Sharma and Mursaleen (2014) [24], who reported better vegetative growth in guava under higher fertigation levels.

Effect of fertigation and Irrigation levels on number of branches of carambola plant

The data presented in Table 1 revealed that different levels of irrigation and fertigation significantly influenced the number of branches. The maximum number of branches (35.28) was observed in the treatment F_3 where 125:75:50 NPK plant^{-1} was applied and it was found to be statistically significant over rest of the treatments. Among the various irrigation levels treatment I_3 (100% ETc) recorded the significantly maximum number of branches (29.83). The combined effect of fertigation and irrigation showed the significant effect on number of branches of carombola. Treatment F_3I_3 (125:75:50 NPK plant^{-1} with fertigation at 100% ETc) recorded the highest number of branches (47.33), whereas the lowest number of branches (5.33) was observed in F_1I_1 (00:00:00 NPK plant^{-1} with fertigation at 60% ETc). This response may be ascribed to adequate soil moisture, precise fertigation scheduling and a continuous supply of nutrients through split applications, which enhanced fertilizer-use efficiency which also resulted in better growth of corambola plant. These results are in accordance with the findings of Challa *et al.* (2021) [4] in different crops, Sharma and Mursaleen (2014) [24] in guava and Agrawal and Agrawal (2007) [1] in pomegranate. Similar observations were also reported by Leal *et al.* (2007) [14], Mahalaxmi *et al.* (2001) [15], Sagvekar *et al.* (2019) [20] and Krishnamoorthy and Rajamani (2013) [10].

Yield contributing characteristics and yield of carambola

Yield and yield contributing characters of carambola were highly influenced by fertigation treatments. The observations on number of fruits plant^{-1}, fruit weight (g), fruit girth and fruit yield were recorded and presented in table 2. The reveled that, the significantly highest number of fruits plant^{-1} (121.57), fruit weight (50.49g), fruit girth(43.18 mm) and fruit yield (4053.19kg ha^{-1}) were recorded in treatment F_3 (125:75:50 NPK plant^{-1}) which was found be statistically significant over all remaining fertigation treatment. Whereas, among the various irrigation treatment I_3 (100% ETc) treatment recorded the significantly highest number of fruits plant^{-1} (71.6), fruit weight (49.78g), fruit girth(33.06 mm) and fruit yield (2613.38 kg ha^{-1}). which found significantly superior over rest of the irrigation levels. It was observed that the interaction effect showed significant results. The F_3I_3 treatment combination i.e. 125:75:50 NPK g plant^{-1} in seven splits and 100% ETc was applied recorded significantly highest number of fruits plant^{-1} (155.79), fruit weight (89.9 g), fruit girth(47.82 mm) and fruit yield (4826.57 kg ha^{-1}). The highest number of fruits plant^{-1}, fruit weight (g), fruit girth and fruit yield was observed in F_3I_3 treatment (125:75:50 NPK g plant^{-1} in seven splits and 100% ETc). The higher dose i.e., 200:100:75 g NPK per plant did not produce significantly higher yield as compared to 125:75:50 NPK g plant^{-1}. This indicates the sufficient nutrients supplied from 125:75:50 NPK g plant^{-1}. On the other hand the low yield observed with lower levels of fertigation, might be due to the low availability of nutrients, resulting in lower yield contributing cahracters and yield of carambola. The higher yield contributing cahracters and yield of carambola this might be due to when irrigation water was applied through drip irrigation system, it enhanced the water use efficiency and maintained adequate soil moisture status, balanced and adequate supply of major nutrients at appropriate time is very essential and responsible for enhanced photosynthesis, carbohydrate synthesis and assimilate production, leading to better fruit development and higher yield of crop. These results are in agreement with the findings of Thanki *et al.* (2025) [29] in dragon fruit, Priya *et al.* (2022) [18] in custard apple, Rao *et al.* (2022) [19] in mango, Kachwaya and Chandel (2015) [9], Sarolia *et al.* (2019) [22] in guava and Sebastian *et al*. (2025) [23].

Quality parameters of carambola fruit

Total Soluble Solids (°B)

The interaction effect fertilizer and irrigation was nonsignificant, though F_4I_1 (200:100:75 g NPK + 60% ETc) recorded the highest TSS (8.07 °B) and F_2I_2 (100:50:25 g NPK + 80% ETc) the lowest (6.10 °B) (table 2). Higher TSS under fertigation is mainly due to improved potassium availability, which enhances sugar translocation and accumulation. Similar findings were reported in strawberry (Kachwaya & Chandel, 2015; Jeyakumar *et al.,* 2008) [9, 8] and mandarin (Kuchanwar *et al*., 2017) [11].

Protein (%)

The interaction between fertilizer and irrigation significantly influenced protein content in carambola. The highest protein (12.06%) was recorded under F_3I_3 (125:75:50 g NPK + 100% ETc), followed by F_4I_3 (11.58%) (table 2), which was statistically similar. Enhanced protein accumulation under F_3I_3 is attributed to adequate nitrogen for amino acid synthesis and full irrigation supporting nutrient uptake. Fertigation improves nutrient translocation and fruit quality, though optimal NPK doses are crop-specific. Similar trends were reported by Sharma *et al*. (2024) [25] and Al-Qurashi *et al*. (2016) [3].

Conclusion

On the basis of the results, the present study revealed that the among various treatment combination of fertigation and irrigation levels treament F_3I_3 (125:75:50 g NPK per plant with 100% ETc through drip irrigation) performed better with respect to growth, yield-contributing characters and overall yield of carambola. The application of 125:75:50 g NPK per plant in seven split doses with 100% ETc irrigation through drip system, significantly improved plant growth and yield-attributing traits, which ultimately enhanced both yield and fruit quality. These findings indicated that fertigation with this optimum dose of fertilizer and irrigation level is highly effective for carambola, particularly after the first year of plantation.

Table 1: Effect of fertigation and irrigation levels on vegetative growth of carambola

	Plant Height (cm)		Stem girth (mm)		Number of Leaves		Number of Branches	
	Initial	April 2025	Initial	April 2025	Initial	April 2025	Initial	April 2025
F_1	62.04	170.47	14.18	19.02	40.33	190.39	1.89	7
F_2	61.47	210.29	14.74	28.28	46.33	391.19	1.72	21.5
F_3	63.38	224.32	14.34	33.7	43.06	585.83	1.56	35.28
F_4	63.23	219.89	13.92	33.17	47.17	579.67	1.61	32.44
SE(m) ±	1.25	1.48	0.29	0.3	4.8	2.16	0.21	0.52
CD at 5%	NS	5.14	NS	1.04	NS	7.49	NS	1.79
I_1	61.17	199.77	14.49	26.87	45.92	261.26	1.5	19.13
I_2	64.01	208.92	14.19	28.72	45.04	407.46	1.79	23.21
I_3	63.35	210.03	14.21	30.04	41.71	641.58	1.79	29.83
SE(m) ±	2.27	1.32	0.3	0.31	3.68	1.21	0.23	0.6
CD at 5%	NS	3.97	NS	0.94	NS	3.62	NS	1.81
F_1I_1	62.19	167.74	13.41	17.95	39.67	126.33	1.17	5.33
F_1I_2	60.72	170.9	14.02	18.74	47	166.83	2.17	6.33
F_1I_3	63.22	172.77	15.12	20.37	34.33	278	2.33	9.33
F_2I_1	61.65	201.12	14.9	25.87	51.33	229.89	1.67	17.5
F_2I_2	60.27	213.31	14.76	28.95	40.17	374.33	1.5	21.33
F_2I_3	62.5	216.45	14.58	30.02	47.5	569.33	2	25.67
F_3I_1	58.97	214.24	15.25	31.35	41.33	330.83	1.5	26.33
F_3I_2	66.87	224.91	13.58	33.54	45.83	508.33	1.67	32.17
F_3I_3	64	233.8	14.2	36.21	42	918.33	1.5	47.33
F_4I_1	61.85	215.99	14.39	32.29	51.33	358	1.67	27.33
F_4I_2	68.18	226.58	14.4	33.66	47.17	580.33	1.83	33
F_4I_3	59.67	217.09	12.96	33.55	43	800.67	1.33	37
SE(m) ±	4.35	2.65	0.61	0.63	7.35	2.42	0.45	1.21
CD at 5%	NS	7.93	NS	NS	NS	17.4	NS	3.63

Table 2: Effect of fertigation and irrigation levels on yield contributing, yield and quality of carambola

	Number of fruit (plant^{-1})	Fruit weight (g)	Fruit Girth (mm)	(Yield) (kg ha^{-1})	T.S.S (^{0}B)	Protien (%)
F_1	0	0	0	0	0	0
F_2	35.75	36.47	36.06	1472.88	6.82	8.82
F_3	121.57	50.49	43.18	4053.19	6.89	10.41
F_4	83.11	41.91	39.13	3256.78	7.27	10.69
SE(m) ±	6.25	1.49	0.78	171.07	0.12	0.09
CD at 5%	21.62	5.14	2.69	591.88	0.42	0.31
I_1	49.09	20.15	27.37	1908.75	5.79	6.63
I_2	59.04	26.72	28.35	2065	4.78	7.46
I_3	71.6	49.78	33.06	2613.38	5.16	8.36
SE(m) ±	3.33	0.19	0.47	114.32	0.21	0.14
CD at 5%	9.97	0.58	1.42	342.68	0.63	0.43
F_1I_1	0	0	0	0	0	0
F_1I_2	0	0	0	0	0	0
F_1I_3	0	0	0	0	0	0
F_2I_1	32.41	26.62	32.95	1415.67	7.43	7.81
F_2I_2	32.43	45.29	33.33	1484.67	6.1	8.85
F_2I_3	42.41	37.51	41.9	1518.29	6.93	9.79
F_3I_1	87.6	29.2	40.43	3476	7.67	8.85
F_3I_2	121.32	32.37	41.29	3857	6.3	10.31
F_3I_3	155.79	89.9	47.82	4826.57	6.7	12.06
F_4I_1	76.33	24.78	36.1	2743.33	8.07	9.83
F_4I_2	84.4	29.24	38.77	2918.33	6.73	10.67
F_4I_3	88.2	71.7	42.53	4108.67	7	11.58
SE(m) ±	6.66	0.39	0.94	228.64	0.42	0.29
CD at 5%	19.55	1.17	2.83	685.37	NS	0.87

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