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Effect of planting geometry on growth and pod yield of drumstick (*Moringa oleifera* L.)

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Abstract
The present investigation was conducted A randomized block design with three replications was used. Nine treatments with different spacing configurations-T_1:4.0 m × 2.5 m, T_2:2.5 m × 2.5 m, T_3:1.5 m × 3.0 m, T_4: 5.0 m × 5.0 m, T_5: 2.5 m × 5.0 m, T_6: 3.0 m × 4.0 m, T_7: 2.5 m × 3.0 m, T_8: 2.0 m × 3.0 m and T_9: 2.0 m × 2.5 m were evaluated. The results concluded that the growth and yield parameter was found significantly superior in the treatment T_4 (5.0 m × 5.0 m) for most of the characters i.e. plant highest (274.28 cm), number of branches/plant (14.68), stem base diameter (6.41 cm), days to first flowering (190.95 days) and highest number of flowers per inflorescence (79.39), fruit set percentage (3.24%), pod length (71.16 cm), number of pods per plant (36.89), seeds per pod (18.93), pod weight (92.39 g) and highest pod yield per plant (3.41 kg/plant). Treatment T_2 registered highest pod yield in hectare (3.92 t/ha).

Keywords: Planting geometry, pod yield**,** Moringa and drumstick

Introduction
Moringa is botanically known as (*Moringa oleifera* L.) and belongs to the family Moringaceae and its chromosome numbers 2n=28 Moringa is one of the important vegetable crops of Southern India, particularly Tamil Nadu. It is also known as The Miracle Tree, Drumstick Tree, etc. Planting geometry refers to the spatial arrangement of plants in the field with regards to row and plant spacing. Different spacing combinations can significantly influence growth, yield and quality of drumstick (Arora and Saini, 2019) [5]. Wider spacing accommodates better plant growth due to reduced plant competition for space, nutrients, water and sunlight (Samira *et al*. 2016) [41]. However, wider spacing leads to lower plant population and potential yield loss per unit area. On the contrary, closer spacing results in higher plant density but lesser individual plant growth due to competition. Proper planting geometry, which refers to plant population and spacing, is crucial for optimizing plant growth and yield. Suitable spacing facilitates efficient utilization of resources like sunlight, soil nutrients, and water. It also aid s in maintaining aeration and controlling weeds in the field.

Materials and Methods
The experiment was carried out during the year 2022-23 under Research and Instructional Farm, RABL College of Agriculture and Research Station Chhuikhadan, dist.-Khairagarh-Chhuikhadan-Gandai, (C.G.). The experiment was laid out in Randomized Block Design (RBD) with three replications. Nine treatments were allocated in each replication (T_1:4.0 m × 2.5 m, T_2: 2.5 m × 2.5 m, T_3:1.5 m × 3.0 m, T_4 :5.0 m × 5.0 m, T_5: 2.5 m × 5.0 m, T_6: 3.0 m 4.0 m, T_7: 2.5 m × 3.0 m, T_8: 2.0 m × 3.0 m and T_9: 2.0 m × 2.5 m) Drumstick (var. PKM-1) was under present investigation.

Results and Discussion
The data presented in Table 1 show that plant height (cm) was significantly influenced by different planting geometries on growth and pod yield of *Moringa oleifera*. The tallest plants (274.28 cm) were recorded in treatment T_4 (5.0 m × 5.0 m), which was statistically similar to T_5 (2.5 m × 5.0 m) with 250.24 cm and T_6 (3.0 m × 4.0 m) with 248.66 cm.

Wider spacing under these treatments allowed for better utilization of sunlight, nutrients, and moisture, resulting in enhanced vegetative growth and taller plants. Similar findings were reported by Kumar *et al*. (2022) [18].

Significant variation was also observed in the number of branches per plant due to different planting geometries. The maximum number of branches (14.68) was recorded in T_4 (5.0 m × 5.0 m), which was statistically at par with T_5 (2.5 m × 5.0 m) and T_6 (3.0 m × 4.0 m), producing 13.96 and 13.88 branches per plant, respectively. Wider spacing facilitated better light interception, which enhanced photosynthetic efficiency and promoted the development of more branches. These results are in close agreement with those reported by Ponnuswami and Rani (2019) [30].

Regarding stem base diameter, the significantly largest diameter (6.41 cm) was found in T_4 (5.0 m × 5.0 m), which was statistically comparable to T_5 (2.5 m × 5.0 m) and T_6 (3.0 m × 4.0 m), recording 5.86 cm and 5.70 cm, respectively. Optimal spacing facilitated uniform light distribution and reduced inter-plant competition, leading to greater accumulation of photosynthates and consequently thicker stems. Similar observations were reported by Kumar *et al*. (2022) [18].

Flowering behavior was also affected by planting geometry. The earliest initiation of flowering (190.95 days) was recorded in T_4 (5.0 m × 5.0 m), followed by T_5 (2.5 m × 5.0 m) at 194.14 days and T_6 (3.0 m × 4.0 m) at 198.12 days. Wider spacing likely provided better exposure to sunlight and reduced competition for growth resources, enabling plants to attain physiological maturity earlier. These findings are consistent with Bharathi *et al*. (2018) [7].

The number of flowers per inflorescence also varied significantly among treatments. The highest number of flowers (79.39) per inflorescence was recorded in T_4 (5.0 m × 5.0 m), which was statistically similar to T_5 (2.5 m × 5.0 m) recording 77.36 flowers per inflorescence. The wider spacing of plants in these treatments enhanced flower production due to efficient utilization of available resources such as light, moisture, and nutrients. Similar results were reported by Quintin *et al*. (2013) [31].

Table 1: Effect of planting geometryon various growth parameters of drumstick.

Tr. No.	Treatment Details	Plant height (cm)	No. of branches per plant	Stem base diameter (cm)	Days to first flowering	Number of Flower per inflorescence
T_1	4.0 m × 2.5 m	243.87	13.52	5.47	201.93	55.55
T_2	2.5 m × 2.5 m	227.45	10.91	3.94	209.97	51.47
T_3	1.5 m × 3.0 m	183.84	8.37	2.79	220.84	27.17
T_4	5.0 m × 5.0 m	274.28	14.68	6.41	190.95	79.39
T_5	2.5 m × 5.0 m	250.24	13.96	5.86	194.14	77.36
T_6	3.0 m × 4.0 m	248.66	13.88	5.70	198.12	57.34
T_7	2.5 m × 3.0 m	238.48	12.32	4.80	205.21	55.82
T_8	2.0 m × 3.0 m	203.30	9.94	3.94	213.31	45.29
T_9	2.0 m × 2.5 m	196.71	8.83	3.48	217.32	32.38
	Sem (±)	11.18	0.50	0.31	6.20	3.38
	CD (5%)	33.52	1.51	0.94	18.58	10.15
	CV (%)	8.43	7.30	11.56	5.22	10.95

The data presented in Table 2 indicate that planting geometry significantly influenced the fruit-setting percentage, pod length, number of pods per plant, number of seeds per pod, and pod girth of *Moringa oleifera*.

The results showed that treatment T_4 (5.0 m × 5.0 m) recorded the highest fruit-setting percentage (3.24%), which was statistically at par with T_5 (2.5 m × 5.0 m) (3.16%) and T_6 (3.0 m × 4.0 m) (2.94%). The wider spacing in T_4 and T_5 facilitated optimum utilization of growth resources, resulting in enhanced photosynthetic activity and efficient translocation of assimilates to developing fruits. Consequently, these treatments achieved superior fruit set. Similar results were reported by Abo El-Enien *et al*. (2015) [1].

Pod length also varied significantly with planting geometry. The longest pods (71.16 cm) were recorded in T_4 (5.0 m × 5.0 m), which was statistically similar to T_5 (2.5 m × 5.0 m) and T_6 (3.0 m × 4.0 m) recording 68.61 cm and 64.30 cm, respectively. Optimal plant spacing in T_4 and T_5 facilitated better light penetration and air circulation, ensuring uniform flowering and fruit development. This led to the production of longer pods due to sufficient assimilate translocation. Similar findings were reported by Rajamanickam and Arokiamary (2022) [35].

The number of pods per plant also showed significant variation among treatments. The maximum number of pods per plant (36.89) was observed in T_4 (5.0 m × 5.0 m), which was statistically comparable to T_5 (2.5 m × 5.0 m) with 35.67 pods and T_1 (4.0 m × 2.5 m) with 34.97 pods. The optimal plant population and minimal interplant competition in T_1, T_4, and T_5 ensured efficient light interception and uniform nutrient distribution, leading to greater photosynthate production and consequently more pods per plant. These outcomes are consistent with those of Quintin *et al*. (2013) [31].

The results also revealed that the highest number of seeds per pod (18.93) was recorded in T_4 (5.0 m × 5.0 m), which was statistically at par with T_5 (2.5 m × 5.0 m) (18.52) and T_6 (3.0 m × 4.0 m) (17.83). The wider spacing in T_4 and T_5 ensured balanced nutrient and moisture availability, promoting better pod filling and seed development. Consequently, these treatments recorded maximum seeds per pod. These findings are in line with the observations of Ravani *et al*. (2020) [38].

Significant variation was also noted in pod girth among the treatments. The maximum pod girth (2.07 cm) was observed in T_5 (2.5 m × 5.0 m), which was statistically similar to T_4 (5.0 m × 5.0 m) recording 1.96 cm. The wider plant spacing in these treatments ensured uniform pod development and thicker pod walls due to better nutrient uptake and assimilate translocation. In contrast, narrow spacing restricted resource availability and resulted in thinner pods. Similar results were reported by Kumar *et al*. (2022) [18].

Table 2: Effect of planting geometry on varius growth parameter on drumstick.

Tr. No.	Treatment Details	Fruit setting percentage (%)	Pod length (cm)	Number of pods per plant	Number of seeds per pod	Pod girth (cm)
T_1	4.0 m × 2.5 m	2.77	60.36	35.09	17.31	1.68
T_2	2.5 m × 2.5 m	2.46	52.19	32.88	15.61	1.50
T_3	1.5 m × 3.0 m	1.84	40.46	23.69	12.61	1.18
T_4	5.0 m × 5.0 m	3.24	71.16	36.89	18.93	1.96
T_5	2.5 m × 5.0 m	3.16	68.61	35.67	18.52	2.07
T_6	3.0 m × 4.0 m	2.94	64.30	34.97	17.83	1.81
T_7	2.5 m × 3.0 m	2.67	56.18	33.27	16.41	1.64
T_8	2.0 m × 3.0 m	2.27	48.45	25.08	14.52	1.42
T_9	2.0 m × 2.5 m	2.39	44.27	24.04	14.01	1.31
	Sem (±)	0.21	2.81	1.76	0.65	0.07
	CD (5%)	0.63	8.43	5.28	1.94	0.22
	CV (%)	13.69	8.66	9.75	6.91	7.93

The data presented in Table 3 revealed that the number of pods per cluster was significantly influenced by different planting geometries. The highest number of pods per cluster (4.48) was recorded in T_4 (5.0 m × 5.0 m), which was statistically comparable with T_5 (2.5 m × 5.0 m) and T_6 (3.0 m × 4.0 m) recording 4.34 and 4.00 pods per cluster, respectively. The greater availability of sunlight, space, and nutrients in these wider spacings promoted better photosynthesis and physiological activity of the peduncles, resulting in enhanced flowering and fruit set. Wider spacing also improved aeration and reduced interplant competition, thereby supporting a higher number of pods per cluster. These findings are in close agreement with those of Rajamanickam and Arokiamary (2022) [35].

The number of clusters per plant also exhibited significant variation among treatments. The maximum number of clusters (12.25) was recorded in T_4 (5.0 m × 5.0 m), followed by T_5 (2.5 m × 5.0 m) with 11.54 and T_6 (3.0 m × 4.0 m) with 11.30 clusters per plant. The wider spacing facilitated optimal vegetative growth with greater branching and better light penetration, leading to higher cluster formation. In contrast, closer spacing restricted internodal elongation and limited vegetative expansion, resulting in fewer clusters. These results are in accordance with Rajamanickam and Arokiamary (2022) [35].

Significant differences were also recorded in pod weight due to different spacing treatments. The maximum pod weight (92.39 g) was obtained in T_4 (5.0 m × 5.0 m), which was statistically at par with T_5 (2.5 m × 5.0 m) and T_6 (3.0 m × 4.0 m), recording 89.81 g and 85.40 g, respectively. The higher pod weight at wider spacing may be attributed to efficient utilization of growth resources and improved photosynthate translocation, resulting in the development of heavier pods. These results are consistent with the observations of Rajamanickam and Arokiamary (2022) [35].

Pod yield per plant also varied significantly among the treatments. The highest pod yield per plant (3.41 kg) was obtained from T_4 (5.0 m × 5.0 m), followed by T_5 (2.5 m × 5.0 m) with 3.17 kg and T_6 (3.0 m × 4.0 m) with 3.01 kg. The wider spacings allowed for optimal canopy development and maximum interception of sunlight, thereby enhancing photosynthetic activity and resulting in higher pod yield per plant. Similar findings were also reported by Kumar *et al*. (2022) [18] and Rajamanickam and Arokiamary (2022) [35].

However, pod yield on a hectare basis exhibited a contrasting trend. The significantly highest yield (3.92 t/ha) was obtained under T_2 (2.5 m × 2.5 m), which was statistically similar to T_7 (2.5 m × 3.0 m) (3.52 t/ha). The lowest yield (1.36 t/ha) was recorded in T_4 (5.0 m × 5.0 m). The higher hectare yield under moderate spacing treatments such as T_2 and T_7 is attributed to the greater plant population per unit area, despite the lower individual plant performance. This reflects a balance between per plant productivity and planting density. Similar results were reported by Kumar *et al*. (2022) [18] and Rajamanickam and Arokiamary (2022) [35].

Table 3: Effect of planting geometry on varius growth and yield parameter of drumstick.

Tr. No.	Treatment Details	Number of pods per cluster	Number of clusters per plant	Pod weight (gm)	Pod yield (kg/plant)	Pod yield (t/ha)
T_1	4.0 m × 2.5 m	3.80	10.35	82.34	2.89	2.89
T_2	2.5 m × 2.5 m	2.91	8.72	74.60	2.45	3.92
T_3	1.5 m × 3.0 m	1.74	7.80	63.31	1.50	3.34
T_4	5.0 m × 5.0 m	4.48	12.25	92.39	3.41	1.36
T_5	2.5 m × 5.0 m	4.34	11.54	89.81	3.17	2.54
T_6	3.0 m × 4.0 m	4.00	11.30	85.40	3.01	2.50
T_7	2.5 m × 3.0 m	3.39	9.70	79.64	2.64	3.52
T_8	2.0 m × 3.0 m	2.21	10.35	71.49	1.81	3.02
T_9	2.0 m × 2.5 m	2.06	8.14	66.69	1.60	3.20
	Sem (±)	0.23	0.48	3.16	0.18	0.22
	CD (5%)	0.70	1.44	9.47	0.53	0.65
	CV (%)	12.65	8.28	6.98	12.32	12.83

The data presented in Table 4 reveal that the total cost of cultivation per hectare was considerably influenced by different planting geometries. The highest total cost (₹1,91,092/ha) was observed in T_3 (1.5 m × 3.0 m), followed by T_9 (2.0 m × 2.5 m) with ₹1,72,000/ha and T_8 (2.0 m × 3.0 m) with ₹1,43,362/ha. The increased expenditure under

closer spacing was primarily due to the higher number of plants per unit area, leading to increased input costs such as planting material, fertilizer, irrigation, and labour. In contrast, the lowest total cost (₹34,400/ha) was recorded under T_4 (5.0 m × 5.0 m), owing to the reduced plant population and input requirement.

Gross return (₹/ha) also exhibited a similar trend across treatments. The highest gross return (₹3,92,421.30/ha) was obtained in T_2 (2.5 m × 2.5 m), followed by T_7 (2.5 m × 3.0 m) and T_3 (1.5 m × 3.0 m), yielding ₹3,52,092.96/ha and ₹3,33,711.81/ha, respectively. The lowest gross return (₹1,36,411.47/ha) was recorded in T_4 (5.0 m × 5.0 m). The higher gross returns under moderate and closer spacings can be attributed to the greater plant population per unit area, which compensated for the relatively lower yield per plant. These findings align with the results reported by Kumar *et al*. (2022) [18].

Regarding net return (₹/ha), the significantly highest value (₹2,54,821.30/ha) was recorded in T_2 (2.5 m × 2.5 m), followed by T_7 (2.5 m × 3.0 m) (₹2,37,454.96/ha) and T_1 (4.0 m × 2.5 m) (₹2,03,074.39/ha). The lowest net return (₹1,02,011.47/ha) was obtained under T_4 (5.0 m × 5.0 m) due to the lower plant population and total yield per hectare. These results suggest that a moderate planting density can provide a favorable balance between input cost and output value.

Interestingly, the benefit-cost (B:C) ratio followed a slightly different pattern. The highest B:C ratio (2.97) was observed in T_4 (5.0 m × 5.0 m), followed by T_5 (2.5 m × 5.0 m) (2.69) and T_6 (3.0 m × 4.0 m) (2.50). The lowest B:C ratio (0.75) was recorded under T_3 (1.5 m × 3.0 m). Despite lower gross and net returns, the wider spacing treatments (T_4-T_6) achieved higher B:C ratios because of substantially reduced cultivation costs. In contrast, higher-density treatments incurred greater expenses, which reduced profitability even when total output was higher.

These results clearly indicate that while high-density planting increases total yield per hectare, it does not necessarily maximize profit due to elevated input costs. Wider spacings, on the other hand, ensure cost efficiency and sustainable returns over the production cycle. However, when considering annual net return, T_2 (2.5 m × 2.5 m) emerged as the most profitable treatment, balancing yield and cost efficiency effectively. Similar economic trends in *Moringa oleifera* spacing studies were reported by Kumar *et al*. (2022) [18] and Rajamanickam and Arokiamary (2022) [35].

Table 4: Effect of planting geometry on economics of drumstick.

Tr. Name	Tr. Details	Price/plant estimation (Rs/plant)	Plant Population	Total Cost (Rs/ha)	Yield (t/ha)	Gross Return (Rs/ha)	Net Return (Rs/ha)	B:C ratio
T_1	4.0 m × 2.5 m	86	1000	86000	2.89	289074.39	203074.39	2.36
T_2	2.5 m × 2.5 m	86	1600	137600	3.92	392421.30	254821.30	1.85
T_3	1.5 m × 3.0 m	86	2222	191092	3.34	333711.81	142619.81	0.75
T_4	5.0 m × 5.0 m	86	400	34400	1.36	136411.47	102011.47	2.97
T_5	2.5 m × 5.0 m	86	800	68800	2.54	253642.05	184842.05	2.69
T_6	3.0 m × 4.0 m	86	833	71638	2.50	250443.08	178805.08	2.50
T_7	2.5 m × 3.0 m	86	1333	114638	3.52	352092.96	237454.96	2.07
T_8	2.0 m × 3.0 m	86	1667	143362	3.02	301516.07	158154.07	1.10
T_9	2.0 m × 2.5 m	86	2000	172000	3.20	320312.31	148312.31	0.86

Conclusion

The present investigation clearly demonstrated that planting geometry exerts a profound influence on the growth, flowering, yield, and economic performance of *Moringa oleifera* under the prevailing agro-climatic conditions. Among the various spacing treatments evaluated, wider spacing of 5.0 m × 5.0 m (T_4) consistently recorded superior vegetative growth in terms of plant height, number of branches, and stem base diameter. This spacing also promoted early flowering and higher numbers of flowers per inflorescence, owing to reduced inter-plant competition for sunlight, water, and nutrients, thereby creating a more favorable microenvironment for optimum physiological functioning.

In terms of reproductive and yield attributes, wider spacing, particularly 5.0 m × 5.0 m and 2.5 m × 5.0 m, significantly enhanced pod set, pod length, pod girth, and number of seeds per pod. These results suggest that wider spacing facilitates better resource utilization and photosynthetic efficiency, which translates into improved per plant performance and superior pod quality. However, on an area basis, moderate spacing of 2.5 m × 2.5 m produced the highest yield per hectare due to a greater plant population, thereby balancing productivity and resource use.

Economic analysis further revealed that spacing had a direct bearing on profitability. Although closer spacing (2.5 m × 2.5 m) yielded maximum gross and net returns due to higher plant density, wider spacing (5.0 m × 5.0 m) recorded the highest benefit-cost ratio because of reduced input costs and better long-term sustainability.

Therefore, it may be concluded that a spacing of 2.5 m × 2.5 m is most suitable for maximizing annual yield and profitability, whereas 5.0 m × 5.0 m spacing is recommended for achieving superior growth, pod quality, and long-term economic efficiency in *Moringa oleifera* cultivation.

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