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Investigation of planting geometry and harvesting heights in annual moringa var. PKM 1 (*Moringa oleifera* Lam.) for leaf yield under irrigated conditions of Tamil Nadu

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Abstract
The present investigation on planting geometry and harvesting heights of annual moringa var. PKM 1 for leaf yield was carried out during 2021 at Western block, Horticultural College and Research Institute, Periyakulam. Experiment was laid out in split plot design with three replications. Treatment combinations comprised of four planting geometries in main plot *viz.*, 1.50 m x 0.25 m (S_1), 1.50 m x 0.50 m (S_2), 1.50 m x 0.25 m x 0.25 m (S_3), 1.50 m x 0.50 m x 0.50 m (S_4) and three harvesting heights *viz.*, 30 cm (T_1), 45 cm (T_2) and 60 cm (T_3) in subplot. Plant height, fresh and dry leaf yield were significantly higher in the treatment 1.50m x 0.25m x 0.25m while number of primary branches, number of secondary branches, stem girth, light interception, total chlorophyll, ascorbic acid and vitamin A were higher in the treatment 1.50m x 0.50m. Harvesting heights had no impact on growth parameters in first harvest but made a significant impact in second harvest. Stem girth recorded no variations with the harvesting heights in both harvests. Harvesting height of 30 cm recorded maximum yield (3.96 tonnes/ha) in first harvest but at subsequent harvest 45 cm made significantly more yield (4.77 tonnes/ha). No significant variations was recorded on total chlorophyll, ascorbic acid and vitamin A content with harvesting heights in both harvests.

Keywords: Annual moringa, planting geometry, harvesting heights, leaf yield

Introduction
Moringa (*Moringa oleifera* Lam.) is native to South Asia and cultivated throughout the tropical areas. In India Andhra Pradesh, Tamil Nadu and Karnataka are the states involved in the production of moringa both for pods and leaves. Moringa is fast growing, drought tolerant, can be grown in many dry regions with minimum irrigation and fertilization, and continues to produce edible leaves during dry seasons (Pandey *et al.*, 2010). Moringa leaves contain four times more vitamin A than carrots, three times more potassium than banana, seven times more vitamin C than oranges, three times more vitamin E than almonds, four times more calcium than milk and three times more iron than spinach. Moringa leaves also reduces the risk of cancer since it has the anti-oxidative properties (Gandji *et al.*, 2018) [7]. Phytohormones extracted from moringa leaves have growth enhancing effect on various plants, including black gram, peanut, soybean, sugarcane and coffee. Moringa extracts is an important botanical drug against many different pathogenic bacteria due to their low toxicity and low cost of production. Moringa seeds are used in water treatment, food preservation and antibacterial treatments. Moringa leaves as well as seed cake is highly nutritious and can be used as feed for poultry, rabbits, goats, horses, pigs, sheep and cattle. Moringa feed supplementation has anthelmintic activity improving animal health, nutrition, weight gain, milk production, digestibility and also reduce parasite loads. Moringa leaves are found to be a potential source of natural antioxidants due to their marked antioxidant activity (El Sohaimy *et al.*, 2015) [4]. Now a days, considering the nutritive value of moringa leaves, they are dried and then processed into various forms such as powder, capsules, tablets etc. Value added products such as moringa biscuits and moringa soup are prepared from moringa leaves. Moringa leaves and its products has a lot of demand throughout the world and there is a good scope for moringa leaves. So there is a need to increase the production of moringa leaves. Various planting geometries has to be followed for increasing the productivity of leaves. Harvesting heights also determines the productivity of leaves and harvesting heights need to be standardized.

Therefore, the present study was carried out to optimize the planting geometry along with the suitable harvesting heights in annual moringa var. PKM 1 for leaf yield.

Materials and Methods

The experiment was conducted in Field No.13, Western block farm in Department of Vegetable Science, Horticultural College and Research Institute, Periyakulam, Theni, Tamil Nadu (Latitude $10^0 1283^{'}$ N and longitude $77^0 5998^{'}$ E) during the year 2021. Annual moringa variety PKM 1 seeds were sown during the month of February 2021 following all the standardized cultivation practices. Treatments imposed consists of four different planting geometries *viz.*, 1.50 m x 0.25 m (S_1), 1.50 m x 0.50 m (S_2), 1.50 m x 0.25 m x 0.25 m (S_3) and 1.50 m x 0.50 m x 0.50 m (S_4) and three harvesting heights 30 cm (T_1), 45 cm (T_2) and 60 cm (T_3). Experiment was laid out in Split plot design and replicated thrice. Main plot is randomly assigned with the various planting geometry while the subplot is assigned with different harvesting heights. First harvesting of leaves was taken in 90 days after sowing and the subsequent harvest was taken after 45 days according to the treatment combinations.

The morphological observations such as the plant height, number of primary branches, number of compound leaves and stem girth were recorded. After the first harvest, number of lateral branches arised from the cut end was observed along with plant height, number of compound leaves and stem girth. Fresh leaf yield was recorded in all the treatment combinations and the harvested leaves were dried using solar drier. The dry leaf yield was recorded in all the treatment combinations. Quality parameters such as total chlorophyll content, vitamin A content, ascorbic acid content were analyzed during both the harvests. Light Interception (%) was taken using lux meter for all the treatments before each harvesting.

Results and Discussions

Plant height (cm)

The closer spacing (S_3) recorded significantly higher plant height (151.59 cm) in first harvest whereas the minimum plant height of 143.14 cm was obtained under wider spacing (S_2) of 1.50 m x 0.50 m. This might be associated with the etiolation character of the plants since closer spacing competes for light. Harvesting heights and their interaction with plant spacing made no impact in first harvest. During second harvest, maximum plant height (191.49 cm) was observed in S_3 (1.50 m x 0.25 m x 0.25 m). The similar result was also reported by Bagri *et al.*, (2018) [2]. Among harvesting heights, maximum plant height (191.20) was observed in the treatment T_3 (60 cm). Interaction between planting geometry and harvesting heights significantly influenced the plant height in the second harvest.

Number of primary branches

The number of primary branches arising from the nodes of main stem were significantly higher (4.09) in the wider spacing S_2 (1.50 m x 0.50 m). Closest spacing S_3 (1.50 m x 0.25 m x 0.25 m) has the least number of primary branches (2.63). The results were in similarity with the findings of Ramkumar and Anuja (2017) [12, 13] and reported that the number of primary branches were more in wider spacing of 120 cm x 120 cm over 45 cm x 45 cm, 60 cm x 60 cm, 75 cm x 75 cm and 90 cm x 90 cm in moringa. Harvesting heights made no impact and also no significant interaction between harvesting heights and spacing for the number of primary branches in first harvest.

Table 1: Planting geometry and harvesting heights on growth and quality parameters of moringa during first harvest of leaves

Treatment	Growth parameters					Quality parameters		
	Plant height (cm)	Number of primary branches	Number of Compound leaves	Stem girth (cm)	Light Interception	Total chlorophyll (mg/100g)	Ascorbic acid (mg/100g)	Vitamin A (mg/100g)
Spacing								
S_1	150.02	2.97	25.92	6.55	6.41	46.18	80.40	12.37
S_2	143.14	4.09	24.41	7.39	10.00	50.29	88.97	14.16
S_3	151.59	2.63	29.19	5.96	4.41	40.87	59.58	7.65
S_4	145.05	3.81	27.48	6.85	5.18	44.83	75.47	10.23
SEd	2.12	0.32	1.06	0.29	1.13	2.10	6.29	1.35
CD (P=0.05)	5.20	0.79	2.61	0.70	2.77	5.14	15.41	3.31
Harvesting heights								
T_1	147.95	3.48	27.26	6.59	6.36	45.42	79.59	11.51
T_2	146.96	3.40	26.69	6.85	6.64	45.57	74.34	10.22
T_3	147.45	3.25	26.30	6.63	6.49	45.26	74.38	11.58
SEd	1.68	0.13	0.96	0.21	0.21	1.37	6.87	0.85
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Main plot
S1 – 1.50 m X 0.25 m
S2 – 1.50 m X 0.50 m
S3 – 1.50 m X 0.25 m X 0.25 m
S4 – 1.50 m X 0.50 m X 0.50 m

Sub plot (harvesting heights)
T1- 30 cm
T2- 45 cm
T3- 60 cm

Number of secondary branches

The number of secondary branches were significantly higher (11.01) in S_2 (1.50 m x 0.50 m) while the lowest number of secondary branches (6.46) were recorded in S_3 (1.50 m x 0.25 m x 0.25 m). Closer spacing may attribute to the lower number of secondary branches. Harvesting height of 45 cm shown significantly higher number of secondary branches (10.35) followed by harvesting at 60 cm. There exists significant interaction between the spacing and the harvesting heights.

Number of compound leaves: The spacing 1.50 m x 0.25 m x 0.25 m (S_3) shown significantly higher number of compound leaves (29.19) in the first harvest stage due to

increased plant height which is followed by 1.50 m x 0.50 m x 0.50 m (S_4) while least number (24.41) was seen in the spacing of 1.5 m x 0.5 m (S_2). Harvesting heights and its interaction with spacing had no influence during first harvest. S_2 (1.50 m x 0.50 m) exhibited higher number of compound leaves (71.60) in second harvest since it has the highest number of secondary branches whereas less number of compound leaves (56.49) was observed in S_3 (1.50 m x 0.25 m x 0.25 m). Harvesting height of 45 cm (T_2) recorded highest number of compound leaves (70.86) followed by T_1 (60 cm) followed by T_3 (30 cm). Interaction of planting geometry with harvesting heights significantly influenced the number of compound leaves. (Table 1)

Stem girth (cm): Stem girth is significantly higher in the wider spacing 1.5 m x 0.50 m since the plants grow without any competition and results in better growth and development of stem during first (7.39 cm) and second harvest stage (11.51 cm) while closer spacing has the lower stem girth. Denser population reduced the stem diameters as reported by Goss 2012. Harvesting heights had no significant influence on stem girth. Interaction of planting geometry and cutting heights made no impact in stem girth.

Light interception (%)

Light interception (%) was maximum (10.00%) in the wider spacing of 1.5 m x 0.50 m while minimum (4.41%) in the closer spacing of 1.50 m x 0.25 m x 0.25 m in first harvest. Similar trend was also observed during second harvest for light interception (10.95%). Harvesting heights made no impact on the light interception in first harvest but harvesting height of 30 cm made highest light interception (8.32%) on second harvest since minimum number of laterals are produced. Interaction had made significant influence on light interception. (Table 2)

Total chlorophyll (mg/100g)

During first and second harvests, total chlorophyll was estimated and found that the total chlorophyll content was significantly higher (50.29) with the wider spacing (S_2) and lowest in closer spacing (S_3) whereas harvesting heights did not affect the total chlorophyll content. Ramkumar and Anuja (2017) [12, 13] observed that the chlorophyll content of moringa leaves decreased in the closer spacing and increased in the wider spacing. Interaction made significant impact on the total chlorophyll in second harvest but no impact during first harvest.

Table 2: Planting geometry and harvesting heights on growth and quality parameters of moringa during second harvest of leaves

Growth parameters						Quality parameters		
Treatment	**Plant height (cm)**	**Number of lateral branches**	**Number of Compound leaves**	**Stem girth (cm)**	**Light Interception (%)**	**Total Chlorophyll (mg/100g)**	**Ascorbic acid (mg/100g)**	**Vitamin A (mg/100g)**
Spacing								
S_1	183.92	8.52	64.54	10.63	7.50	45.40	92.49	14.68
S_2	171.23	11.01	71.60	11.51	10.95	50.07	111.74	19.03
S_3	191.49	6.46	56.49	9.83	6.35	42.09	77.97	10.42
S_4	181.44	10.39	68.51	11.20	6.70	44.99	86.43	13.11
SEd	3.81	0.98	4.12	0.35	0.32	1.86	7.71	1.90
CD (P=0.05)	9.32	2.42	10.09	0.87	0.79	4.55	18.87	4.66
Harvesting heights								
T_1	171.56	7.34	57.20	10.67	8.32	45.67	90.74	13.71
T_2	183.32	10.35	70.86	10.96	7.50	46.23	91.90	13.04
T_3	191.20	9.60	67.79	10.75	7.80	45.01	93.84	16.18
SEd	2.64	0.39	1.29	0.29	0.10	1.32	5.13	1.41
CD (P=0.05)	5.61	0.83	2.75	NS	0.22	NS	NS	NS
Interaction (S x T)								
SEd	5.29	0.78	2.59	0.58	0.21	2.64	10.27	2.83
CD (P=0.05)	11.22	1.66	5.49	NS	0.44	NS	21.79	6.00
Interaction (T x S)								
SEd	8.46	1.88	7.59	0.84	0.59	4.16	16.85	4.34
CD (P=0.05)	19.62	4.50	18.30	NS	1.44	NS	39.19	10.04

Main plot
S1 – 1.50 m X 0.25 m
S2 – 1.50 m X 0.50 m
S3 – 1.50 m X 0.25 m X 0.25 m
S4 – 1.50 m X 0.50 m X 0.50 m

Sub plot (harvesting heights)
T1- 30 cm
T2- 45 cm
T3- 60 cm

Ascorbic Acid (mg/100g)

The ascorbic acid content was significantly highest (88.97 mg/100g) in the spacing S_2 (1.5 m x 0.50 m) while S_3 (1.50 m x 0.25 m x 0.25 m) showed the minimum (59.58 mg/100g) ascorbic acid content in the first harvest. Wider spacing exhibited significantly higher (111.74 mg/100g) ascorbic acid content in second harvest. Ponnuswami and Alli Rani (2019) [11] also revealed that wider spacing increased the ascorbic acid content in moringa leaves. Harvesting heights had no significant difference for ascorbic acid content in the first and second harvest. Interaction of planting geometry with harvesting heights has no significance in the first harvest while the interaction made a significant impact in the second harvest for ascorbic acid content.

Vitamin A (mg/100g)

Significantly higher Vitamin A content of 14.16 mg/100g and 19.03 mg/100g was recorded in the wider spacing of 1.5 m x 0.50 m (S_2) respectively during first and second harvests. This was in accordance with the findings of Ponnuswami and Alli Rani (2019) [11]. Harvesting heights showed no significance in both the harvests for vitamin A content. Planting geometry and its interaction with harvesting height made no impact for vitamin A content on first harvest while it was significantly

influenced the vitamin A content during second harvest.

Fresh leaf yield (tonnes/hectare)

First harvest revealed that the fresh leaf yield was significantly highest (4.71 t/ha) in closer spacing S_3 (1.50 m x 0.25 m x 0.25 m) while it was lower (2.97 t/ha) in wider spacing S_2 (1.5 m x 0.50 m) as closer spacing accommodates more plant population and resulted in increased yield per hectare. Higher plant density leads to the more biomass production (Basra *et al.*, 2015) [3]. Similar trend was noticed for yield during second harvest also. Adegun and Ayodele (2015) [1] stated that the yield was greater in the closest spacing of 30 cm x 40 cm than wider spacing of 40 cm x 60 cm, 60 cm x 80 cm and 100 cm x 100 cm. The same was revealed by Maheswari *et al.*, 2019 [9]. In the present study significantly high leaf yield was recorded at 30 cm harvesting height above the ground level during first harvest (3.96 t/ha). Cutting height at 30 cm had recorded more yield than 45 cm and 60 cm as reported by El-Morsy (2009). During second harvest, the harvesting height of 45 cm recorded significantly higher leaf yield (4.77 t/ha) followed by 60 cm (4.63 t/ha) and least in 30 cm (4.53 t/ha). More number of secondary branches are obtained when harvested at 45 cm above ground level, which was associated in maximum fresh leaf yield. Interaction between planting geometry and spacing is significant to each other in both first and second harvests for fresh leaf yield. (Table 3).

Table 3: Planting geometry and harvesting heights on fresh leaf yield and dry leaf yield of moringa PKM 1

Treatments	Fresh Leaf yield (tonnes/hectare)										Dry Leaf Yield (tonnes/hectare)									
	First Harvest					Second Harvest					First Harvest					Second Harvest				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
T_1	3.64	3.04	5.36	3.80	3.96	4.38	3.05	6.00	4.69	4.53	0.66	0.55	0.98	0.70	0.72	0.80	0.57	1.09	0.85	0.83
T_2	3.53	2.98	4.47	3.76	3.69	4.47	3.15	6.71	4.74	4.77	0.65	0.54	0.83	0.69	0.68	0.82	0.58	1.22	0.86	0.87
T_3	3.52	2.87	4.29	3.71	3.60	4.42	3.07	6.31	4.71	4.63	0.64	0.53	0.77	0.68	0.65	0.81	0.57	1.14	0.86	0.85
Mean	3.56	2.97	4.71	3.76	3.75	7.03	3.09	6.34	4.71	4.64	0.65	0.54	0.86	0.69	0.69	0.81	0.58	1.15	0.86	0.85
	S	T	S x T	T x S		S	T	S x T	T x S		S	T	S x T	T x S		S	T	S x T	T x S	
SEd	0.08	0.11	0.22	0.26		0.16	0.06	0.13	0.31		0.01	0.02	0.04	0.05		0.03	0.01	0.02	0.05	
CD (P = 0.05)	0.19	0.23	0.47	0.57		0.39	0.14	0.29	1.73		0.04	0.04	0.09	0.11		0.07	0.03	0.05	0.13	

Main plot
S1 – 1.50 m X 0.25 m
S2 – 1.50 m X 0.50 m
S3 – 1.50 m X 0.25 m X 0.25 m
S4 – 1.50 m X 0.50 m X 0.50 m

Sub plot (harvesting heights)
T1- 30 cm
T2- 45 cm
T3- 60 cm

Dry Leaf Yield (tonnes/hectare)

Closer spacing (S_3) showed significantly maximum dry leaf yield (0.86 t/ha) significantly and lowest (0.54 t/ha) in wider spacing (S_2) at first harvest. During second harvest S_3 (1.50 m x 0.25 m x 0.25 m) exhibited significantly higher dry leaf yield (1.15 t/ha) and lower (0.58 t/ha) in S_2 (1.5 m x 0.50 m). Less number of plants accommodated in S_2 (1.5 m x 0.50 m) resulted in minimum dry leaf yield (Basra *et al.*, 2015) [3]. Harvesting height at 30 cm showed significantly higher dry leaf yield (0.72 t/ha) during first harvest. In second harvest, harvesting height of 45 cm recorded maximum (0.87 t/ha) dry leaf yield. There exist significant effect of interaction among the various planting geometries in the main plot and harvesting heights in subplot at both the harvests.

Conclusion

Planting geometries influenced the plant growth, yield characters and quality parameters of moringa leaves. Harvesting heights influenced the yield parameters in both the harvests but has no influence on the total chlorophyll, ascorbic acid and vitamin A content of moringa leaves. Growth parameters are influenced by the harvesting heights in second harvest whereas no variations was observed in first harvest. From the overall results it can be concluded that the spacing S_3 (1.50 m x 0.25 m x 0.25 m) coupled with harvesting height of 45 cm (T_2) provided increased yield of moringa leaves.

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