

## Growth and Biomass Production of Moringa Cultivated in Semiarid Region as Responses to Row Spacing and Cuts

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### ABSTRACT

The management of the moringa to produce biomass, as it is for other vegetal species, must consider some aspects that foster productivity. Among these aspects, cultivation density is a crucial element. This research aimed to assess the effects of spacing and cuts on the growth of the moringa. The treatments consisted of four spacings: 0.5 x 1.0 m; 0.83 x 1.0 m; 1.25 x 1.0 m; and 1.66 x 1.0 m. The experimental design was a randomized-block design with five repetitions. The standardization cut of the plants was performed at a one-meter height from the ground, fifty days after the seedlings transplantation. The assessments were performed every sixty days, totaling six cuts. Spacing impacted the growth and biomass production but did not affect the height of the plants. The stem diameter, branch number, and the plant's mass increased at increasing the spacing. On the other side, the total mass and the masses of the stem, the leaflet, and the petiole per hectare decreased at increasing the spacing. Spacing did not affect the ratio between leaf/stem and leaflet/petiole. Plant growth and dry matter production were highest after the first two cuts and decreased significantly from the third cut on. The spacing of 0.5 x 1.0 m should be used for planting *Moringa oleifera* Lam. because this configuration, even reducing the gain per plant, increased the production of dry matter per unit area.

**Keywords:** protein-bank; cultivation density; dry matter; *Moringa oleifera* L.

### INTRODUCTION

The moringa (*Moringa oleifera* Lam.) belongs to the family Moringaceae. It is a rustic tree native from India, tolerating drought, and adapted to a great variety of soils (Santos *et al.*, 2011). It is a rapid-growth species, with flexible branches which ease the cutting management. This species requires a low amount of agricultural inputs, is resistant to pests, and its seeds do not require dormancy (Catunda *et al.*, 2017).

Moringa culture is crucial, mainly in developing countries. In subtropical and tropical areas, as an example, its leaves are used in human nutrition, being rich in calcium, iron, phosphorus, vitamin C, beta carotene, and essential fatty acids (Leone *et al.*, 2016). The young fruits are also edible, and the seeds produce an oil, which is comestible and is a high-quality lubricant (Olson & Fahey, 2011).

In north-eastern Brazil, moringa was introduced aiming to fulfill the necessities of animal nutrition due to its high regrowth potential and its adaptation to the semiarid climate. The plant also has a high level of raw protein in the leaves and satisfactory values of essential amino acids (Moyo *et al.*, 2012; Valdez-Solana *et al.*,

2015). For these features, the moringa is a high-quality forage crop. *Moringa oleifera* consumption has been reported to improve the health status, feed conversion efficiency, growth performance, and product quality of several livestock species (Falowo *et al.*, 2018).

The management of the moringa to produce biomass, as it is for the other vegetal species, must consider some aspects that foster productivity. Among these aspects, cultivation density is a crucial element (Padilla *et al.*, 2017). The planting density of this species depends on the aim of its use (Sánchez *et al.*, 2006; Leone *et al.*, 2016). Goss (2012) assessed the initial establishment of moringa. The author observed higher dry matter production per unit area by using a 25 x 25 cm spacing (197.528 plants/ha) instead of more spaced cultivations. On the other hand, Mendieta-Araica *et al.* (2013) recommended a planting density of 167.000 plants/ha for providing a greater forage production.

Even though high densities are positively related to higher forage production (Kumalasari *et al.*, 2017), in practical conditions, the need for labor and difficulties during harvesting make high densities impractical for small and medium farmers (Mendieta-Araica *et al.*, 2013). Therefore, studies on planting densities more

adapted to the practical needs of small and medium-sized properties in semiarid regions are still needed. In this context, this paper aimed to assess the effect of spacing and cuts on the growth and dry matter production of the moringa.

## MATERIALS AND METHODS

The experiment was performed in the Agrarian Sciences Campus of the Federal University of the São Francisco Valley (UNIVASF) in the municipality of Petrolina, State of Pernambuco, Brazil (9° 09' South, 40° 22' West), between September 2017 until February 2019. According to the Köppen classification, the climate in the region is BSwH type (warm and dry region). A meteorological station placed at 30 meters from the experimental area provided the data on average rainfall and temperature (Figure 1).

The soil was classified as yellow Argissolo, with medium/sandy texture (EMBRAPA, 2006). A soil sample in the 0-40 cm layer was collected before the development of the experiment and destined for chemical analysis (Table 1).

The seedlings were produced in plastic bags (20 x 30 cm) filled with the ground from the experimental area and matured bovine manure at a 1:1 ratio. The seedlings were kept above the ground level on platforms in a screened environment and watered daily manually.

The ground of the area was prepared in a conventional form, plowed, and harrowed 30 days before the transplanting of the seedlings. The size of the hole for planting was 20 cm of length x 20 cm of wide x 40 cm of depth. The transplantation of the seedlings in the field was performed three months after the seeding. In the bag used for the transplants, 100 grams of matured bovine manure mixed with soil were used. The manure

was used in order to increase water retention. It was not necessary to fertilize or correct the soil. The natural soil fertility of the experimental area showed adequate values for plant growth, according to the results obtained by Bakke *et al.* (2010).

The standardization cut of the plants was performed 50 days after the transplanting at a one-meter height. The drip irrigation was performed with an average water column of six mm day<sup>-1</sup>, five days a week, along all the experimental period. The area was preserved free of weeds by hand removal.

The experimental design was performed by randomized block design, with a scheme of measurements repeated over time (cuts). The treatments consisted of four spacings between the plants: 0.5 m, 0.83 m, 1.25 m, and 1.66 m. The spacing between the lines was fixed at 1.0 m, with five repetitions. Each experimental unit occupied a 16.5 m<sup>2</sup> area and was composed of three lines of plants. Only the plants of the central line were considered as a useful portion area.

Before each cut was measured, the height, the diameter of the stem, and the number of branches were measured. The height of the plants was measured by a scaled rod. The height was considered from the ground until the apical bud of the highest branch. Stem diameter was assessed at the height of ten centimeters from the ground level using a digital caliper (Rodrigues *et al.*, 2016). The number of branches was assessed by counting all the branches emerging over the height of one meter from the ground level (cutting height).

The cuts were performed at a 60 days interval, counted starting from the standardization cut. Plants were cut at one meter above the ground level and transported to the laboratory, where the mass of the plants of each parcel was assessed using a digital balance. Representative samples of entire and uniform branches, with an average weight of 1.0 kg, were sampled. Stem

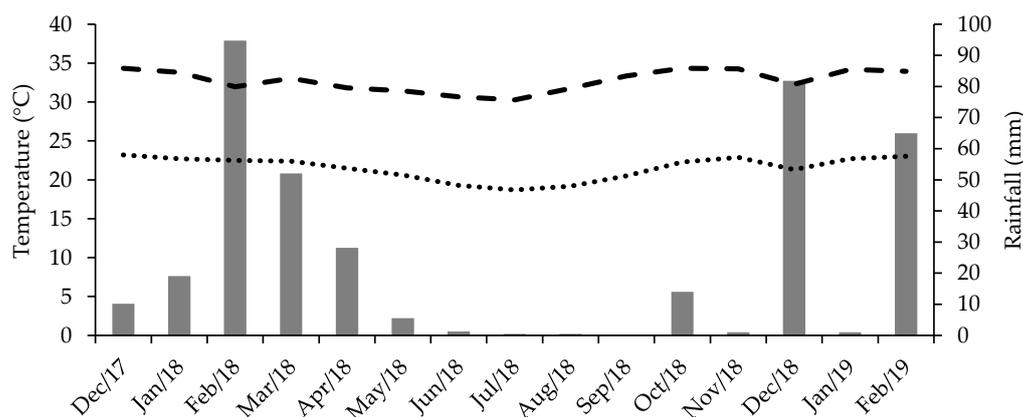


Figure 1. Rainfall, minimum and maximum temperatures from December 2017 until February 2019  
 ■ Precipitation    - - - Maximum temperature    ..... Minimum temperature

Table 1. Chemical features of the soil in the 0-40 cm layer

pH (H <sub>2</sub> O)	P (mg dm <sup>-3</sup> )	Ca (cmol <sub>c</sub> dm <sup>-3</sup> )	Mg (cmol <sub>c</sub> dm <sup>-3</sup> )	K (cmol <sub>c</sub> dm <sup>-3</sup> )	Na (cmol <sub>c</sub> dm <sup>-3</sup> )	Al (cmol <sub>c</sub> dm <sup>-3</sup> )	H+Al (cmol <sub>c</sub> dm <sup>-3</sup> )	CTC (cmol <sub>c</sub> dm <sup>-3</sup> )	V (%)
6.0	28.46	1.9	0.60	0.41	0.02	0.00	1.65	4.58	64

and leaves were separated manually to determine the mass of each one of these components. Samples were placed in an oven with forced air circulation at 55°C for 72 hours. After that, the samples were weighed again to determine the dry matter weight (Silva & Queiroz, 2002). After drying, leaves were separated by hand, dividing leaflets and petioles. The mass of each one of these components was assessed.

Data were submitted to the Lilliefors and Bartlett tests to verify the normality and homoscedasticity. After that, the data were submitted to the analysis of variance. The effect of spacing was assessed by regression analysis, choosing the models that best explained the results based on the coefficient of determination ( $R^2$ ). Tukey's test compared the effect of the cut. Both tests were performed at a 5% significance level, using the program SISVAR 5.6 (Ferreira, 2011).

## RESULTS

The height of the plant was not affected by the spacing, with an average height of 1.93 m (Table 2). The diameter of the stem and the number of branches per plant displayed a linear and positive association ( $p < 0.05$ ) with the spacing between the plants.

Spacing affected the mass of the plants in a linear and positive form ( $p < 0.05$ ), with the highest values corresponding to the spacing of 1.66 x 1.0 m (Table 2). The total mass was adjusted to the linear and negative equation as a function of the spacing (Table 3).

The results of the mass of these components were similar to that of the total dry mass, which decreased ( $p < 0.05$ ) linearly as the spacing was increasing. Spacing did not affect the leaf/stem and leaflet/petiole ratios with average values of 1.66 and 1.94, respectively (Table 3).

The experiment highlighted differences ( $p < 0.05$ ) among the cuts as it refers to the height of the plants, stem diameter, number of branches, and mass of the plant. The height and mass of the plant were higher in the first two cuts compared to the other. The stem diameter and the number of branches were the highest at the sixth cut (Table 4).

The total leaves', stem, leaflet, and petiole mass per hectare followed the same tendency of the height and the mass of the plant, displaying the highest values ( $p < 0.05$ ) in the first two cuts compared to the other. The leaf/stem ratio was the lowest ( $p < 0.05$ ) in the two first cuts. The cuts also influenced the leaflet/petiole ratio ( $p < 0.05$ ) with higher values in the third cut compared to the others (Table 5).

Table 2. Growth and yield of moringa grown with different spacings

Variables	Distance between plants (m)				Equation	$R^2$ (%)
	0.50	0.83	1.25	1.66		
Plant's height (m)	1.93	1.86	2.02	1.93	$\hat{y} = 1.935$	-
Stem's diameter (mm)	46.25	47.31	53.33	57.11	$y = 9.9887x + 40.412$	96.4
Number of branches	4.80	4.91	5.96	6.39	$y = 1.5068x + 3.9178$	94.1
Plant mass (kg of DM)	0.14	0.17	0.29	0.31	$y = 0.1621x + 0.0557$	92.4

Note:  $R^2$ = Coefficient of determination.

Table 3. Growth and morphologic composition of moringa grown with different spacings

Variables	Distance between plants (m)				Equation	$R^2$ (%)
	0.50	0.83	1.25	1.66		
Total mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	2871.8	1610.9	1540.0	891.1	$y = -1509.9x + 3328.9$	84.5
Leaf mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	1551.3	846.6	785.7	485.7	$y = -816.54x + 1782.8$	83.3
Stem mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	1320.5	764.3	754.3	405.4	$y = -693.34x + 1546.1$	85.4
Leaf/stem ratio	1.68	1.66	1.47	1.81	$\hat{y} = 1.66$	-
Leaflet mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	966.1	552.7	513.9	311.1	$y = -503.29x + 1119.4$	85.4
Petiole mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	585.2	293.9	271.8	174.6	$y = -313.25x + 663.41$	79.7
Leaflet/petiole ratio	1.74	2.03	2.03	1.96	$\hat{y} = 1.94$	-

Note:  $R^2$ = Coefficient of determination.

Table 4. Growth and yield of moringa according to the number of cuts

Variables	Cuts						CV (%)
	1°	2°	3°	4°	5°	6°	
Plant's height (m)	2.20 <sup>a</sup>	2.33 <sup>a</sup>	1.90 <sup>b</sup>	1.78 <sup>bc</sup>	1.73 <sup>bc</sup>	1.56 <sup>c</sup>	12.43
Stem's diameter (mm)	42.81 <sup>c</sup>	45.96 <sup>bc</sup>	46.48 <sup>bc</sup>	54.32 <sup>ab</sup>	55.99 <sup>ab</sup>	60.08 <sup>a</sup>	23.41
Number of branches	4.20 <sup>b</sup>	5.25 <sup>b</sup>	5.95 <sup>b</sup>	4.65 <sup>b</sup>	4.36 <sup>b</sup>	9.21 <sup>a</sup>	33.57
Plant mass (kg of DM)	0.415 <sup>a</sup>	0.413 <sup>a</sup>	0.192 <sup>b</sup>	0.128 <sup>bc</sup>	0.075 <sup>c</sup>	0.076 <sup>c</sup>	27.51

Note: CV= Coefficient of variation. Means in the same row with different superscripts differ significantly ( $p < 0.05$ ).

Table 4. Growth and yield of moringa according to the number of cuts

Variables	Cuts						CV (%)
	1 <sup>o</sup>	2 <sup>o</sup>	3 <sup>o</sup>	4 <sup>o</sup>	5 <sup>o</sup>	6 <sup>o</sup>	
Total mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	3125.6 <sup>a</sup>	3219.2 <sup>a</sup>	1415.7 <sup>b</sup>	984.2 <sup>b</sup>	619.2 <sup>bc</sup>	549.1 <sup>c</sup>	26.5
Leaf mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	1840.6 <sup>a</sup>	1758.0 <sup>a</sup>	868.8 <sup>b</sup>	632.9 <sup>bc</sup>	416.9 <sup>bc</sup>	324.3 <sup>c</sup>	22.80
Stem mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	1285.0 <sup>a</sup>	1461.2 <sup>a</sup>	546.9 <sup>b</sup>	351.4 <sup>bc</sup>	224.9 <sup>c</sup>	202.3 <sup>c</sup>	34.48
Leaf/stem ratio	1.19 <sup>cd</sup>	0.9 <sup>d</sup>	2.32 <sup>a</sup>	1.76 <sup>ab</sup>	2.28 <sup>a</sup>	1.58 <sup>bc</sup>	18.68
Leaflet mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	1116.6 <sup>a</sup>	1106.1 <sup>a</sup>	626.5 <sup>b</sup>	394.9 <sup>bc</sup>	283.8 <sup>cd</sup>	194.8 <sup>d</sup>	23.24
Petiole mass (kg ha <sup>-1</sup> Cut <sup>-1</sup> DM)	723.9 <sup>a</sup>	651.9 <sup>a</sup>	242.3 <sup>b</sup>	237.9 <sup>bc</sup>	133.1 <sup>cd</sup>	129.4 <sup>d</sup>	23.60
Leaflet/petiole ratio	1.56 <sup>c</sup>	1.71 <sup>c</sup>	2.83 <sup>a</sup>	1.71 <sup>c</sup>	2.15 <sup>b</sup>	1.68 <sup>c</sup>	11.34

Note: CV= Coefficient of variation. Means in the same row with different superscripts differ significantly ( $p < 0.05$ ).

## DISCUSSION

The plants grown with larger spacing displayed higher lateral growth, producing more dense canopies, with higher thickening of the stem and higher branches number, due to the lower competition among the plants, and, as a consequence, higher nutrients' availability (Kumalasari *et al.*, 2017). Adegun & Ayodele (2015) claim that the lower spacing between the plants on the same line might reduce the lateral growth of the plants, inducing a higher vertical growth. Even the same, our experiment displayed no difference among the height of the plants.

Mabapa *et al.* (2017) observed similar results as the authors assessed the effect of the density of planting in the productivity of the moringa. The authors described that the height of the plant was not affected by the different spacings and that the higher the cultivation density, the higher the production of dry matter per unity of surface occupied.

The plant's highest value mass in the spacing of 1.66 x 1.0 m is due to the increase in the number of branches with the increasing of the spacing. Castro Filho *et al.* (2016) observed similar behavior in gliricidia (*Gliricidia sepium* (Jacq.) Walp.). The author observed a decrease in the yield per plant as increasing the plantation density.

There was a 226% increase in the total mass compared to the highest spacing (1.66 x 1.0 m), highlighting that the total yield per unity of surface occupied may counterbalance the low yield per plant. Other studies performed with the same species highlighted that higher productions were associated with more dense plantings (Nouman *et al.*, 2014; Basra *et al.*, 2015; Zheng *et al.*, 2016; Kumalasari *et al.*, 2017).

The similarity of the age of all the plants used in the different treatments could explain there are no differences for the leaf/stem and leaflet/petiole ratios. These results may be considered satisfactory: our experiment highlighted an increase in the production of dry matter per hectare using lower spacing between the plants, without affecting the proportion of leaf/stem and leaflet/petiole, preserving, in this form, the quality of the biomass produced.

Even the higher amount of branches at the sixth cut displayed low development and did not contribute to an increase in the plant's mass. The increase of the stem

diameter was due to its uninterrupted growth during the experimental period, as the plants were cut at one meter above the ground, and the measurement of this parameter was performed at ten cm from the ground level. The lowest leaf/stem ratio in the first cuts was due to the higher initial growth in height. This element contributed to a higher development of the stem and, as a consequence, a lower proportion of leaves (Teixeira *et al.*, 2010).

The lack of manuring, mainly the nitrogen one, can explain the lower development of the plants, displaying a decrease in the production along the experimental period. According to Padilla *et al.* (2017), moringa can extract huge amounts of nutrients from the ground, requiring proper management of the manuring to maintain the productivity stable along the time.

Sánchez *et al.* (2006) studied the production of moringa in Nicaragua. The authors observed a decrease in production during the second year of the study in comparison to the first. The authors suggested that the supply of nutrients in the ground might have been insufficient to preserve a constant biomass production. In another study, Lok & Suárez (2014) assessed the effect of fertilizers on the production of moringa biomass. The authors claimed that in lack of fertilization, this species could significantly reduce the amount of nutrients in the ground.

Mendieta-Araica *et al.* (2013) also studied the effect of different planting densities and nitrogen fertilization concentrations. The authors suggest that moringa's productivity can be maintained stable as long as the soil is regularly provided with approximately 521 kg ha<sup>-1</sup> year<sup>-1</sup> N in conditions when the phosphorus and potassium are not limiting elements.

## CONCLUSION

The spacing between the plants affected the growth and productivity of the moringa but did not affect the morphological composition of the plants. Dry matter production was higher after the first two cuts and decreased from the third cut on, considering a frequency of six cuts during one year. The spacing that produced the highest biomass was 0.5 x 1.0 m. This setting, even reducing the earning per plant, increased the dry matter production per area unit.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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