AGRO PRODUCTIVIDAD

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Yield and nutritional value of *Moringa oleifera* Lam, forage at different population densities

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ABSTRACT

Objective: To assess the aerial biomass yield and nutritional value of *Moringa oleifera* at densities of 50,000 (D1), 100,000 (D2), and 200,000 (D3) plants ha^{-1}.

Design/methodology/approach: The experiment was established under a randomized complete block design, with a split-plot arrangement and three replications. From 155 days after sowing, 5 cuts were made every 28 days. The following variables were assessed: total dry matter (TDM) and leaf dry matter (LMD) yield (kg ha^{-1}) and crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) content (g kg^{-1}).

Results: An interaction between densities and cuts was observed. Regarding TDM yield, D1 surpassed D2 and D3, by 71 and 83%, respectively, in cuts 1 and 2; however, D3 showed the highest TDM yield ($P<0.05$) in cuts 3 and 4, surpassing D2 by 47% and D1 and D2 by 46 and 76%, respectively. The highest SDM yield occurred in D1, in cuts 1 and 2 (561 and 852 kg ha^{-1}, respectively); while D3 obtained the highest values in cuts 3 and 4 (901 and 1054 kg ha^{-1}, respectively). An 11% CP content reduction ($P<0.05$) was observed by the density increased from D1 to D2 (222 *vs.* 198 g kg^{-1}). In regard to NDF and ADF values, no differences ($P>0.05$) were found between the densities assessed.

Limitations/Implications: Planting density in *Moringa oleifera* determines the forage yield potential and nutritional value.

Findings/Conclusions: *Moringa oleifera* grown in semi-arid conditions at a density of 50,000 ha^{-1} plants and with 28-day cutting intervals showed the best productive behavior (yield and protein concentration).

Key words: Forage tree, morphological composition, semi-arid.

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INTRODUCTION

The state of Tamaulipas allocates approximately 4.98 million hectares (62% of its territory) to livestock, 75% of which is used to develop this activity through extensive grazing systems, mainly in native grasslands (SAGARPA, 2010) and crop residues with

low nutritional value (Katoch and Tripathi, 2020). Additionally, the instability of climatic conditions resulting from climate change affects the livestock sector (Hatfield *et al*., 2020), especially during the dry season, when forage production is reduced by more than 90% (Garay *et al*., 2019).

The use of forage trees to feed ruminants can be an option to maintain a more sustainable animal production (García *et al*., 2006). Such is the case of *Moringa oleifera* Lam., a tree species native to the tropical forests of northeastern India (Ramachandran *et al*., 1980). In Mexico, *Moringa oleifera* has been adapted to tropical regions with the following characteristics: an altitude of less than 600 masl, an absolute minimum temperature of 15 °C, a bimodal/monomodal rainfall regime, an annual rainfall of up to 1000 mm, and drained soils that do not prevent the oxygen passage to the roots (Olson and Alvarado-Cárdenas, 2016).

This plant achieved approximately 12.85 t ha^{-1} $year^{-1}$ dry matter yields, with up to 240 and 800 g kg^{-1} of crude protein and *in vitro* digestibility, respectively (Zheng *et al*., 2016). However, Zheng *et al*. (2016) and Rojas-García *et al*. (2021) have reported that, in the case of forage trees, topological arrangements and planting density can modify the yield and nutritional values of forage. Therefore, the purpose of this study was to assess the forage yield and nutritional value of different population densities of *Moringa oleifera*, in the climate and soil conditions of Tamaulipas, Mexico.

MATERIALS AND METHODS

The study was performed under rain-fed agriculture conditions, from July to November 2017, in the Zoological Research Station "Ing. Herminio García González" of the Facultad de Ingeniería y Ciencias, Universidad Autónoma de Tamaulipas, located in the municipality of Güémez, Tamaulipas, Mexico (23° 56' 26" N and 99° 05' 59" W, at 193 masl). The clayey soil is moderately alkaline (pH 8.4), has an 0.84 dS m^{-1} electrical conductivity, and 4.43 and 0.264% of organic matter and nitrogen, respectively. It has a BS_1(h') hw climate (Vargas *et al*., 2007), characterized by summer rains and scarce rain the rest of the year. Table 1 shows the weather conditions that occurred during the evaluation period.

Three population densities were assessed: 50,000 (D1), 100,000 (D2), and 200,000 (D3) plants ha^{-1}. A 2×2 m (4 m^2) useful plot was established in the center of a 4×4 m (16 m^2) experimental plots. Soil preparation consisted of two crossed patterns made with a drag harrow (discs) and one with a power harrow (rotavator); the latter was used to incorporate plant debris and to crumble the soil. The seeds were sown on February 5, 2017. Two

Table 1. Accumulated rainfall and minimum and maximum temperature of the experimental site, recorded per cut during the evaluation period (2017).

Variable	Cut 1 05-aug	Cut 2 01-sep	Cut 3 29-sep	Cut 4 27-oct	Cut 5 24-nov
Precipitation (mm)	10	61	98	128	7
Maximum Temperature (°C)	42	42	39	35	35
Minimum Temperature (°C)	21	21	17	10	7

botanical seeds (without pregerminative treatment) were placed per point at a 2-cm depth, 0.10, 0.20, and 0.40 m apart from each other; there was a distance of 0.50 m between rows. Thirty days after sowing, thinning was conducted to obtain densities D3, D2, and D1. In addition, supporting irrigation was used at field capacity and weeding was performed every 14 days to ensure the establishment of the crop.

On July 7, 2017 (155 days after sowing), a uniform cut was made 25 cm above ground level and the soil was fertilized with 100, 50, and 50 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. Urea (46% N), calcium triple superphosphate (46% P_2O_5), and potassium chloride (60% KCl) were used as sources. Then, five plants were selected from each useful plot using the five diagonal point sampling method (four corners and the center) and they were labeled. Subsequently, five samples were taken (every 28 days), harvesting all the regrowths (branches) above the uniformity cut. Height of regrowth (HR, cm) was evaluated, along with total dry matter (TDM), leaf dry matter (LDM), and stem dry matter (SDM) yields (t ha^{-1}). HR was measured before each cut from the uniform level cut up to the canopy's upper edge. In the case of the yield, regrowths were harvested (25 cm from the ground) and separated into leaves (compound leaves) and stems, then weighed on a digital scale (ADAM® Core balance™ CQT2601 model) to obtain the green matter weight. Afterwards, fresh leaf (250 g) and stem (100 g) subsamples were taken and placed separately in kraft paper bags and then put in a stove of forced air circulation (Thermo Scientific™ Heratherm™ OGS100 model) at 60 °C for 72 h. Subsequently, they were weighed on a digital scale (ADAM® Core balance™ CQT2601 model) to determine their dry weight and calculate the LDM, SDM, and TDM.

A hammer mill (Thomas Model 4 Wiley® Mill) was used to determine the nutritional value of samples that had been previously ground with a 1-mm sieve. Crude protein (CP) and ash (AS) content was determined using AOAC methodologies (1990) and neutral detergent fiber (NDF) and acid detergent fiber (ADF) content, using methodology Van Soest *et al.* (1991). Hemicellulose (Hem) was obtained using the following formula:

$$Hem = NDF - ADF$$

Data was analyzed with the GLM procedure (SAS, 2002), based on a completely randomized split-plot arrangement design with three replications. The large plot was the population density and the small plot, the cuts. Means were compared using the Tukey's test (α=0.05).

RESULTS AND DISCUSSION

Significant differences ($P<0.05$) between densities, cuts, and density × cut interaction became evident as a result of the analysis of the yield of total, leaf, and stem dry matter (DM) and height of regrowths (HR) in the evaluation period (Table 2).

D1 surpassed D2 by 71% (686 *vs.* 399 kg ha^{-1}) and D3 by 83% (1004 *vs.* 550 kg ha^{-1}) in TDM yield in cuts 1 and 2, respectively (Figure 1). However, D3 obtained the highest TDM yield ($P<0.05$) in cuts 3 and 4, surpassing D2 by 47% (1028 *vs.* 700 kg ha^{-1}) and D1 and D2 by 46 and 76% (1193 *vs.* 816 and 678 kg ha^{-1}), respectively (Figure 1).

Table 2. Significance of yield of total, leaf, and stem dry matter, and height of regrowth.

Variable	Source of variation		
	Density	Cut	Density × Cut
Total dry matter (t ha^{-1})	**	**	**
Leaf (t ha^{-1})	**	**	**
Steam (t ha^{-1})	**	**	*
Regrowth height (cm)	**	**	**

*: P≤0.05, **: P≤0.01.

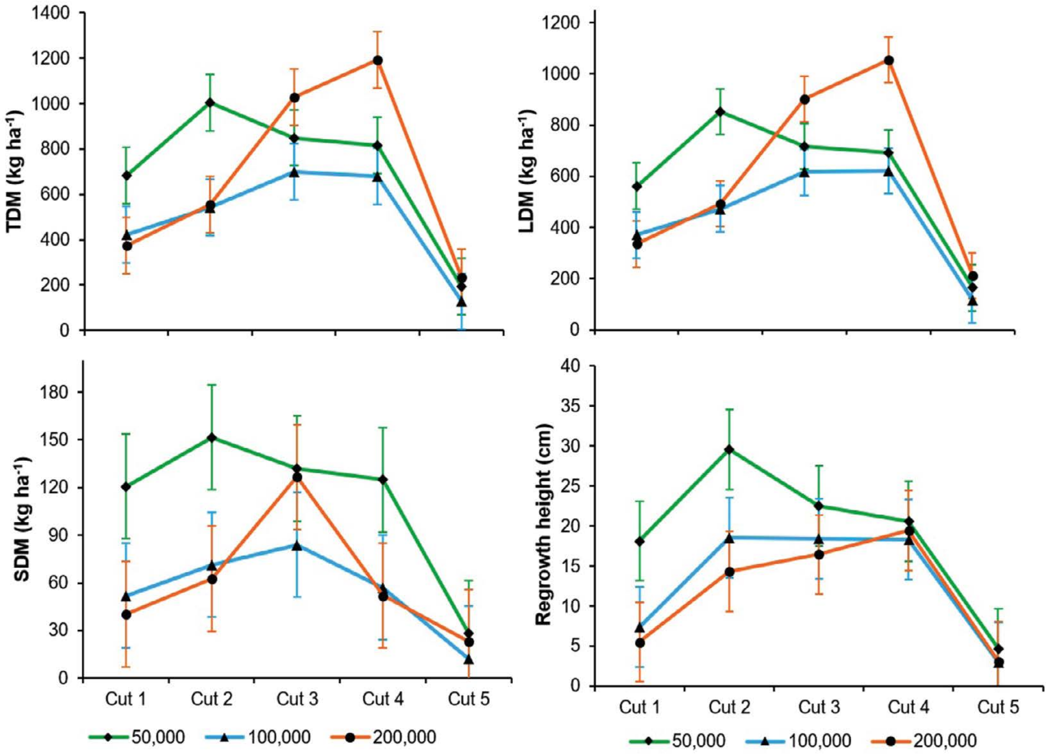

Figure 1. Yield of total dry matter (TDM), leaf dry matter (LDM), and stem dry matter (SDM) and height of regrowth in *Moringa oleifera* Lam. with different population densities (50,000, 100,000 and 200,000 plants ha^{-1}). Bars indicate least significant difference (Tukey; α=0.05).

D1 had the highest LDM yields in cuts 1 and 2 (561 and 852 kg ha^{-1}); meanwhile, in cuts 3 and 4, D3 obtained the highest LDM (901 and 1054 kg ha^{-1}, respectively) (Figure 1). D1 showed the highest TDM yields only in cuts 1, 2, and 4 (121, 152, and 125 kg ha^{-1}), while TDM values were similar (P>0.05) between D2 and D3 and ranged from 12 to 127 kg ha^{-1} (Figure 1). D1 showed the HR values in the first two cuts: 18 *vs*. 6 cm and 30 *vs*. 16 cm, respectively (P>0.05). A positive trend was observed in TDM, LDM, and HR values, as well as in cuts 1-4; however, values decreased significantly towards the end of the evaluation (cut 5) (Figure 1).

The CP content decreased ($P<0.005$) by 11% (222 *vs*. 198 g kg^{-1}) when D1 increased to D2; no differences were found ($P>0.05$) when D1 increased to D3 (Table 3). Ash content was 4% higher ($P<0.05$) in D1 than in D2 and D3 (103 *vs*. 99 g kg^{-1}). No differences were found ($P>0.05$) between the assessed densities of the NDF, ADF, and hemicellulose values (Table 3).

Bopape-Mabapa *et al.* (2020) reported that, in species with arboreal or shrubby growth habit, there is a positive correlation between planting density and aerial biomass yield. In this regard, Zheng *et al.* (2016) reported a 165% increase in TDM yield in moringa, when density increased from 15,625 to 250,000 plants ha^{-1}. However, no differences were found in TDM yield, within the first year that the same species was established. These results were obtained with both high —250,000 to 750,000 plants ha^{-1} (Reyes *et al.*, 2006)— and low —62,500 to 125,000 plants ha^{-1} (Manh *et al.*, 2005)— densities.

The variable agroecological conditions from one region to another can account for the difference in the results obtained in this study. Additionally, when a positive relationship between population density and biomass yield was found, rainfall replaced the gravimetric moisture demand (Zheng *et al.*, 2016).

The most suitable environmental conditions for the growth of this tropical species were observed in cut 3 (17-39 °C, 98 mm) and cut 4 (10-35 °C, 128 mm) (Table 1). The highest density (D3) had a positive response: a biomass yield increase of 85 and 16% regarding cut 2 and 3 (Figure 1). With a lower plant population, water availability per plant is greater, resulting in a higher biomass yield (Mabapa *et al.*, 2017). Consequently, under humidity restriction conditions (Table 1) —such as in the case of cut 1 (10 mm) and cut 2 (61 mm)—, the lowest density (D1, 50,000 plants ha^{-1}) had the highest TDM yields (Figure 1).

The height of regrowth has a positive correlation with plant density (Sosa-Rodríguez *et al.*, 2017). However, the results of this study were different: the highest values were obtained with the lowest density (D1), because this density had greater availability of nutrients, water, and space than D2 and D3 (Figure 1). The height of regrowth differed between densities and, therefore, might explain the variability observed in the nutritional value. According to Guzmán-Maldonado *et al.* (2015), the height of the plant at harvest influences the nutrient content in moringa leaves; the same phenomenon took place with CP content in this study, since D1 ranked first regarding height of regrowth and concentration of this nutrient. Likewise, these results differ from the findings of Reyes *et al.* (2006) for the case of

Table 3. Nutritional value of *Moringa oleifera* Lam. with different population densities.

Variable (g kg^{-1})	**Population density (plants ha^{-1})**		
	D1 (50,000)	**D2 (100,000)**	**D3 (200,000)**
Crude protein	222 a	198 b	215 ab
Neutral detergent fiber	258 a	260 a	251 A
Acidic detergent fiber	126 a	123 a	116 A
Hemicellulose	132 a	137 a	135 A
Ash	103 a	99 b	99 B

Means with different letters within the same row are statistically different (Tukey, $\alpha=0.05$).

Nicaragua; they did not report any effect of density on CP concentration and plant height, with the exception of the results obtained for the average density (500,000 plants ha^{-1}) in the first year of evaluation, which did not have influence on CP.

Meanwhile, NDF, ADF, hemicellulose, and ash content showed a similar behavior to that reported by Zheng *et al.* (2016), who assessed moringa at densities between 15,625 and 250,000 plants ha^{-1}, and found that they did not have a significant influence on the structural carbohydrates content. However, those densities did impact ash content, which decreased with increasing density. This situation could be the result of the reduced range (28 days) between cuts. Therefore, lowest density plants did not have enough time to fully develop. Additionally, plants need to maintain a balance in their chemical composition through compounds synthesis. These compounds include structural carbohydrates, which provide support and rigidity to the plant (Mendieta-Araica *et al.*, 2012).

Several factors could have influenced ash, such as the physicochemical characteristics of the soil (Lukhele and Van Ryssen, 2003; Rubio-Sanz and Jaizme-Vega, 2022) and the maturity status of the plant (Méndez *et al.*, 2018). Finally, the low availability of minerals for each plant in the soil at densities with higher number of plants per area unit also had an impact.

CONCLUSIONS

Moringa oleifera established at a 50,000 plants ha^{-1} density, with a planting pattern of 0.50 and 0.40 m between row and plant, respectively, and 28-day cutting intervals achieved the best productive behavior (yield and protein concentration). Additionally, its establishment requires less seed and labor.

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