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Technical note

Organic matter fertilization improves morphological variables in *Nopalea cochenillifera* Salm Dyck cv. Miúda grown as forage in Pernambuco, Brazil

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Abstract:

In forage crops such as cactus morphological characteristics respond to management practices such as fertilization. An evaluation was done to determine if organic matter (OM) fertilization (0, 10,000, 20,000 and 30,000 kg OM ha^{-1} yr^{-1} bovine manure), mineral fertilization (0, 120, 240 and 360 kg N ha^{-1} yr^{-1}, using urea) and cut frequency (annual and biennial) influenced cladode length, width and perimeter, and Cladode Area Index (CAI) values in *Nopalea cochinillifera* Salm Dyck cv. Miúda, and how these variables related to productivity. The experimental design was random blocks, using a sub-sub-plot arrangement with four replicates. Fertilization with 30,000 kg OM ha^{-1} $year^{-1}$ increased cladode width by 9.8 % and length by 17.8 % compared to the control. Cladode perimeter increased proportionally to OM fertilization level. At the optimum fertilization level (25,970 kg ha^{-1}) the CAI value was 68.29 % higher than the control. Mineral fertilization only affected cladode perimeter at 120 kg ha^{-1} and only with an annual cut; however, at this fertilization level the CAI value was higher with a biennial cut. Organic matter fertilization increased cladode width and length, and CAI values in *N. cochenillifera* cv. Miúda, while mineral fertilization had only a minimal effect. Biennial cutting frequency results in higher CAI values. Correlations were high between the evaluated variables and dry matter production, highlighting the utility of morphological variables in evaluating productivity.

Key words: Forage cactus, Cladode area index (CAI), Fertilization, Cut frequency.

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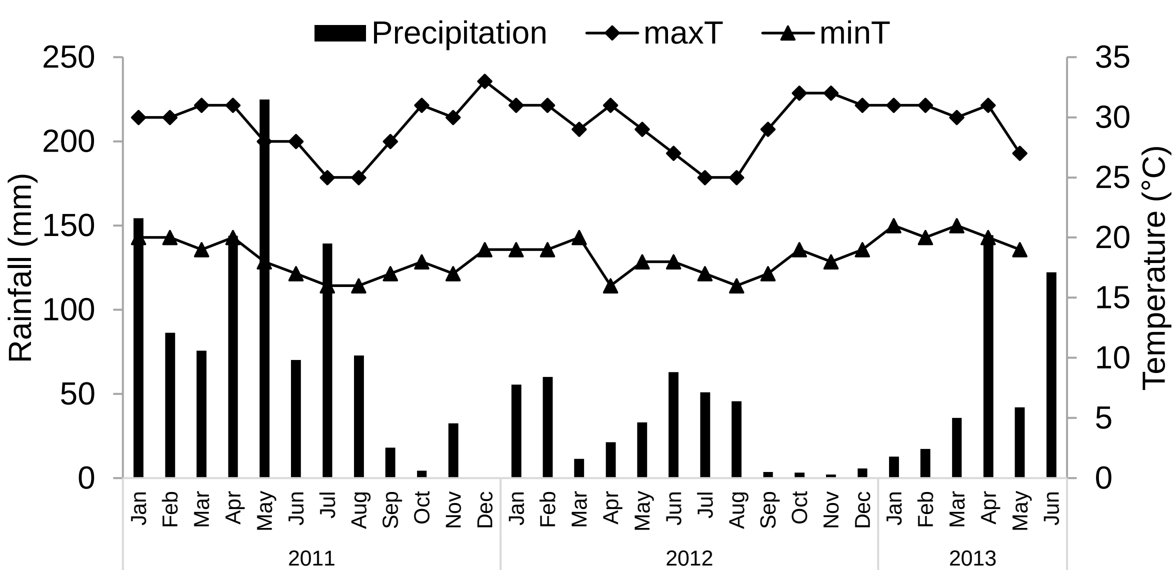
The northeast of Brazil accounts for 18.27 % of the country, and most (62.11 %) of this region is semiarid[1]. Annual rainfall distribution (500 mm)[2] is irregular, leading to severe feed shortages in ruminant livestock systems. The cactus species *Opuntia* sp. and *Nopalea* sp. can be used as ruminant forage and are adapted to water scarcity, high temperatures and poor soils[3,4,5]. They are thus valuable alternative feed sources, especially during the dry season. *Opuntia ficus-indica* Mill and *Nopalea cochenillifera* Salm Dyck are the two most widely cultivated cactus species in northeast Brazil[6].

Nopalea cochenillifera cv. Miúda, commonly known as Nopal Dulce, is a fodder that has the advantage of being resistant to cochineal (*Dactylopius opuntiae* Cockerell)[7,8]. This characteristic, in addition to its 6.2 % crude protein (CP) content, 26 % neutral detergent fiber (NDF) content and 78 % digestibility[9], makes it a promising alternative livestock feed source. As with any cultivated forage species, *N. cochenillifera* requires adequate soil fertility to produce properly. Fertilization with organic matter and minerals is common practice in cactus cultivation to compensate for nutrient extraction by this crop and increase forage production efficiency(10,11).

The variables used in forage plant ecophysiology research exhibit different responses depending on plant management. In cacti, cladode morphological characteristics are directly related to fresh and dry matter yields(12), but few studies use morphological characteristics as productivity indicators. The present study objective was to evaluate the effect of organic and mineral fertilization, and cladode harvest frequency on cladode morphological characteristics in *Nopalea cochenillifera* Salm Dyck cv. Miúda cultivated in the agreste region of Pernambuco, Brazil.

The experiment was done between June 2011 and May 2013 at the Experimental Station of the Pernambuco Agronomic Institute, Caruaru Municipality, in the agreste region of the state of Pernambuco. This is a transition zone between humid and semi-arid tropical forest zones. This region's stony soil supports sparse (<40 and >20% coverage), low-level (<1.5 m height) vegetation(13). It is in northeast Brazil (8°14' S; 35°55' W) at an altitude of 575 m asl and contains Neolithic Regolithic soil(14). During the experimental period precipitation at the site was 1,068.3 mm but varied widely from month to month (Figure 1).

Figure 1: Monthly rainfall (mm) and maximum and minimum temperatures in Caruaru Municipality, Pernambuco, Brazil, from January 2011 to June 2013



Soil samples were collected at the surface and 20 cm depth and chemically analyzed following the soil analysis method of Empresa Brasileira de Pesquisa Agropecuária[15] (Table 1).

Table 1: Prefertilization soil chemistry in experimental area in Caruaru Municipality, Pernambuco, Brazil

Component	Mean	SME	Component	Mean	SME¶¶
pH (water)	4.78	0.1	Sodium, mg dm^{-3}	11.50	0.01
Phosphorous, mg dm^{-3}†	10.45	3.81	Aluminum, mg dm^{-3}	17.98	0.03
Potassium, mg dm^{-3}	74.29	0.04	Hydrogen, mg dm^{-3}	24.70	0.14
Calcium, mg dm^{-3}	428.00	0.26	S.B.¶, cmolc dm^{-3}	2.78	0.33
Magnesium, mg dm^{-3}	48.62	0.05	CIC§, cmolc dm^{-3}	5.46	0.38
Manganese, mg dm^{-3}	70.42	10.27	Vþ, %	50.05	3.21
Zinc, mg dm^{-3}	12.46	1.66	Carbon, %	1.15	0.06
Iron, mg dm^{-3}	46.20	3.06	M¤, %	8.15	1.97
Copper, mg dm^{-3}	0.06	0.02	OM††, %	1.97	0.10

†Mehlich 1; ¶sum of bases; §cation interchange capacity; þbase saturation; ¤aluminum saturation; †† soil organic matter; ¶¶ standard mean error.

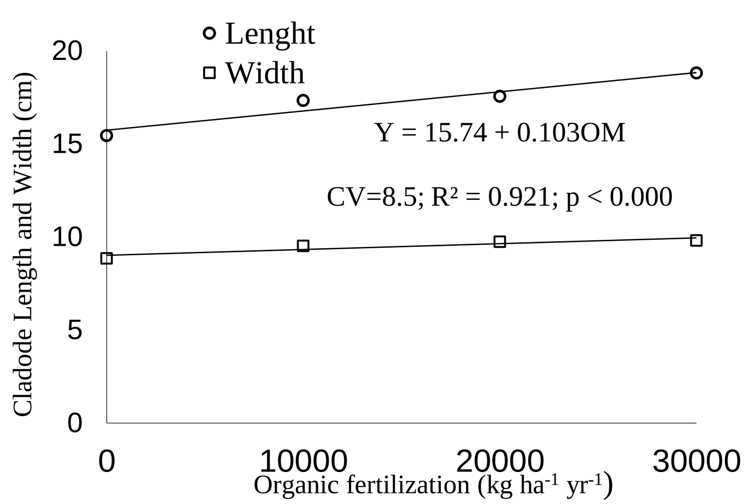
Seven fertilization treatments were evaluated: negative control with no fertilization; fertilization with bovine manure at 10,000, 20,000 and 30,000 kg OM ha^{-1} yr^{-1}; and mineral fertilization (with added urea) at 120, 240 and 360 kg N ha^{-1} yr^{-1}. Annual and biennial harvest cutting frequencies were applied. The experimental design was randomized blocks sub-divided into plots, with four replicates. The largest plot (14.4-8.0 m) was used to test organic matter levels; subplots (7.2 x 8.0 m) to evaluate cutting frequencies, and other sub-plots (14.4 x 2.0) to assess nitrogen levels. Each experimental unit consisted of six rows of plants. The two side rows and three plants at the ends were considered edges, leaving an effective sampling area of 33.84 m^2 containing 282 plants.

Planting was done between April and May 2011 by sowing mature *N. cochenillifera* cladodes in rows with 1.2 m between rows and 0.1 m between cladodes. Overall density was 83,336 plants per hectare. Organic fertilization was done at the time of planting (June 2011) and after the first annual cut (June 2012) using bovine manure containing 1.1 kg^{-1} N, 3.74 kg^{-1} P and 16.5 g kg^{-1} K (determined using AOAC methods)[16]. During the first year of cultivation mineral fertilization was done from 5 June to 19 July 2011, and during the second year on 28 June, 23 July and 19 August 2012. Harvest of cladodes was complete, leaving only the mother plant. Cladode length (cm), width (cm) and perimeter (cm) were traced onto a sheet of white paper (A4 size). The outline of two cladodes per sub-subplot were drawn and examined with a leaf area analyzer (Portable Laser Leaf Area Meter CI -202 Bio-Science Inc.®). The CAI was evaluated by adding the area of one plant's cladodes (m^2) (considering both sides of the cladode) and dividing it by the soil surface (0.12 m^2) occupied by each plant[17]. Calculations were done of the correlation coefficient between dry matter (DM) production[18] and the variables of cladode length, width and perimeter, as well as the CAI. The data were analyzed using the MIXED procedure in the SAS software package[19]. The Tukey test ($P \leq 0.05$) was applied to the factor cut frequency, and polynomial orthogonal contrasts ($P \leq 0.05$) were applied to the factors organic and nitrogen fertilization.

Cladode length, width and the CAI values exhibited no effects ($P > 0.05$) from mineral fertilization. This could have been due to irregular rainfall during the experimental period (Figure 1), which would affect nutrient absorption, or low soil organic matter content (Table 1). Similar effects have been reported for mineral fertilization on morphological characteristics and biomass production in *N. cochenillifera* cv. Miúda. In one study these were attributed to the root system, the growth of which responds to rainfall, meaning that irregular rainfall distribution can negatively affect nitrogen absorption efficiency and increase nutrient loss through leaching during excess rainfall or volatilization during its absence[20]. Positive effects from nitrogen and mineral phosphate fertilization have been observed in the production of other cactus species such as *Opuntia lindheimeri*, but only two years after crop establishment[21].

Organic fertilization is known to promote crop growth and production[22]. In the 30,000 kg ha^{-1} $year^{-1}$ treatment, cladode width and length increased proportionally to organic fertilization (R^2= 0.26 and 0.47; $P \leq 0.001$), and increased 9.8 and 17.8 % (respectively) *versus* the control ($P \leq 0.05$) (Figure 2).

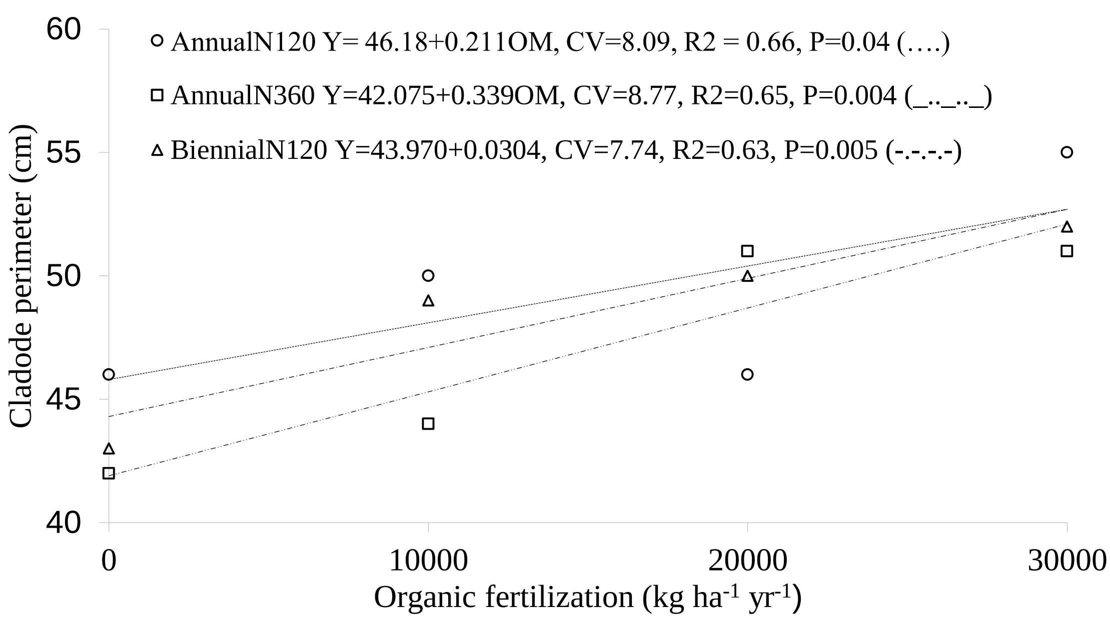
Figure 2: Cladode length and width in *Nopalea cochenillifera* Salm Dyck cv. Miúda fertilized with bovine manure (Agreste region, Pernambuco, Brazil)



This is similar to studies showing that cladode length in *O. ficus-indica* cv. Lisa increased gradually over three consecutive years in response to organic fertilization with bovine manure at 20,000, 40,000 and 60,000 kg ha^{-1} yr^{-1}, as well as in the control (0 kg ha^{-1} yr^{-1} fertilization)[(23)]. In another study using higher fertilization rates (90,000 kg ha^{-1} yr^{-1} bovine manure) over a shorter period (600 d), cladode length in *O. ficus-indica* cv. Gigante increased only 8 % compared to the control[(24)]. In a previous study cladode width in *O. ficus-indica* did not change (P>0.05) in response to application of bovine manure at 0, 20,000, 40,000 and 60,000 kg ha^{-1}[(23)].

Organic fertilization, mineral fertilization and an annual cut frequency affected cladode perimeter ($P\leq$0.05). This increase became larger ($P\leq$0.05) in a linear manner in response to organic matter fertilization. Cladode perimeter also depended on the interaction between mineral fertilization and cut frequency (Figure 3). This variable increased at 0.339 cm per 1,000 kg OM and 360 kg N per ha^{-1}, and 0.211 cm per 1,000 kg OM and 120 kg N ha^{-1}. The cladode perimeter increase rate was higher with annual cuts (0.211 cm per 1,000 kg OM) than biennials (0.0304 cm per 1,000 kg OM).

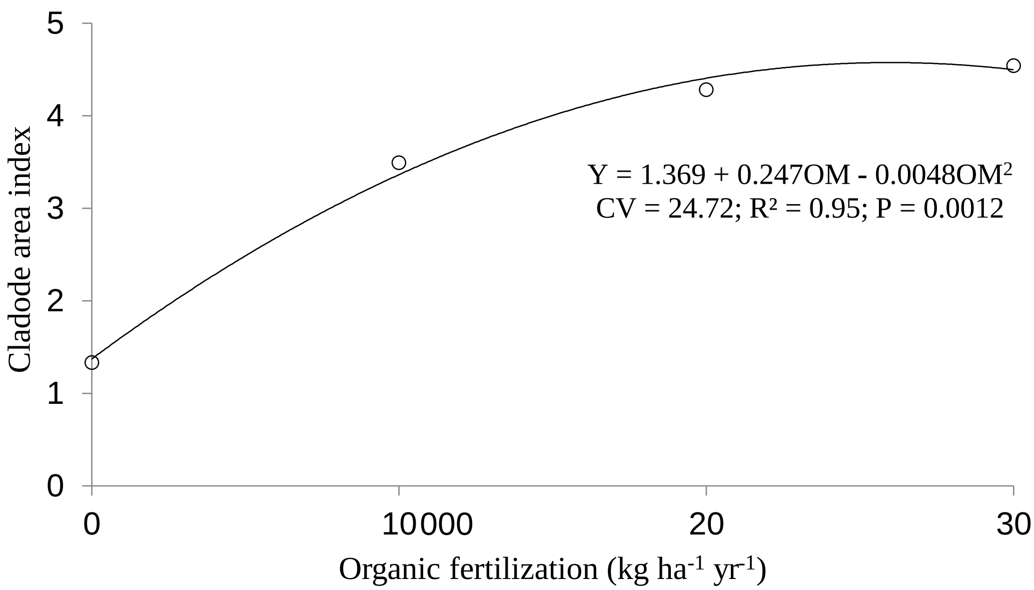
Figure 3: Cladode perimeter in *Nopalea cochenillifera* Salm Dyck cv. Miúda in response to organic fertilization, mineral fertilization and cut frequency (Pernambuco, Brazil)



In response to organic fertilization level the cladode area index (CAI) exhibited a quadratic trend ($P\leq$0.05) with proportional increases in the 10,000 and 20,000 kg OM ha^{-1} $year^{-1}$ treatments (Figure 4). The maximum CAI value was reached at 25,970 kg OM ha^{-1} $year^{-1}$;

organic fertilization levels higher than this did not affect CAI values. This plateau in CAI values may be due to the shading effect, which consists of lack of exposure of the photosynthetically active area and can lead to lower production under high plant densities[25]. For instance, in one study spacing between plants and organic fertilization level affected CAI values in *Opuntia ficus-indica* cv. Gigante, with higher values at spacings of 1 x 0.5 m and organic fertilization levels between 60,000 and 90,000 kg ha^{-1} yr^{-1}[24]. Both this spacing and fertilization level are higher than those used in the present study. Other types of organic fertilizers produce different responses. When a biofertilizer based on bat guano and chopped up cladodes was used at 15,000, 30,000, 45,000 and 60,000 kg ha^{-1} yr^{-1} on *O. ficus-indica* cv. Gigante increases of 30 % in the photosynthetically active area were observed[26]. However, this 30 % increase in CAI values is notably less than the 68.9 % (*versus* the control) observed in the present study at the of 25,970 kg ha^{-1} yr^{-1} fertilization level.

Figure 4: Cladode area index (CAI) values in *Nopalea cochenillifera* Salm Dyck cv. Miúda in response to organic fertilization (Pernambuco, Brazil)



Cut frequency did affect CAI ($P \leq 0.05$). Plants cut at two years had higher ($P \leq 0.05$) average CAI values (4.7) than those cut annually (2.2). This difference can be attributed to a smaller residual photosynthetic area in plants subjected to annual cutting than in those cut biennially since a low CAI value represents light interception and slower plant growth[27]. The effect of cutting frequency may also be due to other factors. For instance, dry matter production in *O. ficus-indica* was reported to be higher when secondary cladodes were not cut[28], possibly because plants with secondary-level cladodes have a larger CAI which represents a larger photosynthetic area[29,30].

Correlation coefficient analyses between productivity and morphological variables identified a high correlation between the evaluated variables, suggesting that measurement of morphological variables can be used as a productivity indicator (Table 2).

Table 2: Correlation coefficients between morphological variables and production (t DM) in *Nopalea cochenillifera* Salm Dyck cv. Miúda

Variables	Production[ǂ]	CAI	Width	Length	Perimeter
Production[ǂ]		0.94**	0.95**	0.82**	0.91**
CAI			0.86**	0.86**	0.83**
Width				0.81**	0.95**
Length					0.88**
Perimeter					

** (P<0.01); * (P<0.05). CAI = cladode area index. [ǂ] Source: Souza TC, 2015[18].

In *Nopalea cochenillifera* Salm Dyck) cv. Miúda, fertilization with bovine manure increases cladode width and length, and cladode area index (CAI) values, while mineral fertilization with urea has little or no impact on these variables. Cladode area index (CAI) values were higher when using a biennial cut frequency. Correlation was high between morphological and production variables, highlighting the importance of studying morphological variables in this forage crop.

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