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# Morphology and biomass yield of forage cactus under mineral fertilization in organic soil

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**The objective of this study was to evaluate the morphological characteristics and yield of the biomass of forage cactus in mineral fertilizers in organic soil. The experiment was conducted in vases, in the open in the experimental area of the Federal University of Campina Grande - UFCG. The experimental design was completely randomized in a factorial scheme 3×2 with four replications in which factors consisted of three palm varieties (Orelha de Elefante, Baiana and Miúda) and two managements fertilization (M1 - without application of fertilizer in the foundation and M2 - with NPK application on the foundation). The cultivars and the type of isolated fertilization significantly influenced the morphology and yield of the biomass of forage cactus under mineral fertilizers in organic soil. Treatment with NPK application had positive influence on the morphology and yield of cultivars biomass. The length, width, thickness and green mass cladodes weight of Orelha de Elefante and Baiana showed maximum yield. The interaction between the factors was significant only in the yield in kg$^{-1}$ vase of forage cactus, with the NPK fertilization that led to maximum yield for cultivar Miúda.**

**Key words:** Morphometry, *Opuntia*, *Nopalea*, green mass production, fertilization types.

## INTRODUCTION

The spineless cactus is one of the main sources of livestock feed in the Northeast of Brazil; it serves as an important source of water, energy and minerals to the livestock (Almeida et al., 2012). This plant is notable for its juicy and roughage nature food which makes it highly digestible, and which is indeed of paramount importance for the formulation of feed for livestock (Morais and Vasconcelos, 2007).

According to Donato et al. (2014) several supplementary feeding alternatives have been used in the semi-arid region to manage the effect of water, energy and minerals limitations. Due to these limitations, plants which are tolerant to the effect of water stress, high temperature and radiation are planted more in the region.

The spineless cactus *Opuntia ficus-indica* (L.) Mill., stands out for its cactaceous, features which include numerous anatomical characteristics and morphological and physiological adaptation to the dry ecological condition which is prevalent in the semi-arid Northeast

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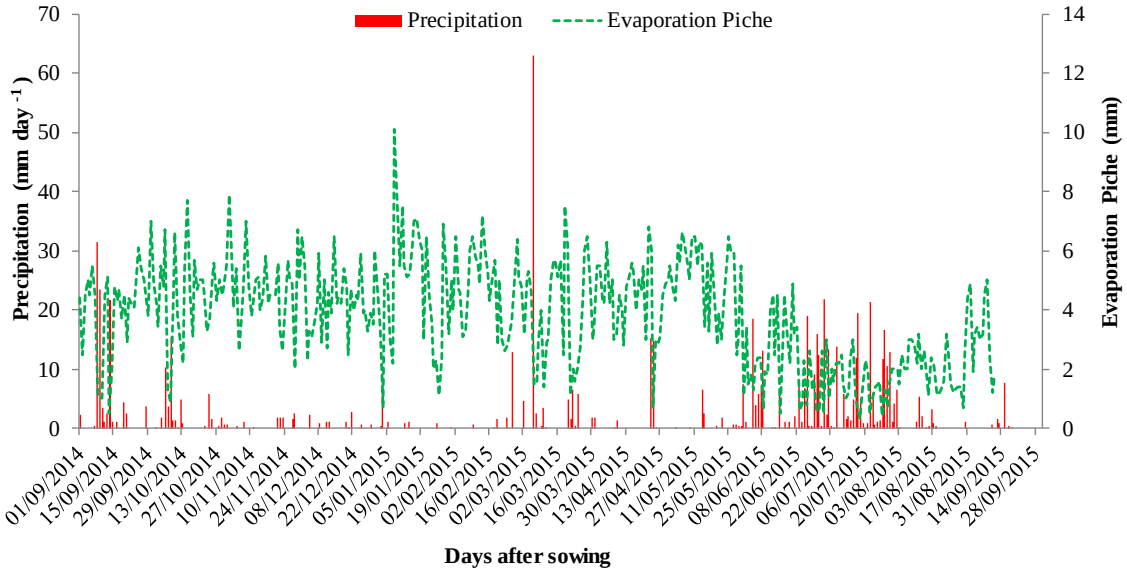


**Figure 1.** Rainfall and evaporation Piche during the experiment period.

(Oliveira et al., 2010).

According to Silva et al. (2010) the reason for the forage palm's highly efficient water use is due to their morphological and physiological characteristics, which allows high-capacity daily $CO_2$ capture and reduced water loss. Phenomenally at night, its gas exchange is termed as the crassulacean acid metabolism (CAM).

Management techniques such as fertilization, plant spacing, and crop management have been indicated as the most influential factors on the productivity of forage cactus (Alves et al., 2007). Consoli et al. (2013) in their study of Miúda growth obtained a yield of 12.9 Mg $ha^{-1}$ $yearr^{-1}$. Cunha et al. (2012) also in their study of Miúda cultivar reported an average production of 180 t $ha^{-1}$ in green matter forage cactus at 20 months, with a density of 40,000 plants per $ha^{-1}$.

Other factors such as greater availability of nutrients in the soil, mineral fertilizers are essential for obtaining high yields are also examined.

The aim with this study was to evaluate the morphological characteristics and yield of the biomass of forage cactus under mineral fertilizers in organic soil.

## MATERIALS AND METHODS

The experiment was conducted in pots which were placed in an open area at the academic unit of agricultural engineering, linked to the Center for Technology and Natural Resources (CTRN) of the Federal University of Campina Grande (UFCG - PB), located in the geographical coordinates: 7° 15' 18'' South latitude, 35° 52' 40'' West longitude and average altitude of 550 m. According to the Köppen climate classification, adapted to Brazil (Coelho and Soncin, 1982), the climate is the Csa type, which is climate mesothermal, sub-humid, with periods of hot and dry season of about 4-5 months and rainy season from autumn to winter.

The daily data of rainfall and evaporation Piche of Campina Grande – PB as in Figure 1, from September 2014 to September 2015, which corresponds to the period of the research were obtained from the National Institute of Meteorology (INMET). According to Macedo et al. (2011) studying the intensity of the rainfall in the city of Campina Grande - PB using a time series of climate data an average rainfall of 804.9 mm was obtained; less rainfall was observed from October to December.

Figure 2 presents the maximum air temperature; average, minimum, and relative humidity in the experimental period from the National Institute of Meteorology (INMET). The average maximum temperature recorded is 30.6°C, the minimum 18.6°C and an annual average of 25.0°C (Cabral Junior et al., 2013). The average relative humidity of air is 83.0% (Alves et al., 2009; Guedes Filho et al., 2012).

The soil used in the study was classified as Typic Dystrophic (Embrapa, 2013), and the chemical characteristics in depth of 0-20 cm, are presented in Table 1.

The treatments consisted of the combination of two factors: Three cactus pear cultivars (Orelha de Elefante, Baiana and Miúda) and two fertilization management (M1 - without application of fertilizer in the foundation and M2 - with NPK application in the foundation).

The experimental design used was completely randomized, with four replications, so that the factors studied were arranged in a factorial design of 3 × 2. The six proposed treatments were arranged in 24 vases of 22.5 L each, with space of 0.5 m between plants and 1.0 m between rows. Each experimental unit consisted of one vase with holes in the bottom, containing a 1 cm layer of crushed stone, covered with geotextile to facilitate drainage; then layered with about 20 kg of soil.

The forage cactus cultivars used in the experiment were Orelha de Elefante - Palmepa - PB3 - *Opuntia Tuna* L. Mill; IPA - Sertânia (Baiana) or Palmepa - PB1 and Miúda or sweet or Palmepa - PB4 - *Napolea cochenillifera* Salm - Dyck. These were chosen because they are resistant cochineal carmine (*Dactylopius opuntiae* Cockerell).

Racquets outputs free from infestations of pests and diseases were selected for planting, these included cochineal-de-scales. These rackets passed through the shadow healing period where

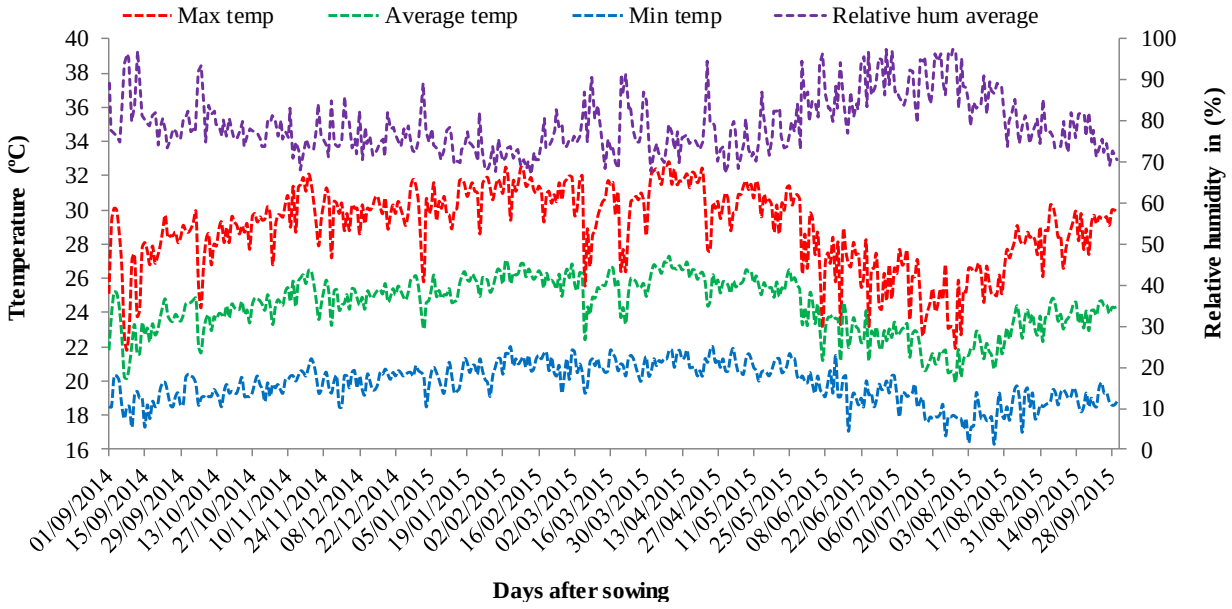


**Figure 2.** Maximum air temperature; average, minimum, and relative humidity during the experiment period.

**Table 1.** Physical and chemical characteristics of the soil used in the experiment.

| pH | M.O | P | K | Na | Ca | Mg | Al | CTC | V |
|---|---|---|---|---|---|---|---|---|---|
| | g kg$^{-1}$ | Mg dm$^{-3}$ | | | | cmol$_c$ dm$^{-3}$ | | | % |
| 6.8 | 222.55 | 486.36 | 2124 | 0.07 | 6.85 | 10.35 | 0.0 | 38.23 | 63.54 |

the cladodes lost some moisture caused by the cutting operation in the field. The rackets were arranged in front of the pits to the sun and buried 50% with an inclination of 45º.

Irrigation was carried out before planting to raise the soil capacity. This was done following the gravimetric method (standard) of Greenhouse, and a humidity capacity of U = 26.32% was obtained.

The irrigation was performed weekly, always at the end of the afternoon. The irrigation management was fixed and water slide was obtained by crop evapotranspiration (ETc) from the drain reading in the lysimeters (vases), which indicated the average balance of water inlet and outlet to keep moisture in values close to field capacity throughout the crop cycle, as Equation 1.

$$ETc = I - D \quad (1)$$

Where: ETc = crop evapotranspiration in mm day $^{-1}$; I = blade applied by irrigation in mm day $^{-1}$;
D = drainage blade in lysimeter in mm day $^{-1}$.

Fertilizer was applied in the foundation according to the result of soil analysis. In M2, urea was used as a source of nitrogen, single superphosphate as source of phosphorus and potassium chloride as source of potassium in doses of 200 kg ha$^{-1}$ N, 150 kg ha$^{-1}$ $P_2O_5$ and 100 kg ha$^{-1}$ $K_2O$ according Novais et al. (1991)..

At 360 days after planting, variables were examined. Width and height of plants were measured, length and width of cladodes perimeter was measured using tape measure; cladodes were counted; thickness of cladodes was measured using digital caliper and finally, weight of green matter of cladodes and yield were taken.

The estimated production of green biomass of the cultivars was determined according to the methodology proposed by Menezes et al. (2005) and the average mass of cladodes estimated based on the Equation 2.

$$BMVC = C * L * E * 0.535 \quad (2)$$

Where: BMVC = biomass of green cladodes matter, in g; C = average length of cladodes in cm;
L = average width of the cladodes, in cm; E = average thickness of the cladodes, in cm.

The results of the study variables were subjected to analysis of variance by F test analyses where the interaction was significant, the mean comparison was calculated based on the 5% Tukey test, with the aid of Statistical Software SISVAR (Ferreira, 2008).

## RESULTS AND DISCUSSION

The summary of the analysis of variance for plant height (AP), plant width (LP), number of cladodes (NC), length of cladodes (CC) and width of cladodes (LC) of forage cactus under mineral fertilization at 360 days after planting are shown in Table 2.

It should be noted that the variables were significant at 1% probability to cultivars, except for width of plants. For the fertilizer factor, there was a significant effect for the variables plant height, width and number of plant

**Table 2.** Analysis of variance of plant height (AP), plant width (LP), number of cladodes (NC), length of cladodes (CC) and width of cladodes (LC) of forage cactus in mineral fertilization at 360 days after planting.

| Variation sources | G.L | AP (cm) | LP (cm) | NC | CC (cm) | LC (cm) |
|---|---|---|---|---|---|---|
| Cultivar (C) | 2 | 476.16** | 76.63$^{ns}$ | 151.54** | 28.67** | 139.40** |
| Fertilization (A) | 1 | 450.66** | 1247.04* | 198.37** | 0.63$^{ns}$ | 6.12$^{ns}$ |
| Interaction (C x A) | 2 | 27.16$^{ns}$ | 99.29$^{ns}$ | 27.12$^{ns}$ | 10.59$^{ns}$ | 10.37$^{ns}$ |
| Residue | 15 | 28.73 | 175.33 | 11.11 | 4.33 | 7.03 |
| General average | - | 57.33 | 74.13 | 11.71 | 23.52 | 14.13 |
| Coefficient of variation (%) | - | 9.35 | 17.86 | 28.48 | 8.85 | 18.77 |

$^{Ns}$Not significant at the 0.05 level of probability by F test; *,** Significant at 0.05 level of probability and 0.01, respectively, by F test.

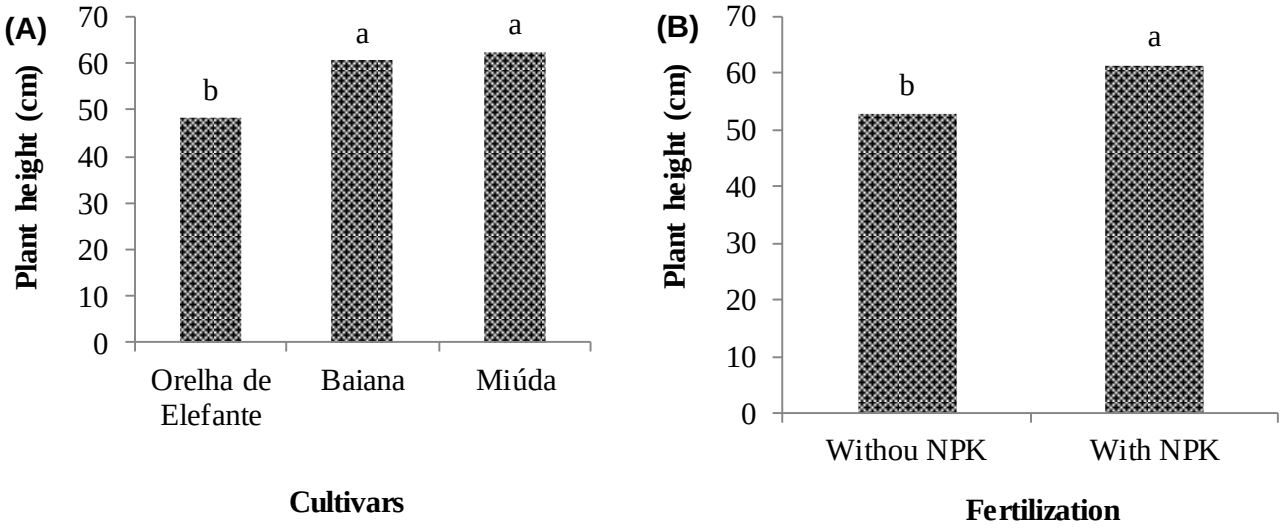


**Figure 3.** Height of spineless cactus plants depending on cultivars (A) and with and without NPK in the foundation (B) at 360 days after planting.

cladodes at 5 and 1%, respectively, with no significant effect for the length and width of cladodes. However, no significant interaction between cultivar (C) and fertilization (A) of the forage palm was found at 360 days after planting (Table 2).

Silva et al. (2015b) in their study of the growth and production of forage cactus in mineral fertilization observed that there was no difference in the evaluations of morphological characteristics at 60 days after planting. This result differs from those obtained in the present study; this fact is associated with the slow growth of the species with acid metabolism of CAM crassulacean in the initial phase (Silva et al., 2010).

Plant height in function of cultivar presented better performance in cultivars Baiana and Miúda when compared to elephant ear, at 360 days after planting (Figure 3A). This is probably related to genetic and morphological characteristics of the cactus pear, that is, species *Opuntia tuna* (L.) Mill (Elephant Ear) has horizontal growth and *Nopalea cochenillifera* (Bahia and Miúda) has vertical growth (Embrapa, 2002).

Silva et al. (2015a) reported that the cultivar IPA-Sertânia (Baiana) and Miúda are those with higher plant height compared to other cultivars, a result consistent with that obtained in the present study.

On the factor, fertilization, it is noted that plant height was higher in the treatment with NPK; this fact is possibly associated with an increased supply of nutrients culture as compared to the treatment without NPK (Figure 3B).

According to Silva et al. (2012) nitrogen is the nutrient with the most influence on the plant height, particularly under adequate phosphorus supply. Ramos et al. (2011) when studying the vegetative growth of *Opuntia ficus-indica* at different planting spacing found that plant height differed statistically at 5% probability, the highest average being 74.6 cm at 455 days after planting for cultivar Italiana. These results are similar to those obtained in the present study where the average height observed was 60 cm at 360 days after sowing.

There were significant differences observed in the

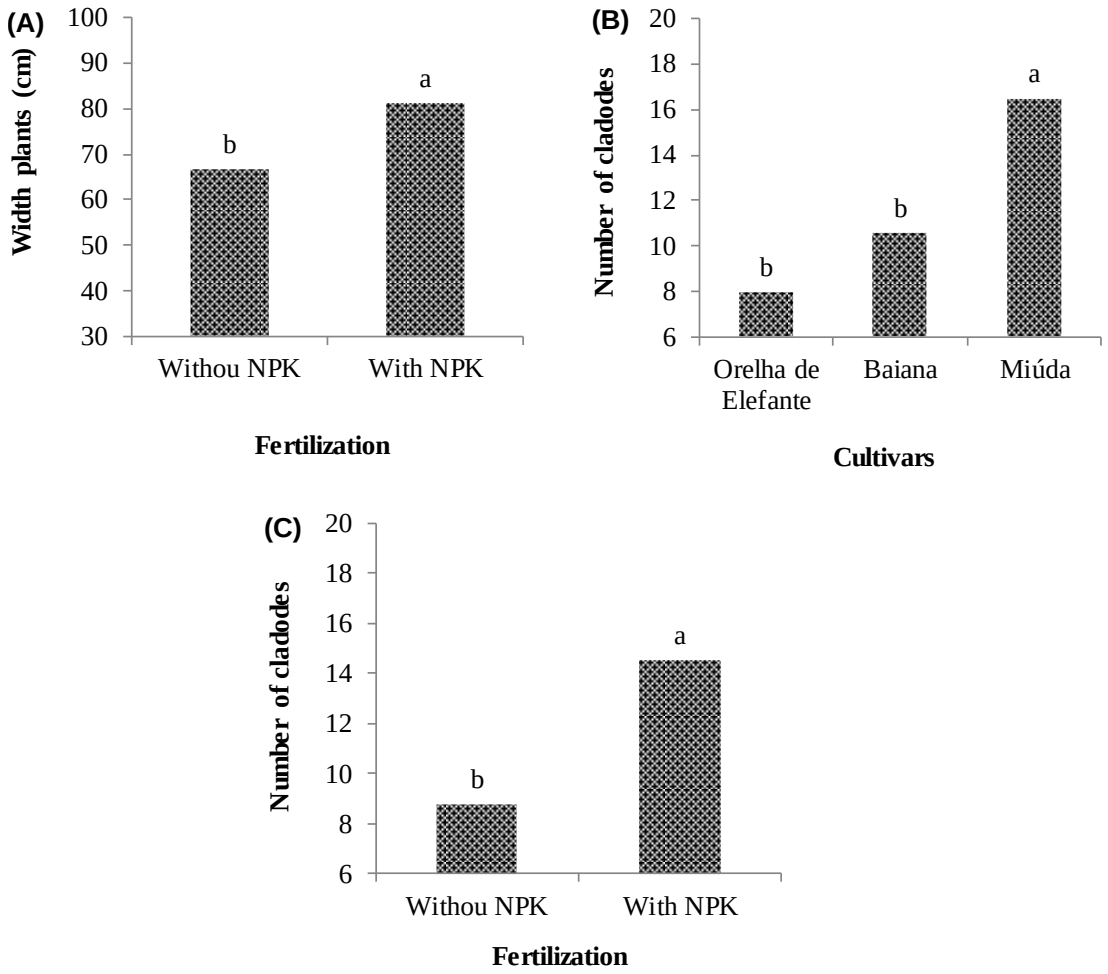


**Figure 4.** Plant width spineless cactus with and without NPK application in foundation (A), cladodes number depending on the cultivar (B) and with and without NPK foundation fertilization (C) at 360 days after planting.

Tukey test at 5% probability for plant width of cactus forage depending on fertilizer (Figure 4A), and treatment with NPK application was resulting in maximum increments LP. This fact associated with the availability of nutrients and consequently the absorption by the plant aiding in their growth.

Nascimento et al. (2011) studied the morphometric characteristics of forage cactus submitted to organic fertilizer, mineral and cutting. The study report shows that there was no significant difference between the fertilization used on the cactus forage in the experiment to the variable-width of plants.

The numbers of cladodes (depending on the cultivars) differed statistically in the Tukey test at 5% probability, and cultivar Miúda showed higher cladodes emission per plant (Figure 4B). This fact is closely related to the growth habit of the species gender Nopalea spp., since they have open growth habit favoring the formation of areolas, or axillary buds, allowing the emergence of new cladodes, not only in cladodes apex mother as well as at their side edges (Amorim et al., 2015).

Despite that the cultivar Miúda presents more cladodes, the result is lower in green biomass production. However according to Silva et al. (2015b), cultivar Miúda showed superiority of over 200% in the number of cladodes per plant compared to the cultivars IPA - Sertânia (Baiana) and Orelha Elefante.

Cunha et al. (2012) reports that lower cladodes are observed in cultivar Miúda. This function is needed to distribute the nutrients to a larger number of cladodes, but their superiority as the number is effectively associated with the morphological characteristics of the genre.

To study the influence of the fertilization on number cladodes, it was observed that the treatment with the NPK application which showed maximum emission of cladodes in cultivars (Figure 4C). Probably this fact is related to the existing synergistic interaction that makes nutrients available in the soil, making it readily available to plants (Araújo and Machado, 2006).

According to Silva et al. (2014) when soils are fertilized with phosphorus, there is an increase in the availability of

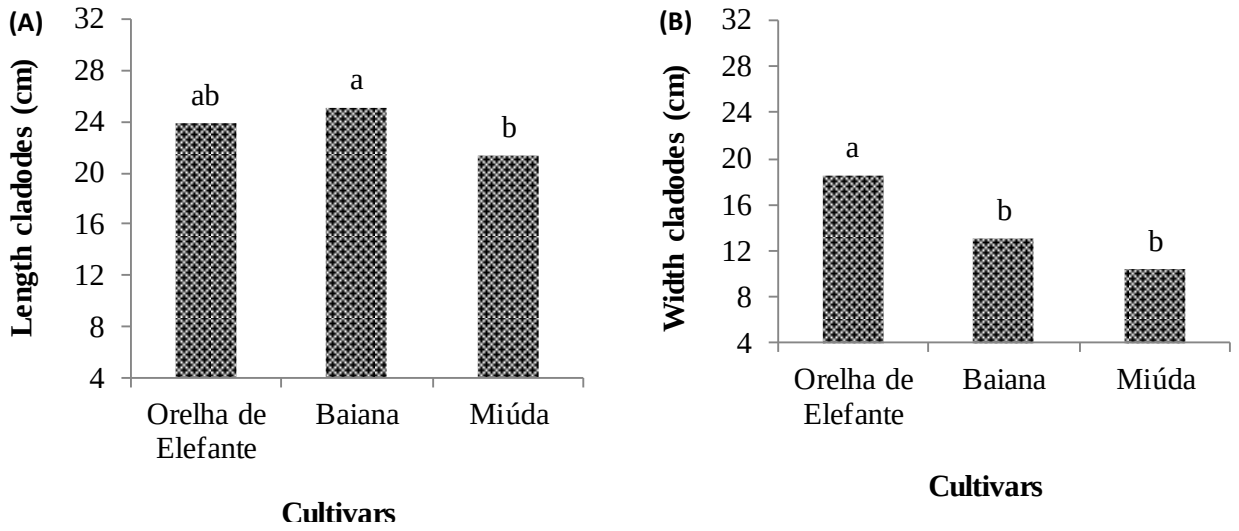


**Figure 5.** Cladodes length (A) and cladodes width (B) of forage palm at 360 days after planting.

**Table 3.** Analysis of variance for perimeter cladodes (PC), thickness of cladodes (EC), weight green cladodes matter (PMVC) and yield (R) of forage cactus in mineral fertilization at 360 days after planting.

| Variation sources | G.L | PC (cm) | EC (mm) | PMVC (g) | R (kg vaso$^{-1}$) |
|---|---|---|---|---|---|
| Cultivar (C) | 2 | 369.77** | 131.67** | 4201639.62** | 323.69* |
| Fertilization (A) | 1 | 2.77$^{ns}$ | 3.98$^{ns}$ | 8123.89$^{ns}$ | 1218.29** |
| Interaction (C x A) | 2 | 33.39$^{ns}$ | 7.71$^{ns}$ | 2094676.10$^{ns}$ | 258.31* |
| Residue | 15 | 28.89 | 3.08 | 584643.41 | 60.28 |
| General average | - | 55.47 | 18.38 | 3201.32 | 34.52 |
| Coefficient of variation (%) | - | 9.69 | 9.55 | 23.88 | 22.49 |

$^{ns}$Non- significance at the 0.05 level of probability by F test; *,** Significant at 0.05 level of probability and 0.01, respectively, by F test.

adenosine triphosphate (ATP) which encourages the absorption of nitrogen as amino acids and promotes protein synthesis.

The length of the cladodes depending on the cultivars differed statistically at 5% according to Tukey test (Figure 5A). It should be noted that cultivar Baiana was statistically similar to Orelha and Elefante but different from cultivar Miúda. However, the highest length of cladodes was observed in cultivar Baiana.

According to Silva et al. (2015b) in the study of the productivity of forage cactus cultivars observed at different times, the cultivar showed better length of cladodes (21 cm) in the Orelha Elefante, at 150 days after planting, corroborating the findings of the present study where the cultivar of Orelha Elefante did not differ from that of Baiana and the observed mean was 24 cm.

Regarding the width of cladodes, it was observed that the growth rate of Orelha Elefante had higher value at 360 days after planting (Figure 5B). Note that the Baiana and Miúda cultivars did not differ by Tukey test, leaving only cultivar Orelha Elefante. The low value of cladodes width of Baiana and Miúda cultivars is associated with features of the cultivars that belong to *Nopalea* genre.

According to Dubeux Junior et al. (2010) the differences observed in the studied cultivars can be associated to their peculiar morphological structure which is seen in the width and thickness of each cladode.

The summary of the analysis of variance for the variables perimeter of cladodes (PC), thickness of cladodes (EC), weight of green cladodes matter (PMVC) and yield (Y) of forage cactus in mineral fertilization at 360 days after planting are shown in Table 3.

It is observed that the variables were significant at 1 and 5% probability factor to cultivar. For the fertilization factor, there was a significant effect for the yield variable at the level of 1%. Significant effect at 1% probability for interaction between cultivar (C) x fertilization (A) of the forage cactus was observed at 360 days after planting only for yield variable (Table 3).

There was a significant difference at 5% probability observed by Tukey test for perimeter of cladodes depending on the cultivars at 360 days after planting

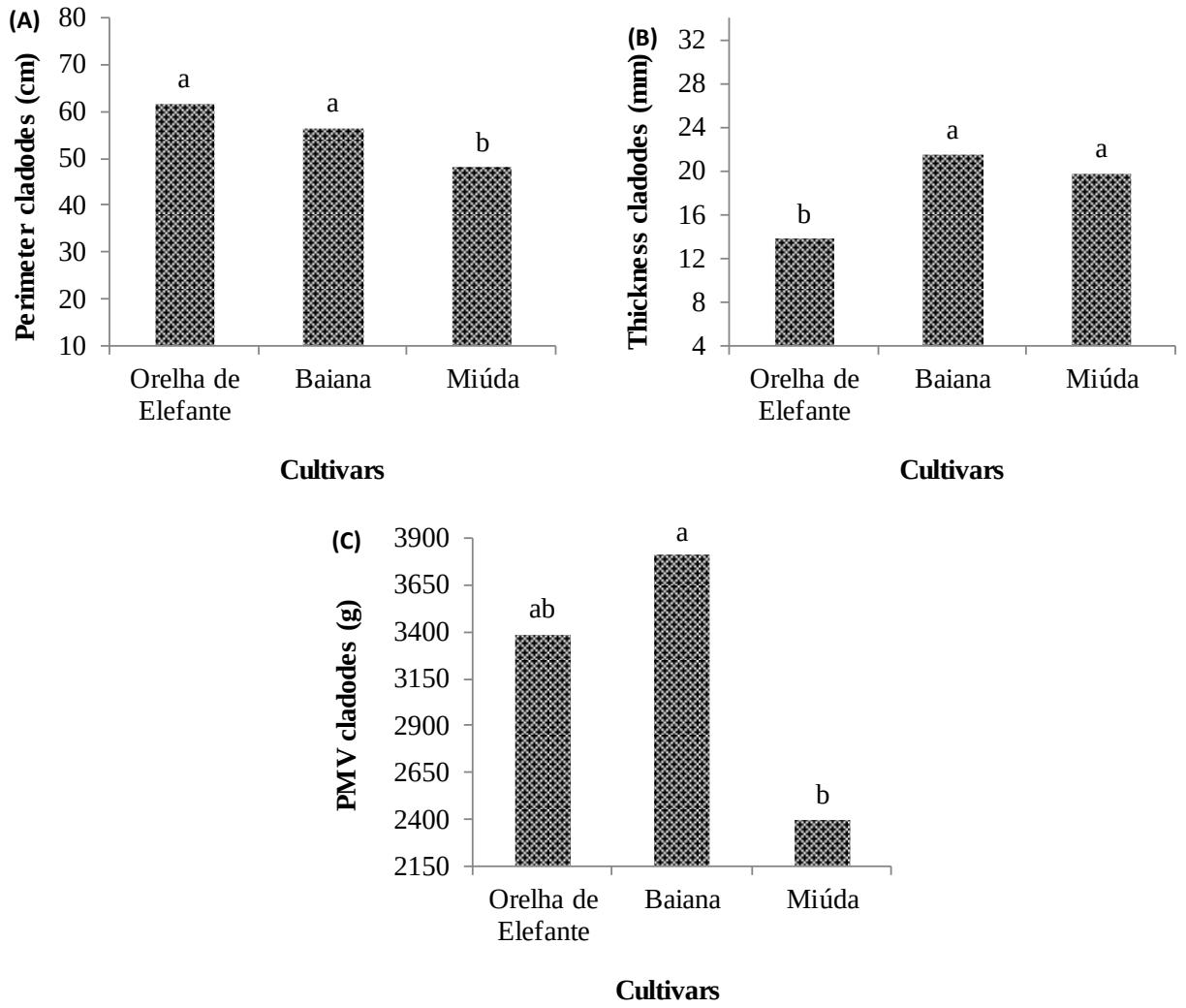


**Figure 6.** Perimeter of cladodes (A), thickness of cladodes (B) and green mass weight cladodes (C) depending on the cultivars at 360 days after planting.

(Figure 6A). It should be noted that the cultivars Orelha Elefante and Baiana did not differ; difference was only noticed in cultivar Miúda. It is also observed that the maximum perimeter was found in cultivar Orelha Elefante corresponding to approximately 66 cm. The largest perimeter observed in cultivar Orelha Elefante is associated with its anatomy which shows wider perimeter compared to other cultivars.

This result is consistent with those obtained by Leal et al. (2008) and Oliveira Júnior et al. (2009), using the same cultivars, they found averages for the perimeter of 60.42 and 60.50 cm to 270 days after planting, respectively.

The thickness of cladodes differ statistically by Tukey test at 5% probability, and the Baiana and Miúda cultivars presented the greatest thickness of cladodes corresponding to 21.5 and 19.8 mm, respectively (Figure 6B).

This fact probably is related to the genre cladodes format Nopalea be of oblong type that influences a greater thickness for the cladodes, as well as increasing the same volume resulting in increased biomass production by plants fact of great importance since cultivars of this kind generally have lower fresh mass production, when compared to the genre Opuntia (Dubeux Junior et al., 2010).

Regarding the green mass weight of cladodes, depending on the cultivars at 360 days after planting, it is noted that this differed statistically at 5% by Tukey test. It appears that the highest average value of green mass weight was obtained in cultivar Baiana, corresponding to 3800 g (Figure 6C). The greater the thickness of the cladodes, the higher their weight will be.

As a feature of simple visualization and measurement, green mass production in the semiarid region aids the calculation of the size and number of animal flow on the

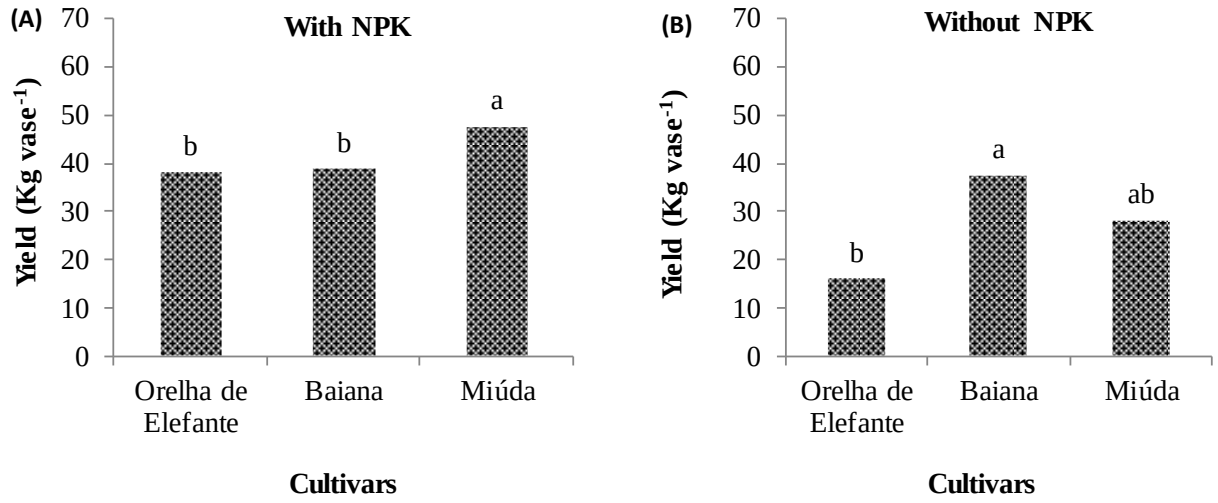


**Figure 7.** Yield per kg vase $^{-1}$ depending on cultivar x fertilization with NPK (A) and cultivars x fertilization without NPK (B) of forage palm 360 days after planting.

farm.

Silva et al. (2015) obtained similar results to those reported in this study, at 150 days after planting; cladodes green mass production reached approximately 1000 g in cultivar Baiana.

The interaction between Cultivar x Fertilization was significant at 5% by Tukey test for yield of forage palm at 360 days after planting (Figure 7). Note that the yield of treatments with NPK application in kg vase$^{-1}$ was higher in 'Miúda, with a maximum yield of 47.0 kg vase$^{-1}$ (Figure 7A).

Lopes et al. (2007) state that for spineless cactus to have good yields, it needs to be grown in well-structured soil with good aeration and excellent fertility, given that the plant requires large amount of nutrient due to its high number of cladodes. Considering all the above, it is preferable to cultivar Miúda, since it produces more cladodes than cultivars Orelha Elefante because of its morphological structure.

Almeida et al. (2012) reported that fertilization, either mineral or organic is indispensable when one wants to have high yields, since it provides the supply of macro and micronutrients necessary for the full development of the cactus forage.

Cultivar Miúda compared to Orelha Elefante is more nutritious and appreciated by cattle (palatable), but has a lower resistance to drought (Silva and Sampaio, 2015).

Regarding cultivars within the treatment without NPK application there was a significant difference at 5% probability by Tukey test (Figure 7B); it is observed that the Baiana, Orelha Elefante and Miúda cultivars did not differ. This is possibly due to the genetic characteristics of each gender and how it responds to conditions of low nutrient availability.

Silva et al. (2015) reports that when NPK was applied to the Baiana and Miúda cultivars, they showed higher yield in kg vase$^{-1}$ at 150 days after planting, these results are consistent with that observed in this present study.

## Conclusions

1. The isolated treatments significantly influenced the morphology and yield of the biomass of forage cactus.
2. Treatment with NPK application improved the morphology and yield of the biomass of cultivars cactus forage.
3. The length, width, thickness and green mass weight of cladodes had maximum yield for the cultivars Orelha Elefante and Baiana.
4. The interaction between the factors was significant only for the yield of cactus forage in kg vase$^{-1}$ with the NPK fertilization that resulted in maximum yield for cultivar Miúda.

## Conflict of Interests

The authors have not declared any conflict of interests.

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