

## Establishment of Sufficiency Ranges to Determine the Nutritional Status of ‘Gigante’ Forage Cactus Pear—Micronutrients

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### Abstract

Micronutrient sufficiency ranges are of great importance in crop nutritional diagnosing for improved fertilizer recommendations under field conditions. The objective of this paper was establishing the micronutrients ranges in the cladodes for the evaluation of the nutritional status of ‘Gigante’ forage cactus pear. Micronutrients contents in cladodes and dry matter yield of 72 plots were used. The experiment was composed of four cattle manure rates (0, 30, 60, and 90 Mg ha<sup>-1</sup> year<sup>-1</sup>), three spacings (1.00 × 0.50, 2.00 × 0.25, and 3.00 × 1.00 × 0.25 m), and two production cycles, in a 4 × 3 × 2 factorial plan, designed in randomized blocks, with three replicates. Sufficiency ranges of plots with dry matter ≥ 19.93 Mg ha<sup>-1</sup> cycle<sup>-1</sup> were determined as well as the mathematical chance for plots with dry matter ≥ 23.75 Mg ha<sup>-1</sup> cycle<sup>-1</sup> and the critical level. The sufficiency range, critical level and mathematical chance are, respectively, for each micronutrient, in mg kg<sup>-1</sup>: B, 22.3-32.7; 23.7; 20.36-27.94; Cu, 2.0-3.7; 1.6; 1.8-2.8; Fe, 61.1-126.6; 62.0; 35.8-85.3; Mn, 260.0-507.7; 111.0; 54.8-252.2; Zn, 34.5-57.8; 30.3; 19.7-48.5; and, Na, 29.8-56.2; 19.4; 26.6-42.7. For B, Zn, and Na, the sufficiency range, mathematical chance, and the critical level are adequate; for Cu, Fe, and Mn, the critical level and mathematical chance are more adequate for nutritional evaluation of ‘Gigante’ forage cactus pear, associated with dry matter yield ranging from 21.8 to 31.2 Mg ha<sup>-1</sup> cycle<sup>-1</sup>.

**Keywords:** *Opuntia ficus*, fertilization, nutritional evaluation

### 1. Introduction

The forage cactus pear (*Opuntia ficus-indica* Mill) has special morphologic mechanisms that allow it to adapt to drought conditions, which makes its cultivation essential in the Brazilian semiarid (Guimarães et al., 2019). For this reason, when adopting efficient managements in seasons with high water and nutrients availability, mainly concerning fertilization rates, the cactus modifies its physiological behavior, which leads to an increase in growth, yield, and nutritional quality.

Recent studies has considered chemical fertilizers (Silva et al., 2012), organic fertilizers (Donato et al., 2014a), and organo-mineral fertilizers (Padilha Júnior et al., 2016) as alternatives for increasing yields in forage cactus pear. The results show the influence on nutrient uptake (Donato et al., 2017; Silva et al., 2016a), on vegetative growth (Silva et al., 2016b), on nutritional status of the plant (Galizzi et al., 2004), on nutritional value of the forage, and on dry matter yield (Silva et al., 2013).

The chemical analysis of plant tissues is important to evaluate the nutritional status of crops as a complement of the soil chemical analysis and the visual diagnosis; as a result, it reflects the nutrient dynamics within the soil/plant system. Nevertheless, it requires the definition of standards and critical levels of nutrients so as to correctly interpret the results. To do so, there are several methods: sufficiency range (Martinez et al., 2003), mathematical chance (MCh), Diagnosis and Recommendation Integrated System (DRIS), Compositional Nutrient Diagnosis (CND), and critical level through the standard normal distribution (NCRIz) (Maia et al., 2001).

Sufficiency ranges and critical levels were established for forage cactus pear grown in Mexico (Blanco-Macias et al., 2010); though, there is demand for a standard for interpreting the micronutrients contents in tissues of cladodes, which sometimes limits the crop yield. Therefore, the aim of this study was establishing sufficiency ranges of micronutrients in tissues of cladodes for ‘Gigante’ forage cactus pear.

## 2. Material and Methods

A field trial was conducted from 2009 and 2012 on an experimental area of Instituto Federal Baiano, campus Guanambi, Bahia state, Brazil (14°13'30"S, 42°13'53"W, 545 m of elevation). The soil was classified as a typical dystrophic red-yellow Latosol (Oxysol). Climatic conditions were hypoxerophytic Caatinga; mean annual rainfall and temperature were 680 mm and 26 °C, respectively.

In this study, micronutrient contents—boron (B), copper (Cu), Iron (Fe), manganese (Mn), zinc (Zn), and sodium (Na)—as well as dry matter yield (DMY) and green matter yield (GMY) were evaluated using ‘Gigante’ forage cactus pear cladode samples; data from Donato et al. (2014a, 2014b, 2016) and Barros et al. (2016) for the first and second cycle were used, respectively.

Cladode micronutrient contents were measured considering a experimental design with four cattle manure rates (0, 30, 60, and 90 Mg ha<sup>-1</sup> year<sup>-1</sup>), three spacings (1.0 × 5.00, 2.00 × 0.24; and 1.00 × 0.25 m), and two production cycles (600 and 930 days after planting). These treatments were arranged in a 4 × 3 × 2 factorial laid out on a randomized block design with three replicates, totaling 72 experimental plots.

Sufficiency range (SR) and critical range (CR) were standardized by taking into account the mean ± standard deviation of micronutrient contents measured in experimental plots yielding dry matter equal to or higher than the average yield (Martinez et al., 2003). Using the mathematical change procedure (MCh), data from plots with DMY ≥ 23.75 Mg ha<sup>-1</sup> cycle<sup>-1</sup> were selected (Camacho et al., 2012).

Therefore, sufficiency ranges were determined by the equation:  $SR = \bar{x} \pm kS\bar{x}$ ;  $SR \geq (\bar{x} - kS\bar{x}) < (\bar{x} + kS\bar{x})$ , where,  $\bar{x}$  is the mean tissue content of each micronutrient,  $S\bar{x}$  is the standard deviation,  $\sqrt{S}$  is the square root of the variance, and  $k$  is the correction factor for adjusting the sufficiency ranges. The  $k$  values were established based on the coefficient of variation (CV) of each nutrient:  $k = 1.0$  for nutrients with CV below 20%;  $k = 0.8$  for CV between 20.01 and 40%;  $k = 0.6$  for CV between 40.01 and 80%; and  $k = 0.4$  for CV higher than 80% (Martinez et al., 2003).

In addition to SR, cladode micronutrient contents were separated into four levels: deficient (DEF), marginal (MAR), high (HI), and very high (VHI). These classes were established according to the following procedure:  $DEF < (\bar{x} - 2kS\bar{x})$ ;  $MARG \geq (\bar{x} - 2kS\bar{x})$  and  $< (\bar{x} - kS\bar{x})$ ;  $IGH \geq (\bar{x} + kS\bar{x})$  and  $< (\bar{x} + 2kS\bar{x})$ ;  $VHIGH \geq (\bar{x} + 2kS\bar{x})$ .

Cladode micronutrient contents were classified based on confidence intervals (CI) determined by the model:  $CI = \bar{x} \pm t_{\alpha} S\bar{x}$ , where  $\bar{x}$  is the mean,  $S\bar{x}$  is the standard deviation of the mean, and  $t_{\alpha}$  is the bilateral  $t$  value at 10% of probability level for high yielding plots.

By the standard normal distribution, critical levels were determined for cladode micronutrient contents using the model proposed by Maia et al. (2001):  $CL_1 = (1,281552 \cdot S\bar{x}_1 + \bar{x}_1) / (1,281552 \cdot S\bar{x}_2 + \bar{x}_2)$ ; where,  $CL$  is the critical level;  $S\bar{x}_1$  and  $\bar{x}_1$  are the standard deviation and average yield ( $Y$ ); and  $S\bar{x}_2$  and  $\bar{x}_2$  are standard deviation and average of  $Q$ , which is defined as the ratio between  $Y$  and  $n_i$ ,  $Q = Y/n_i$ ; where  $n_i$  is the nutrient content used to determine the critical level.

Using the mathematical chance model (MCh), micronutrient contents were split into classes by the square root of the number of terms whose intervals were calculated by the division between nutrient content and the number of pre-defined classes.

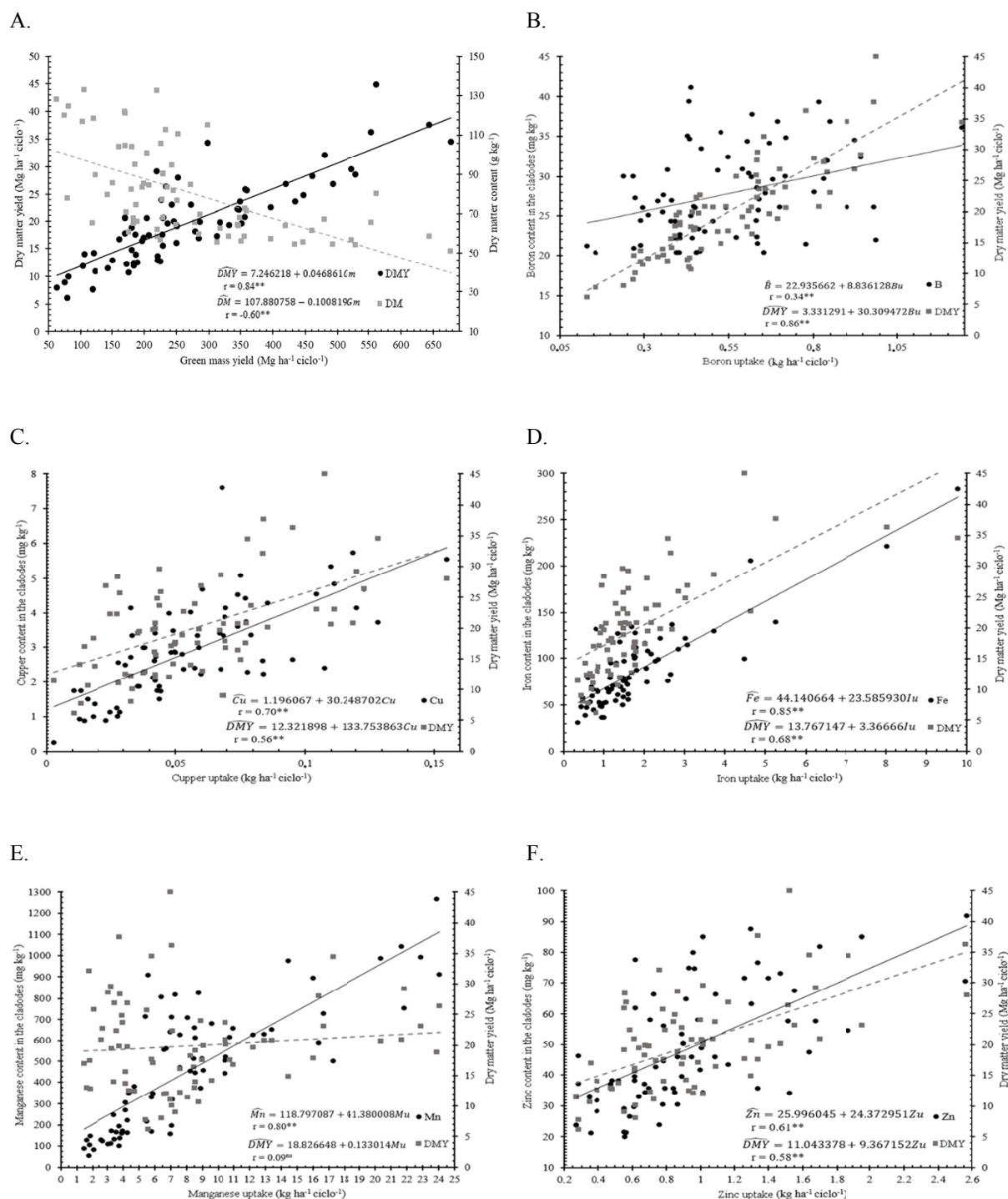
Mathematical chance (MChi) was determined by the following model:  $MCh_i = [MCh(A_i/A) \times MCh(A_i/C_i)]^{0.5}$ , where,  $MCh(A_i/A) = Y(A_i/A) \times YIELD_i$ ;  $Y(A_i/A)$  = frequency of high-yielding plots;  $YIELD_i$ , average yield in the class  $i$  (Mg ha<sup>-1</sup> year<sup>-1</sup>);  $MCh(A_i/C_i) = Y(A_i/C_i) \times YIELD_i$ ; and  $Y(A_i/C_i)$  = frequency of high-yielding plots of class  $i$  in relation to the overall total of high-yielding plots in the class  $i$ .

Lower (LLi) and upper (ULi) limits were established for each micronutrient, which corresponded to the normal range due to its higher reference value:  $MCh_i$ ; furthermore, the highest total frequency of plots in class  $i$  and the highest frequency of plots with dry matter yield equal to or higher than 23.75 Mg ha<sup>-1</sup> cycle<sup>-1</sup> in class I were considered.

Moreover, the correlation between the micronutrients contents in the tissues and DMY with micronutrients uptake and green mass yield was estimated.

### 3. Results and Discussion

The dry matter content linearly decreases alongside the green mass yield, GMY, while the dry matter yield, DMY increases (Figure 1A). The correlations of the micronutrients contents in cladodes and DMY of ‘Gigante’ cactus pear with the extraction of the respective micronutrients from the soil are positive and significant (Figure 1), except for DMY and uptake of Mn, non-significant. The highest values were recorded for DMY with B uptake (0.86), and for Fe content in cladodes with Fe uptake (0.85). Positive correlations between nutrients contents in cladodes and in the soil were established, in which Mn with Ca exhibited a negative correlation (-0.29) while Zn with P, positive (0.26) (Galizzi et al., 2004).



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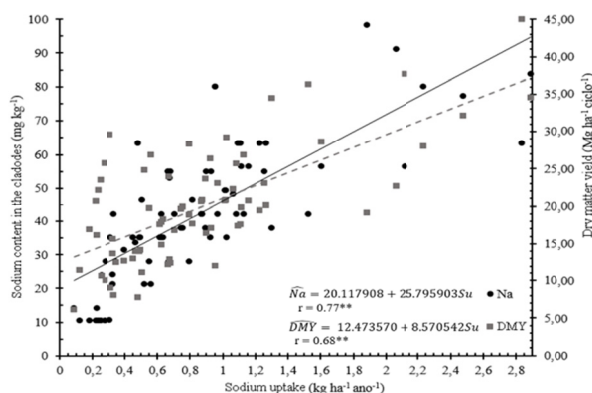


Figure 1. Correlations of yield and dry matter content with green mass yield (A); micronutrients contents in tissues of cladodes and dry matter yield with extraction/exportation of respective micronutrients by ‘Gigante’ forage cactus pear, fertilized with different cattle manure rates, in two production cycles. B: boron, C: copper, D: iron, E: manganese, F: zinc and, G: sodium. Significance level of the coefficients: \*\* 0.01 and <sup>ns</sup> Not significant  
Source: Basic data, Donato et al. (2014a, 2014b, 2016); Barros et al. (2016).

The positive and significant correlations of micronutrients contents in the cladodes and dry matter yield (DMY) with the extraction of respective nutrients (Figure 1) allow to establish sufficiency ranges (SR), as well as to set five classes for the evaluation of the nutritional status of ‘Gigante’ forage cactus pear (Table 1). Donato et al. (2017) added that crop yield highly responds to the availability of nutrients in the soil for the plant to take up; thus, sufficiency range correlates with dry matter yield.

Table 1. Values of micronutrients contents in tissues of cladodes associated with the dry matter yield (DMY) for evaluating the nutritional status of ‘Gigante’ forage cactus pear by the sufficiency range technique

| Contents                        | DMY                                     | B                   | Cu      | Fe          | Mn          | Zn        | Na        |
|---------------------------------|-----------------------------------------|---------------------|---------|-------------|-------------|-----------|-----------|
| Classes                         | Mg ha <sup>-1</sup> cycle <sup>-1</sup> | mg kg <sup>-1</sup> |         |             |             |           |           |
| Deficient                       | <17.0                                   | <17.1               | <1.1    | <28.4       | <136.0      | <15.0     | <16.6     |
| Marginal                        | 17.0-21.8                               | 17.1-22.3           | 1.1-2.0 | 28.4-61.1   | 136.0-260.0 | 15.0-30.6 | 16.6-29.8 |
| Sufficient                      | 21.8-31.2                               | 22.3-32.7           | 2.0-3.7 | 61.1-126.6  | 260.0-507.7 | 34.5-57.8 | 29.8-56.2 |
| Good (high)                     | 31.2-36.0                               | 32.7-37.8           | 3.7-4.5 | 126.6-159.3 | 507.7-631.6 | 57.8-69.5 | 56.2-69.3 |
| Very good (very high)           | ≥36.0                                   | ≥37.8               | ≥4.5    | ≥159.3      | ≥631.6      | ≥69.5     | ≥69.3     |
| Mean <sup>1</sup>               | 19.93                                   | 27.77               | 2.92    | 87.30       | 461.49      | 49.11     | 42.56     |
| Standard Deviation <sup>1</sup> | 7.64                                    | 5.52                | 1.38    | 42.73       | 294.21      | 18.93     | 20.40     |
| CV <sup>1</sup> (%)             | 38.34                                   | 19.89               | 47.17   | 48.94       | 63.75       | 38.54     | 47.93     |
| CI <sup>2</sup>                 | 16.5-36.5                               | 18.7-36.3           | 0.5-5.3 | 1.4-186.3   | 0-909.0     | 13.2-79.2 | 5.8-80.2  |

Note. <sup>1</sup>Mean, standard deviation and coefficient of variation (CV) refer to 72 plots; <sup>2</sup>Confidence interval of crude protein and micronutrients contents in tissues of cladodes of ‘Gigante’ forage cactus pear fertilized with different cattle manure rates, in two production cycles.

The highest values of MCh are for B contents in cladodes of ‘Gigante’ cactus pear associated with DMY higher than or equal to 23.75 Mg ha<sup>-1</sup> cycle<sup>-1</sup> were observed in the classes 4 and 5 (20.3-27.9 mg kg<sup>-1</sup>) (Table 2). These values are within the SR (22.3-32.7 mg kg<sup>-1</sup>), and as for the NCRIz (23.7 mg kg<sup>-1</sup>), it coincides with the middle point of the MCh interval (Table 3). B contents within the MCh and in the lower limit of the SR (22.6 g kg<sup>-1</sup>) were obtained by Silva et al. (2012) with 200-150-100 kg ha<sup>-1</sup>year<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O.

Table 2. Values of mathematical chance (MCh) established for different distribution classes of micronutrients in tissues of cladodes of ‘Gigante’ forage cactus pear, fertilized with different cattle manure rates, in two production cycles

| Classes          | LLi <sup>2</sup><br>(mg kg <sup>-1</sup> ) | UPi <sup>3</sup><br>(mg kg <sup>-1</sup> ) | YIELDi <sup>4</sup><br>(Mg ha <sup>-1</sup> cycle <sup>-1</sup> ) | Plot class i <sup>5</sup> | High-yielding<br>plot class i <sup>6</sup> | P1 <sup>7</sup> | P2 <sup>8</sup> | MCh(A <sub>i</sub> /A) <sup>9</sup> | Classes | LLi <sup>2</sup><br>(mg kg <sup>-1</sup> ) |
|------------------|--------------------------------------------|--------------------------------------------|-------------------------------------------------------------------|---------------------------|--------------------------------------------|-----------------|-----------------|-------------------------------------|---------|--------------------------------------------|
| <i>Boron</i>     |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 35.54                                      | 39.32                                      | 26.06                                                             | 3                         | 1                                          | 0.06            | 0.33            | 1.45                                | 1       | 35.54                                      |
| 2                | 31.74                                      | 35.53                                      | 25.75                                                             | 4                         | 3                                          | 0.17            | 0.75            | 4.29                                | 2       | 31.74                                      |
| 3                | 27.95                                      | 31.73                                      | 23.79                                                             | 7                         | 3                                          | 0.17            | 0.43            | 3.97                                | 3       | 27.95                                      |
| 4                | 24.15                                      | 27.94                                      | 26.50                                                             | 9                         | 5                                          | 0.28            | 0.56            | 7.36                                | 4       | 24.15                                      |
| 5                | 20.36                                      | 24.14                                      | 29.18                                                             | 9                         | 6                                          | 0.33            | 0.67            | 9.73                                | 5       | 20.36                                      |
| <i>Copper</i>    |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 4.76                                       | 5.73                                       | 23.10                                                             | 4                         | 1                                          | 0.06            | 0.25            | 1.28                                | 1       | 4.76                                       |
| 2                | 3.78                                       | 4.75                                       | 24.67                                                             | 4                         | 2                                          | 0.11            | 0.50            | 2.74                                | 2       | 3.78                                       |
| 3                | 2.79                                       | 3.77                                       | 24.06                                                             | 5                         | 1                                          | 0.06            | 0.20            | 1.34                                | 3       | 2.79                                       |
| 4                | 1.81                                       | 2.78                                       | 30.18                                                             | 11                        | 8                                          | 0.44            | 0.73            | 13.41                               | 4       | 1.81                                       |
| 5                | 0.83                                       | 1.80                                       | 25.71                                                             | 8                         | 2                                          | 0.11            | 0.25            | 2.86                                | 5       | 0.83                                       |
| <i>Iron</i>      |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 233.69                                     | 283.13                                     | 34.54                                                             | 1                         | 1                                          | 0.06            | 1.00            | 1.92                                | 1       | 233.69                                     |
| 2                | 184.23                                     | 233.68                                     | 29.44                                                             | 2                         | 1                                          | 0.06            | 0.50            | 1.64                                | 2       | 184.23                                     |
| 3                | 134.78                                     | 184.22                                     | 37.67                                                             | 1                         | 1                                          | 0.06            | 1.00            | 2.09                                | 3       | 134.78                                     |
| 4                | 85.32                                      | 134.77                                     | 26.30                                                             | 10                        | 5                                          | 0.28            | 0.50            | 7.31                                | 4       | 85.32                                      |
| 5                | 35.87                                      | 85.31                                      | 25.27                                                             | 18                        | 10                                         | 0.56            | 0.56            | 14.04                               | 5       | 35.87                                      |
| <i>Manganese</i> |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 844.39                                     | 1041.77                                    | 22.70                                                             | 4                         | 1                                          | 0.06            | 0.25            | 1.26                                | 1       | 844.39                                     |
| 2                | 647.01                                     | 844.38                                     | 24.28                                                             | 3                         | 1                                          | 0.06            | 0.33            | 1.35                                | 2       | 647.01                                     |
| 3                | 449.62                                     | 647.00                                     | 24.78                                                             | 5                         | 2                                          | 0.11            | 0.40            | 2.75                                | 3       | 449.62                                     |
| 4                | 252.24                                     | 449.61                                     | 23.30                                                             | 3                         | 1                                          | 0.06            | 0.33            | 1.29                                | 4       | 252.24                                     |
| 5                | 54.85                                      | 252.23                                     | 28.91                                                             | 17                        | 13                                         | 0.72            | 0.76            | 20.88                               | 5       | 54.85                                      |
| <i>Zinc</i>      |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 77.39                                      | 91.80                                      | 23.92                                                             | 3                         | 1                                          | 0.06            | 0.33            | 1.33                                | 1       | 77.39                                      |
| 2                | 62.97                                      | 77.38                                      | 25.01                                                             | 4                         | 1                                          | 0.06            | 0.25            | 1.39                                | 2       | 62.97                                      |
| 3                | 48.56                                      | 62.96                                      | 26.28                                                             | 5                         | 3                                          | 0.17            | 0.60            | 4.38                                | 3       | 48.56                                      |
| 4                | 34.14                                      | 48.55                                      | 26.38                                                             | 11                        | 6                                          | 0.33            | 0.55            | 8.79                                | 4       | 34.14                                      |
| 5                | 19.72                                      | 34.13                                      | 28.39                                                             | 9                         | 7                                          | 0.39            | 0.78            | 11.04                               | 5       | 19.72                                      |
| <i>Sodium</i>    |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 75.04                                      | 91.17                                      | 29.31                                                             | 4                         | 3                                          | 0.17            | 0.75            | 4.89                                | 1       | 75.04                                      |
| 2                | 58.90                                      | 75.03                                      | 32.53                                                             | 2                         | 1                                          | 0.06            | 0.50            | 1.81                                | 2       | 58.90                                      |
| 3                | 42.76                                      | 58.89                                      | 24.81                                                             | 7                         | 2                                          | 0.11            | 0.29            | 2.76                                | 3       | 42.76                                      |
| 4                | 26.62                                      | 42.75                                      | 26.60                                                             | 12                        | 8                                          | 0.44            | 0.67            | 11.82                               | 4       | 26.62                                      |
| 5                | 10.48                                      | 26.61                                      | 24.83                                                             | 7                         | 4                                          | 0.22            | 0.57            | 5.52                                | 5       | 10.48                                      |
| <i>Boron</i>     |                                            |                                            |                                                                   |                           |                                            |                 |                 |                                     |         |                                            |
| 1                | 35.54                                      | 39.32                                      | 26.06                                                             | 3                         | 1                                          | 0.06            | 0.33            | 1.45                                | 1       | 35.54                                      |
| 2                | 31.74                                      | 35.53                                      | 25.75                                                             | 4                         | 3                                          | 0.17            | 0.75            | 4.29                                | 2       | 31.74                                      |
| 3                | 27.95                                      | 31.73                                      | 23.79                                                             | 7                         | 3                                          | 0.17            | 0.43            | 3.97                                | 3       | 27.95                                      |
| 4                | 24.15                                      | 27.94                                      | 26.50                                                             | 9                         | 5                                          | 0.28            | 0.56            | 7.36                                | 4       | 24.15                                      |

Note. <sup>1</sup>Camacho et al. (2012); <sup>2</sup>Lower limit of class *i*; <sup>3</sup>Upper limit of class *i*; <sup>4</sup>Average dry matter yield (DMY, Mg ha<sup>-1</sup>year<sup>-1</sup>) of plots in the class *i*; <sup>5</sup>Total number of plots in the class *i*; <sup>6</sup>Total number of high-yielding plots in the class *i*, DMY ≥ 23.75 Mg ha<sup>-1</sup>, which corresponds to the average DMY + 0.5 standard deviation; <sup>7</sup>Frequency of high-yielding plots in the class *i* in relation to the total number of high-yielding plots; <sup>8</sup>Frequency of high-yielding plots in the class *i* in relation to the total number of plots in the class *i*; <sup>9</sup>MCh(A<sub>i</sub>/A) = Y(A<sub>i</sub>/A) × YIELD<sub>i</sub>; <sup>10</sup>MCh(A<sub>i</sub>/C<sub>i</sub>) = Y(A<sub>i</sub>/C<sub>i</sub>) × YIELD<sub>i</sub>; <sup>11</sup>MCh<sub>i</sub> = [MCh(A<sub>i</sub>/A) × MCh(A<sub>i</sub>/C<sub>i</sub>)]<sup>0.5</sup>.

Table 3. Normal ranges of micronutrients in tissues of cladodes of ‘Gigante’ forage cactus pear obtained by the sufficiency range technique (SR), by the mathematical chance method (MCh), and by the critical level through the standard normal distribution (NCRIz) associated with the dry matter yield (DMY)

| Attributes         | DMY <sup>1</sup>                        | B                   | Cu      | Fe         | Mn          | Zn        | Na        |
|--------------------|-----------------------------------------|---------------------|---------|------------|-------------|-----------|-----------|
| Methods            | Mg ha <sup>-1</sup> cycle <sup>-1</sup> | mg kg <sup>-1</sup> |         |            |             |           |           |
| SR                 | 21.8-31.2 <sup>1</sup>                  | 22.3-32.7           | 2.0-3.7 | 61.1-126.6 | 260.0-507.7 | 34.5-57.8 | 29.8-56.2 |
| MCh <sup>3</sup>   | >23.75                                  | 20.3-27.9           | 1.8-2.8 | 35.8-85.3  | 54.8-252.2  | 19.7-48.5 | 26.6-42.7 |
| NCRIz <sup>3</sup> | 23.75 <sup>4</sup>                      | 23.7                | 1.6     | 62.0       | 111.0       | 30.3      | 19.4      |

Note. <sup>1</sup>Range of dry matter yield associated with the normal ranges of crude protein and micronutrients; <sup>2</sup>Estimated from the upper and lower limits of the frequency class with higher values of mathematical chance (Camacho et al., 2012), higher frequency of the total number of plots in the class *i* and higher frequency of high-yielding plots in the class *i*; <sup>3</sup>According to Maia et al. (2001); <sup>4</sup>Average DMY + 0.5 standard deviation, used to separate high from low yielding plots in the class *i*; <sup>5</sup>Sufficiency range and critical level (Blanco-Macías et al., 2010).

B was the penultimate micronutrient in the order of extraction/exportation to the dry matter of the plant, 29.8 g Mg<sup>-1</sup> (Donato, 2011) and 22.8 g Mg<sup>-1</sup> (Silva et al., 2016a). This is consistent with the lesser degree of association between the B content in the cladode and its extraction from the soil (0.36), even though there is a higher degree in DMY with B extraction (Figure 1B), and B is the main micronutrient related to the growth of the cactus pear (Dubeux Júnior & Santos, 2005). SR, MCh, and NCRIz are suitable for evaluating the nutritional status of cactus pear.

The highest value of MCh for the Cu contents in cladodes of ‘Gigante’ forage cactus pear was found in the class 4 (1.8-2.8 mg kg<sup>-1</sup>) (Table 2). The lower limit (LLi) of MCh is similar to that of NCRIz (1.6 mg kg<sup>-1</sup>), while the upper limit (ULi) is within the SR (2.0-3.7 mg kg<sup>-1</sup>) (Table 3). Cu contents above the SR (5.1 mg kg<sup>-1</sup>) were obtained by Silva et al. (2012) for forage production, with 200-150-100 kg ha<sup>-1</sup> year<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O; whereas Galizzi et al. (2004) found Cu contents within the SR (2.9 mg kg<sup>-1</sup>) for fruit production, with 100-50-100-50 kg ha<sup>-1</sup> of N-P-K-Mg. Cu is the micronutrient with lower extraction/exportation to the dry matter of forage cactus pear, 3.1 g Mg<sup>-1</sup> (Donato, 2011) and 5.3 g Mg<sup>-1</sup> (Silva et al., 2016a); thus, the NCRIz and MCh are more suitable for evaluating the nutritional status for Cu.

The highest value of MCh for Fe contents in cladodes of the plant was observed in the class 5 (35.87-85.31 mg kg<sup>-1</sup>) (Table 2). The NCRIz (62.0 mg kg<sup>-1</sup>) is an intermediate value within the MCh and is found in the lower limit of the SR. As for the ULi of MCh, it is in the SR (61.1-126.6 mg kg<sup>-1</sup>) (Table 3). Fe contents below the SR, within, however, the MCh, were reported by Silva et al. (2012), 48.5 mg kg<sup>-1</sup> and by Galizzi et al. (2004), 41 mg kg<sup>-1</sup>. Fe was the second micronutrient in order of extraction/exportation to the dry matter of the plant, 72.5 g Mg<sup>-1</sup> (Donato, 2011) and third, 49.3 g Mg<sup>-1</sup> (Silva et al., 2016a). Therefore, the NCRIz and the MCh are more suitable for evaluating the nutritional status for Fe.

As for Mn, the highest MCh is in the class 5 (54.8-252.2 mg kg<sup>-1</sup>) (Table 2). The NCRIz (111.0 mg kg<sup>-1</sup>) is an intermediate value within the MCh and its ULi is found close to the lower limit of the SR (260.0-507.7 mg kg<sup>-1</sup>) (Table 3). Mn contents are well above the MCh and the SR (Silva et al., 2012), 2,006.0 mg kg<sup>-1</sup>, with 200-150-100 kg ha<sup>-1</sup> year<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O, within the MCh and below the SR (Galizzi et al., 2004), 138 mg kg<sup>-1</sup> with 100-50-100-50 kg ha<sup>-1</sup> of N-P-K-Mg. Mn is the highest extracted/exported micronutrient to the dry matter by the cactus pear, 638.1 g Mg<sup>-1</sup> (Donato, 2011) and 1,968.23 g Mg<sup>-1</sup> (Silva et al., 2016a); though, the relation between DMY and Mn uptake is not significant (Figure 1E). For this reason, the NCRIz and the MCh are more suitable for evaluating the nutritional status for Mn.

The elevated value of Mn in tissues of ‘Gigante’ cactus pear (Silva et al., 2012) and the triple extraction/exportation of Mn (Silva et al., 2016a) is a consequence of the ammonium sulfate as source of N, which reduces the pH, increasing the solubility and absorption of Mn<sup>+2</sup>. An evidence of this was the reduction in pH from 5.33 before planting to 4.29 at harvest time due to NPK application. Conversely, lower values are found when manure is applied as it decreases the acidity and increases the adsorption of Mn. Donato et al. (2016) justified the lower contents in the cladodes by the decrease in pH from 5.4 before planting to 6.0, 6.1, and 6.2 in areas that had 30, 60, and 90 Mg ha<sup>-1</sup> year<sup>-1</sup> of manure applied, respectively.

The highest values of MCh for Zn contents in cladodes associated with DMY that is higher than or equal to 23.75 Mg ha<sup>-1</sup> cycle<sup>-1</sup> are in the classes 4 and 5 (19.7-48.5 mg kg<sup>-1</sup>) (Table 2). The NCRIz (30.3 mg kg<sup>-1</sup>) is an intermediate value with the MCh and below the lower limit of the SR (34.5-57.8 mg kg<sup>-1</sup>), the LLi and ULi of

the MCh are below the respective limits of the SR (Table 3). Zn contents above the MCh and the SR were observed by Silva et al. (2012), 67.14 mg kg<sup>-1</sup> and Galizzi et al. (2004) reported Zn contents within the MCh and below the SR, 23.8 mg kg<sup>-1</sup> in average.

Zn is the third most extracted/exported micronutrient to the dry matter, 58.3 g Mg<sup>-1</sup> (Donato, 2011), and the second, 65.1 g Mg<sup>-1</sup> (Silva et al., 2016a). Its deficiency interferes with synthesis of auxin and protein, and with growth (Epstein & Bloom, 2006). Therefore, the SR, MCh, and NCRIZ are suitable for evaluating the nutritional status for Zn.

The highest values of MCh for Na is in the class 4 (26.7-42.7 mg kg<sup>-1</sup>) (Table 2). The LLi and ULi of the MCh are below the limits of the SR (29.8-56.2 mg kg<sup>-1</sup>) and the NCRIZ (19.4 mg kg<sup>-1</sup>) is below the lower limits of the MCh and of the SR (Table 3). Na contents within the MCh and SR were observed by Silva et al. (2012), 40.0 mg kg<sup>-1</sup> and by Galizzi et al. (2004), 38.0 mg kg<sup>-1</sup>. Therefore, SR, MCh and NCRIZ are suitable for evaluating the nutritional status for Na.

Amounts of Na extracted/exported by the plant were 45.9 g Mg<sup>-1</sup> (Donato, 2011) and 32.3 g Mg<sup>-1</sup> (Silva et al., 2016a). Although Na is not considered to be essential, Epstein & Bloom (2006) reported that Na is a micronutrient for plants with crassulacean acid metabolism (CAM), as it is essential for regeneration of phosphoenolpyruvate, substrate in the first carboxylation and its deficiency induces chlorosis and necrosis, and flower drop.

#### 4. Conclusions

As for B, Zn, and Na, the sufficiency range (SR), the mathematical chance (MCh) and the NCRIZ are more suitable for the evaluation of the nutritional status of 'Gigante' forage cactus pear associated with dry matter yield between 21.8 and 31.2 Mg ha<sup>-1</sup> cycle<sup>-1</sup>.

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