Acta Scientiarum. Agronomy
ISSN: 1679-9275
ISSN: 1807-8621
Editora da Universidade Estadual de Maringá - EDUEM

Ramos, João Paulo de Farias; Macêdo, Alberto Jefferson da Silva; Santos, Edson Mauro; Edvan, Ricardo Loiola; Sousa, Wandrick Hauss de; Perazzo, Alexandre Fernandes; Silva, Anderson Samuel; Cartaxo, Felipe Queiroga

Forage yield and morphological traits of cactus pear genotypes

Acta Scientiarum. Agronomy, vol. 43, e51214, 2021, January-December
Editora da Universidade Estadual de Maringá - EDUEM

DOI: https://doi.org/10.4025/actasciagron.v43i1.51214

Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v43i1.51214

CROP PRODUCTION

Forage yield and morphological traits of cactus pear genotypes

João Paulo de Farias Ramos[2], Alberto Jefferson da Silva Macêdo[1], Edson Mauro Santos[2], Ricardo Loiola Edvan[3], Wandrick Hauss de Sousa[4], Alexandre Fernandes Perazzo[2], Anderson Samuel Silva[2*] and Felipe Queiroga Cartaxo[4]

[1]Centro de Saúde e Tecnologia Rural, Universidade Federal de Campina Grande, Avenida Universitária, s/n, Bairro Santa Cecília, Cx. Postal 61, 58708-110, Patos, Paraíba, Brazil. [2]Departamento de Zootecnia, Centro de Ciências Agrárias, Universidade Federal da Paraíba, Areia, Paraíba, Brazil. [3]Departamento de Zootecnia, Universidade Federal do Piauí, Campus Professora Cinobelina Elvas, Bom Jesus, Piauí, Brazil. [4]Empresa Paraibana de Pesquisa, Extensão Rural e Regulação Fundiária, João Pessoa, Paraíba, Brazil. *Author for correspondence. E-mail: andersontacaratu@hotmail.com

ABSTRACT. The objective of this study was to evaluate the forage yield and morphological responses of 34 cactus pear (*Nopalea cochenillifera* and *Opuntia ficus indica*) genotypes. The genotypes were planted in a randomized complete block design, with 34 treatments and three replicates. After 330 days of cultivation, morphological characteristics, plant mortality and pest and disease occurrence on the plants were assessed, and plant cutting was performed. Multivariate analyses were performed to assign the 34 cactus genotypes to homogenous groups. The average Euclidian distance was adopted as a dissimilarity measurement for use with the standardized data Variables with relatively high levels of independence among the agronomic categories and with biological importance to animal nutrition and forage yield were assessed. To identify associative effects, Pearson's correlation analysis was performed among all the studied variables. The formation of five distinct groups was observed, and some morphological responses correlated with the productivity characteristics. Green mass production was positively correlated with dry mass production, water accumulation, water-use efficiency, water accumulation and cladode number per plant. The following genotypes had remarkably high yields of dry and green mass, a greater ability to accumulate water and relatively high water-use efficiency and support capacity: Negro Michoacan (V07), Tamazunchale (V12), California (V14), Orelha de Elefante Mexicana (V17), and Amarillo 2289 (T32).

Keywords: dry mass production; morphological responses; *Nopalea cochenillifera*; *Opuntia ficus indica*; productivity characteristics.

Received on November 30, 2019.
Accepted on April 29, 2020.

Introduction

Cacti have potential for use in animal feeding. In arid and semiarid regions, cacti are preferable over other forage due their high adaptability and capacity to produce herbaceous biomass with little water availability. Due to historical and cultural factors, the main genera of cultivated cactus pear is *Opuntia* spp.; the two dominant genotypes are Gigante and Redonda, but these genotypes are susceptible to pests and diseases (Dubeux Júnior, Santos, Cavalcante, & Santos, 2013).

Due to the particular characteristics of the semiarid region of northeastern Brazil, one of the main difficulties that producers face is the lack of food for herds in drought periods, given the lack of pasture development. The alternative is to use a food source that is better adapted to water scarcity conditions, such as the cactus pear in its natural form, rather than grass or silage.

To identify promising cactus genotypes that may be used as a basis for genetic improvement, studies that assess adaptive, morphological and structural characteristics, such as the number and dimensions of cladodes, which are positively correlated with forage yield, are necessary (Pinheiro et al., 2014).

Barbosa et al. (2018) evaluated the morphological characteristics of three cactus pear genotypes (IPA Sertânia, Miúda, and Orelha de Elefante Mexicana) and found that the growth characteristics (plant height and plant width) were strongly or very strongly positively correlated with the morphological characteristics of the cladodes (basal cladode length, cladode width, cladode thickness, cladode perimeter, and cladode area), contributing to the development of the plant as a whole.

Amorim, Martuscello, Araújo Filho, Cunha, and Jank (2015) evaluated the agronomic characteristics of 24 varieties of cactus pear and verified that the agronomic and morphological characteristics (plant height, plant width, cladode area, and total number of cladodes) were positively correlated with cactus pear mass.

We hypothesized that by evaluating the morphologic and productive characteristics of several cactus pear genotypes belonging to two different genera, it would be possible to identify the genotypes that had relatively high levels of productivity.

The agronomic potential and morphological characteristics of 34 genotypes of cactus pear cultivated for forage were evaluated.

Material and methods

Experimental location and period

The experiment was conducted in Experimental Station Benjamim Maranhão, in the city of Tacima, Paraíba State, Brazil. The station is in the mesoregion of Paraíba and the microregion of Curimataú Oriental (coordinates: 6° 29' 16" East and 35° 38' 13" West), has an altitude of 168 m, and belongs to the Empresa Paraibana de Pesquisa, Extensão Rural e Regularização Fundiária (EMPAER). Weather data were collected throughout the experimental period, resulting in a cumulative rainfall of 586 mm and an average temperature of 25°C from January to November 2016 (Figure 1).

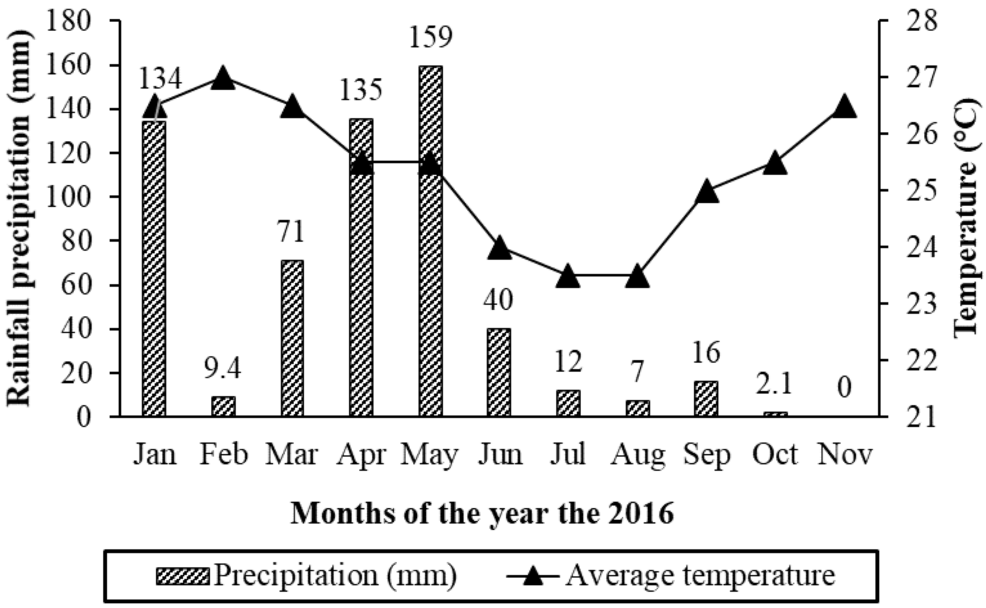

Figure 1. Weather and montly rainfall Meteorological data, during the experimental period (Meteorological station EMPAER, Instituto Nacional de Meteorologia [INMET] (2016).

Treatments and Experimental design

The experiment was established as randomized full blocks, including 34 treatments and three replicates, with 20 plants per experimental unit. The treatments consisted of 34 cactus pear (*Opuntia* spp. and *Nopalea* spp.) genotypes from the germplasm bank of the Empresa Pernambucana de Pesquisa Agropecuária (IPA), Pernambuco State, Brazil, which were donated for research to EMPAER. The genotypes are described by genera below. The common names are given followed by the identification number of the genotype and the reference paper in parentheses:

Opuntia: Moradillha (V03), Copena v1 (V04), Oxaca (V10), Orelha de Elefante Mexicana (V17), Manso San Pedro (V21), Villa Nueva (V22), Liso M. Aleman (V23), Verdura Morado (V26), Huatusco (V30), Copena V1 (F02), Oaxaca (F10), Vila Nuova (F22), Direkteur (FDIR), Raio Vigor (T03), Copena CEII (T12), Raio 3589 (T26), Pabellon (T30), Amarillo 2289 (T32), Amarilla Vach (T42), Plátamo (T57), Rosa Liso (T63), Rosa (T64), Pelona D. Objeto (T73), Rosa S.L.P. (T75), and Tuna Amarilia (T79). All the Opuntia cactus genotypes evaluated are of the species *Opuntia ficus indica*, except genotype V17, which is of the species *Opuntia stricta*.

Nopalea: Negro Michoacan (V07), Polotitlan (V09), Tamazunchale (V12), Texas (V13), Califórnia (V14), Blanco San Pedro (V19), Nopalea Uruapan (V20), Negro Michoacan (F07), and Doce (FD). All the Nopalea cactus genotypes evaluated are of the species *Nopalea cochenillifera*.

Soil characteristics and planting of the cactus genotypes

Before planting, random soil samples representing the experimental area were collected at depths of 0-20 cm to characterize the soil fertility (Table 1). Mineral fertilization was performed by applying 50 kg of P_2O_5 ha^{-1} in triple superphosphate (5 g of fertilizer per plant), 70 kg of K_2O ha^{-1} in potassium chloride to the soil (6 g of fertilizer per plant) and 50 kg of N ha^{-1} in urea. The addition of urea was divided into two applications: one at 60 days after planting with 40% N and the other at 180 days after planting with 60% N (2 g of fertilizer per plant in the 1st application and 3 g of fertilizer per plant in the 2nd application), according to the fertilization recommendations for the soil type at the experimental location (Cavalcanti, 1998).

Table 1. Chemical atributes of experimental area soil.

Sample	pH	P	K^+	Na^+	$H^+ + Al^{+3}$	Al^{+3}	Ca^{+2}	Mg^{+2}	V%	CEC	OM	SB
	$H_2O_{(1:2,5)}$	mg dm^{-3}		$cmol_c$ dm^{-3}							g kg^{-1}	
Average	6.2	86.76	200.82	0.08	1.57	0.00	0.83	0.49	58.4	3.49	9.88	1.91

P, K, Na: Extractor Mehlich 1; H + Al: Extractor Calcium Acetate 0,5 M, pH 7,0; Al, Ca, Mg: Extractor KCl 1 M; CEC: Cation exchange capacity; OM: Organic material – Walkley-Black; V%: Base saturation; SB: Sum of bases.
Data source: Authors.

The planting occurred in November 2015, and the experimental period began in January 2016 and ended in November of the same year. The plantings consisted of a cladode per hole in a vertical position, with 1.0 m between rows and 0.4 m between the plants. There was a total of 25,000 plants per hectare. When necessary, periodic weeding was performed to control the occurrence of weeds.

Evaluated variants

The genotypes were evaluated by the number of cladodes per plant (NCP), widths of the cladodes (WCs), lengths of the cladodes (LCs), diameters of the cladodes (DCs), thicknesses of the cladodes (TCs), heights of the plants (HPs), widths of the plants (WPs), dry matter (DM), green mass production (GMP), dry mass production (DMP), water-use efficiency (WUE), water accumulation (WA), and support capacity (SC). Each variable was evaluated for five plants chosen at random by plot. The correlation among the morphological and productive characteristics and the grouping analysis was also evaluated through the dissimilarity of the characteristics among the cactus pear genotypes evaluated (Ward, 1963).

To determine the NCP, a total count of cladodes per plant was performed, and the values were used to represent each cactus genotype. For the quantification of the WCs, LCs, and DCs (in cm), a graduated measuring tape with a length of 150 cm was used. To quantify the TCs, a digital caliper was used.

To measure the HPs, a tape measure was used, and the measurement was taken vertically, from the base of the plant to the highest point, and expressed in cm. A tape measure was used to quantify the WPs, which are expressed in cm, with the measurement being taken horizontally, from one point to another at the widest part of the plant.

A subsample of each treatment was collected for predrying in an oven with forced ventilation at 55°C until the material reached a constant dry weight to quantify the DM (expressed in g kg^{-1} of natural matter) according to the methodology recommended by method 934.01 (AOAC, 1990).

To determine the GMP in t ha^{-1}, cutting was performed 330 days after planting. The GMP (in t ha^{-1}) was obtained by multiplying the green mass obtained per harvested plant and the population of plants per hectare and dividing the product by "1,000".

To determine the DMP, the plants were cut 330 days after planting. Then, a subsample of each treatment was taken for predrying at 55°C in a greenhouse with forced ventilation until the material reached a constant dry weight. The level of DM (expressed in g kg^{-1} of natural matter) was quantified. The DMP (t ha^{-1}) was estimated from the GMP/plant (kg) multiplied by the population of plants/ha, and the product was divided by 1,000 to determine the result in tonnes. The level of DM was calculated from the green mass product (kg) obtained from the harvested plants converted to the total plants ha^{-1}.

The WUE (kg DM mm^{-1}) was estimated by the division of the DMP (t ha^{-1}) by the quantity of accumulated rain during the experimental period. The WA (t ha^{-1}) was estimated from the GMP (t ha^{-1}) multiplied by the water percentage of the plant, which was calculated by subtracting 100 from the DM level; after this, the result was divided by "1,000".

A simulation of the SC of one hectare of the cactus genotypes (CGs) was performed based on the confinement of sheep for a period of 90 days. We know that DMP is expressed in t ha^{-1}. A sheep with an average live weight (LW) of 25 kg consumes 3% of its LW x 60% CG in a diet with 40% DM. The formula SC = (DMP t ha^{-1})/(individual consumption x 90 days of feedlot) was used, in which SC is the support capacity (i.e., the quantity of the animals).

Statistical analyses

Multivariate analyses were performed and Ward's (1963) method was used to create homogeneous groups among the 34 cactus genotypes. The average Euclidian distance was adopted as a dissimilarity measurement to be used with standardized data and variants with relatively high levels of independence among the agronomic categories and with biological importance to animal nutrition and forage production were used. To identify the associative effects, Pearson's correlation analysis was performed among all the studied variants.

After the data were organized, a variance analysis was used to verify the variability among the agronomic characteristics of the 34 cactus genotypes evaluated.

The differences among the cactus genotypes were evaluated by the following model: $Yij = \mu + \alpha i + \beta j + eij$, in which Yij is the observed value of i–th genotype in the j–th block; μ is the genotype average; αi is the effect of the i–th genotype; i represents 1, 2, 3..., 34; βj is the effect of the j–th block; j represents 1, 2, and 3; and eij is the random error of the j–th observation in the i–th genotype.

For the characteristics for which the analysis of variance was significant, the means were compared by a Scott and Knott test (1974) at a 5% significance level. The statistical analyses were performed using R software (R Core Team, 2018) and the Statistical Analysis System (SAS, 2010).

Results and discussion

There was an effect ($p < 0.05$) on almost all the morphological variants, except the TCs, which had an average value of 1.8 mm (Table 2). Silva et al. (2010), evaluating correlations between the morphological and productive characteristics of 50 cactus pear clones, did not find an effect for cladode thickness, with an average value of 3.9 cm.

The NCP ranged from 4 to 59. The genotypes that showed the highest numbers of cladodes were California (V14), Nopalea Uruapan (V20), and Tamazunchale (V12), which may be due to these genotypes belonging to the *Nopalea* spp. The species belonging to this genera are characterized as being more demanding of edaphoclimatic characteristics compared with cactus species from the *Opuntia* genera and as presenting larger numbers of smaller cladodes.

Evaluating these results practically, it may be inferred that the cultivation of cactus genotypes that produce higher quantities of cladodes may facilitate an increase in cultivation areas, as cacti can be propagated vegetatively. In this system, plantations are filled with clones of the original plants (Amorim et al., 2015; Gebreegziabher & Tsegay, 2015).

The characteristics of the cladode dimensions (width, length and diameter) showed a significant effect ($p < 0.05$) (Table 2). For the WCs, variations from 7.6 to 21.5 cm were verified. The genotypes with smaller cladode widths were Nopalea Uruapan (V20) and California (V14), and larger cladode widths were found in the genotypes Orelha de Elefante Mexicana (V17), Rosa S.L.P. (T75), and Oaxaca (F10). The LCs varied from 15.2 to 32.1 cm, and the genotypes with smaller lengths were California (V14) and Vila Nuova (F22); those with larger lengths were Villa Nueva (V22) and Orelha de Elefante Mexicana (V17). The genotype California (V14) had a smaller cladode diameter, with an average value of 37.2 cm, and the genotype Orelha de Elefante Mexicana (V17) had a larger cladode diameter, with an average value of 77.2 cm.

There was an effect ($p < 0.05$) of the HPs, which varied from 45 to 103.3 cm. The taller genotypes were Moradilha (V03) and Villa Nueva (V22), and the shorter genotypes were Texas (V13) and Verdura Morado (V26). The WPs varied from 17.3 to 125.7 cm. The cladodes of the Rosa S.L.P. (T75) and Copena v1 (V04) genotypes were relatively narrow, while those of the Pabellon (T30) and Negro Michoacan (F07) genotypes were relatively wide.

The genotypes with cladodes that had relatively large dimensions were relatively short and narrow, probably as a function of the structure of the plant, because larger cladodes would require plants to invest in nutrient accumulation at the cladode base, increasing thickness to support growth. Plants that have a higher weight per cladode develop horizontally, and the higher fortification of the base of the primary cladodes sustains the weight of the remaining cladodes instead of the tissues being used to support vertical growth; this pattern was observed in the Orelha de Elefante Mexicana (V17) genotype.

Table 2. Average values of number of cladodes per plant (NCP), width of the cladode (WC), length of the cladode (LC), diameter of the cladode (DC), thickness of the cladode (TC), height of the plant (HP) and width of the plant (WP) of 34 cactus genotypes.

Gender	Genotype	NCP	WC (cm)	LC (cm)	DC (cm)	TC (cm)	HP (cm)	WP (cm)
Opuntia	V03	7c	15.7b	28.9a	69a	1.7a	103.3a	52b
Opuntia	V04	4c	11.9c	20.5c	50.8c	1.8a	67.3b	26.6b
Nopalea	V07	41b	13.8c	25.6b	55.6b	0.9a	83a	117.7a
Nopalea	V09	5c	12.8c	24.7b	58.2b	0.9a	63.7b	43.3b
Opuntia	V10	5c	15.5b	26b	61.8b	0.9a	61.7b	51.3b
Nopalea	V12	58a	10.2c	20.2c	47.8c	1.2a	85.3a	91.6a
Nopalea	V13	10c	9.3c	19.2d	47.7c	0.9a	45b	62.3b
Nopalea	V14	59a	9.1c	15.2d	37.2d	1.1a	78.3a	114.7a
Opuntia	V17	17c	23.9a	29.2a	77.2a	0.8a	83a	104.7a
Nopalea	V19	24c	11.3c	21c	48.1c	0.9a	66.3b	94a
Nopalea	V20	59a	7.6c	18.1d	40.4d	1.5a	86.3a	106a
Opuntia	V21	15c	14.5b	27.4a	66.3a	1.3a	91.3a	91.6a
Opuntia	V22	9c	17.9b	32.1a	77a	1.3a	95.3a	57b
Opuntia	V23	7c	17.5b	26.1b	67.2a	1.1a	87a	93.6a
Opuntia	V26	4c	15.8b	21.2c	54c	1.7a	51b	28b
Opuntia	V30	6c	14.7b	26.5b	61.2b	1.6a	78.3a	70.6b
Opuntia	F02	11c	15.9b	25b	61.7b	0.8a	81.7a	88.9a
Nopalea	F07	39b	12.4c	21.5c	50.4c	0.7a	72b	125.7a
Opuntia	F10	14c	19.7a	25.7b	68.9a	1a	71b	100a
Opuntia	F22	19c	9.8c	17d	40.8b	1.1a	57.7b	102.7a
Nopalea	FD	14c	12.2c	23.4c	55.6b	1.1a	93.3a	94a
Opuntia	FDIR	30b	9.8c	22.2c	43.2d	0.9a	61.3b	87.3a
Opuntia	T03	14c	12.6c	24.6b	57.5b	1.3a	89.7a	114.7a
Opuntia	T12	8c	16.2b	29.1a	68.6a	1.8a	94.3a	62b
Opuntia	T26	7c	13.5c	27.4a	63.8b	1.2a	81a	50.7b
Opuntia	T30	6c	13.4c	22.3c	54.7c	1a	70.7b	46.3b
Opuntia	T32	12c	15.7b	29.6a	68a	0.9a	93.3a	100.7a
Opuntia	T42	6c	14.9b	24.3b	60.1b	1.9a	79a	52.6b
Opuntia	T57	10c	13.7c	23.7c	57.4b	1.3a	77.7a	88.6a
Opuntia	T63	4c	11.2c	21.3c	50.4c	1.1a	72.3b	52b
Opuntia	T64	7c	13.6c	23.2c	56.5b	1.2a	73b	64.6b
Opuntia	T73	8c	11.9c	24.4b	57.3b	1.2a	87.3a	85a
Opuntia	T75	19c	21.5a	18.7d	37.9d	1a	73b	17.3b
Opuntia	T79	5c	15.9b	23.3c	60b	1a	63b	74.6a
	Average	17	13.8	23.8	56.8	1.8	78	76.8
	SEM[1]	0.457	0.117	0.116	0.305	0.010	0.422	0.901

Averages followed by the same letter in column do not differ of each other by Scott-Knott test, at 5% of significance; [1]SEM = standard error of the mean. Data source: Authors.

Rocha, Voltolini, and Gava (2017) studied the productivity of three types of cactus (Orelha de Elefante Mexicana, Miúda and IPA 20) and verified that at 12 months after cultivation, the Miúda genotype had a greater number of cladodes per plant. Similar results were obtained by Silva et al. (2015), who evaluated the morphological and productivity characteristics of three types of cactus (Orelha de Elefante Mexicana, Miúda, and IPA Sertânia).

The shapes and dimensions of the plants and cladodes of different genotypes belonging to the genera *Nopalea* and *Opuntia* differed. Studying how these characteristics are related may facilitate the understanding of how the plants responded under different genetic and environmental conditions. The plants with smaller cladodes may invest in vertical growth and distribute their cladodes accordingly, leading to relatively tall, narrow plants, while plants with larger cladodes may invest in horizontal growth, structuring the arrangement of biomass as needed to support this growth (Neder, Costa, Edvan, & Souto Filho, 2013).

Barbosa et al. (2018) evaluated the morphological and productivity characteristics of three cactus genotypes (IPA Sertânia, Miúda, and Orelha de Elefante Mexicana) and verified that the characteristics of the cladode influenced canopy formation. The genotype Orelha de Elefante Mexicana had a relatively large cladode diameter, width and length, but these values spread in relatively tall, narrow plants.

The height and width characteristics of plants directly influence the productivity characteristics, such as GMP and DMP. Tall plants can be grown with more intensive spacing because, as the plants grow, they do not limit the growth of other plants or make it difficult to carry out culturing treatments. The wider cactus genotypes are indicated to be grown with larger spacing to facilitate culturing treatments and harvest, because in these genotypes, the competition between plants for water, light and nutrients is greater than it is in the narrower plants (Arantes, Donato, & Silva, 2010).

The canopy structure may be defined by various characteristics, such as size, shape, number of cladodes, gender, species, and environmental variants, which may define the structure of the plant. Because plants exhibit phenotypic plasticity in response to handling and cultivation conditions, the accurate measurement of these characteristics is difficult, and plants of the same species may be structured in different ways (Lüttge, 2010; Pinheiro et al., 2014).

There was an effect ($p < 0.05$) on the DM, with the genotypes Moradillha (V03), Copena v1 (V04), and Amarilla Vach (T42) having lower levels of DM, with average values of 72.6, 76.7, and 84.3 g kg^{-1} in natural matter, respectively. In contrast, the genotypes Polotitlen (V09), Vila Nuova (F22), and Oxaca (V10), had higher levels of DM, with average values of 184.4, 179.70, and 173.1 g kg^{-1} of natural matter, respectively (Table 3).

Table 3. Average values of dry matter (DM) levels, green mass production (GMP), dry mass production (DMP), water use efficiency (WUE), water accumulation (WA) and support capacity (SC) of 34 cactus genotypes.

Gender	Genotype	DM (g kg^{-1})	GMP (t ha^{-1})	DMP (t ha^{-1})	WUE (kg MS mm^{-1})	WA (t ha^{-1})	SC (sheep ha^{-1})
Opuntia	V03	72.6c	128.8a	9.3c	15.9c	119.5a	231c
Opuntia	V04	97.7c	36.3b	3.5c	6c	32.8b	88c
Nopalea	V07	102.4b	219.6a	22.5a	38.3a	197.2a	555a
Nopalea	V09	184.4a	21.4b	3.9c	6.7c	17.5b	98c
Opuntia	V10	173.1a	22.1b	3.8c	6.5c	18.3b	95c
Nopalea	V12	121.3b	174.1a	21.1a	36a	153a	521a
Nopalea	V13	90.4c	165.1a	14.9b	25.4b	150.2a	368b
Nopalea	V14	135.3b	227.9a	30.8a	52.6a	197.1a	761a
Opuntia	V17	86.4c	189.8a	16.4b	28b	173.4a	405b
Nopalea	V19	76.7c	131.4a	10.1c	17.2c	121.3a	249c
Nopalea	V20	115.1b	153.3a	17.6b	30.1b	135.7a	436b
Opuntia	V21	101.9b	126.4a	12.9b	22b	113.6a	318b
Opuntia	V22	124.5b	107.4a	13.4b	22.8b	94a	330b
Opuntia	V23	103.1b	83.2b	8.5c	14.6c	74.7b	212c
Opuntia	V26	146.4b	45.7b	6.7c	11.4c	39b	165c
Opuntia	V30	126.2b	75.6b	9.5c	16.3c	66b	235c
Opuntia	F02	153.3a	166a	25.4b	43.3a	140.5a	628a
Nopalea	F07	103.1b	134.4a	13.9b	23.6b	120.6a	342b
Opuntia	F10	157.4a	46.2b	7.3c	12.4c	38.9b	179c
Opuntia	F22	179.7a	31.7b	5.7c	9.7c	26b	141c
Nopalea	FD	139.7b	80.8b	10.3c	17.6c	70.5b	255c
Opuntia	FDIR	127.9b	30.6b	4.3c	7.3c	26.4b	106c
Opuntia	T03	116.6b	105.8a	12.3b	21b	93.5a	305b
Opuntia	T12	86.4c	107.4a	9.3c	15.8c	98.1a	229c
Opuntia	T26	154.7a	33.4b	5.2c	8.8c	28.2b	128c
Opuntia	T30	104.1b	27.8b	2.9c	4.9c	24.9b	72c
Opuntia	T32	144.9b	153.4[a]	22.2a	37.9a	131.2a	549a
Opuntia	T42	84.3c	173.4[a]	14.6b	24.9b	158.8a	361b
Opuntia	T57	156.4a	58.6b	9.2c	15.6c	49.5b	227c
Opuntia	T63	119.8b	14.7b	1.8c	3c	13b	44c
Opuntia	T64	116.9b	15.7b	1.8c	3.1c	13.8b	45c
Opuntia	T73	170.4a	43.3b	7.4c	12.6c	35.9b	182c
Opuntia	T75	109.6b	24.7b	2.7c	4.6c	22b	67c
Opuntia	T79	162.3a	25.6b	4.2c	7.1c	21.5b	103c
	Average	124.8	97.7	9.6	16.4	74.1	237.6
	SEM[1]	0.080	1.946	0.218	0.371	1.743	5.388

Averages followed by the same letter in the column do not differ from each other by Scott-Knott test at 5% of significance; [1]SEM = standard error of the mean.
Data source: Authors.

The results obtained in the present study are in accordance with the results obtained by Santos, Lira, Farias, Dias, and Silva (2006), who evaluated genotypes belonging to the genera *Opuntia* (Gigante, Redonda, Copena v1, Copena f1, and IPA 20) and *Nopalea* spp. (Miúda) in different locations. The authors verified that the Redonda and Gigante varieties had lower levels of DM (from 8.8 to 9.3%), while the Miúda variety had a markedly higher level of DM (11.7%).

There was an effect ($p < 0.05$) on the GMP and DMP. The Rosa (T64) and Rosa Liso (T63) genotypes had lower GMP and DMP, with values of 15.7 and 1.8 t ha^{-1}, respectively, for T64, for genotype T63 showed values of 14.7 t ha^{-1}. The Rosa S.L.P. (T75), Oxaca (V10), and Polotitlan (V09) genotypes had less GMP, and the Rosa (T64), Rosa Liso (T63), and Copena v1 (V04) genotypes had the lowest DMP.

There was an effect on the WUE and WA ($p < 0.05$), and the Rosa Liso (T63) and Rosa (T64) genotypes had relatively low values of both variables, with WUE of 3 kg DM mm^{-1} and WA of 13 t ha^{-1}. The genotypes Rosa Liso (T63) and Rosa (T64) had relatively low values of WUE. The California (V14) and Copena V1 (F02) genotypes presented higher water-use efficiency and conversion to forage mass, with average values of 52.6 and 43.3 kg DM mm^{-1}, respectively.

There was an effect ($p < 0.05$) on the SC, and the genotypes that presented lower SCs were Rosa Liso (T63) and Rosa (T64). Based on the ability to feed sheep for 90 days, higher support capacities were found in the California (V14), Copena V1 (F02), Negro Michoacan (V07), Amarillo 2289 (T32), and Tamazunchale (V12) genotypes, with average values of 761, 628, 555, 549, and 521 sheep ha^{-1}, respectively. This result was due to these genotypes having relatively high DMP.

Three genotypes presented relatively high GMP and DMP: Negro Michoacan (V07), Tamazunchale (V12), and California (V14). However, these genotypes do not have higher levels of DM than the other genotypes; therefore, the high production relative to the other genotypes was due to the relatively high growth rate of the plants. More cladodes were found in the Tumazunchale (V12) and California (V14) genotypes, while the Negro Michoacan (V07) genotype presented fewer cladodes but larger dimensions (i.e., width and height of the plant), indicating that these three genotypes had high growth levels, which also explains why they had higher WUE, higher WA, and higher SC than the other genotypes.

Higher GMP and DMP were found in the California (V14), Negro Michoacan (V07), and Tamazunchale (V12) genotypes than in the other genotypes; the California (V14) genotype had average GMP and DMP values of 174 and 30.8 t ha^{-1}, respectively, the Negro Michoacan (V07) genotype had average GMP and DMP values of 219.7 and 22.5 t ha^{-1}, respectievly, and the Tamazunchale (V12) genotype had average GMP and DMP values of 174 and 21.1 t ha^{-1}, respectively. The California (V14), Negro Michoacan (V07), Orelha de Elefante Mexicana (V17), Tamazunchale (V12), and Amarilla Vach (T42) genotypes had the highest GMP. The California (V14), Negro Michoacan (V07), Amarillo 2289 (T32), and Amarilla Vach (T42) genotypes had the highest DMP.

DMP is a characteristic that is studied and highlighted when it is necessary to identify or select genotypes with high dry mass production. DMP is one of the characteristics that are most sought in the genetic improvement of cacti because it directly influences usage efficiency and leads to the optimization of resources in the cultivation of cactus genotypes with high DMP (Silva et al., 2010; Sales, Leite, Alves, Ramos, & Nascimento, 2013).

The more productive genotypes were also the ones that had higher WUE and WA values. This was due to the relatively high proportion of tissues in these genotypes, which had higher forage value due to their dry mass volume. This means that the higher the water-use efficiency and the larger the production of green mass are, the larger the capacity of the cladodes to store water. These two characteristics, WUE and WA, are interconnected, and the way they are calculated tends to show their dependence on each other.

The Rosa Liso (T64) and Polotitlan (V09) genotypes had relatively low WA values. In contrast, higher accumulations were found in the Negro Michoacan (V07), California (V14), and Orelha de Elefante Mexicana (V17) genotypes.

Water is an essential resource for animals and vegetables; in the case of vegetables, water is mainly responsible for cell expansion. When a plant undergoes hydric stress, relatively little cell and tissue growth occurs, and there is little increase in plant heights and widths. Under hydric stress conditions, plants use survival strategies and paralysis or drastically decrease their growth. Because cacti are cultivated in arid and semiarid environments, offering cacti *in natura* as feed may provide some of the water needed by the animals (Costa, Suassuna, Melo, Brito, & Mesquita, 2012).

These results demonstrate that cacti are an essential food to be used in animal feeding in arid and semiarid regions. Some of the genotypes are highlighted as being well-suited for this purpose, while others present high levels of SC due to their relatively large production of forage mass under cultivation conditions. The high forage production suggests an elevated adaptability to the cultivation environment and consequently elevated animal production per hectare (Mokoboki & Sebola, 2017).

The correlations between the morphological and productivity characteristics are shown in Table 4. The correlations among the productivity and morphological characteristics may be genetically or environmentally induced. The characteristics that did not present correlations among each other were independent of the other characteristics, because the increasing or decreasing of the values of a given characteristic did not influence those of the other characteristics (Silva et al., 2010).

Table 4. Pearson's coefficient relation among growing and yielding characteristics of 34 cactus genotypes.

	GMP	DMP	WUE	WA	NCP	LC	WC	DC	TC	SC
GMP										
DMP	0.925**									
WUE	0.925**	1.000**								
WA	0.998**	0.906**	0.906**							
NCP	0.632**	0.664**	0.664**	0.621**						
LC	-0.072	-0.110	-0.110	-0.067	-0.518					
WC	-0.073	-0.137	-0.137	-0.064	-0.416	0.513**				
DC	-0.044	-0.094	-0.094	-0.037	-0.574	0.937**	0.598**			
TC	-0.175	-0.217	-0.216	-0.168	-0.166	0.185	-0.192	0.106		
SC	0.206	0.217	0.216	0.202	0.06	0.585**	0.139	0.486*	0.429*	
WP	0.648**	0.680**	0.680**	0.637**	0.613**	-0.048	-0.189	-0.039	-0.603	-0.204

GMP: green mass production ($t\ ha^{-1}$); DMP: dry-matter production ($t\ ha^{-1}$); WUE: water use efficiency ($kg/\ DM/mm^{-1}$); WA: water accumulation ($t\ ha^{-1}$); NCP: number of cladode per plant (unity); LC: length of the cladode (cm); WC: width of the cladode (cm); DC: diameter of the cladode (cm); TC: thickness of the cladode (cm); HP: height of the plant (cm); WP: width of the plant (cm); SC: support capacity (quantity of animals); * significance at 5%; ** significance at 1%.

Data source: Authors.

There was a positive and significant correlation between the GMP and DMP (r = 0.925**). The correlation between the GMP and DMP is supported by the fact that they are both dependent variables, and as one increases the other also increases. The difference between the GMP and DMP represents the humidity.

There was a significant positive correlation between the GMP and WUE (r = 0.925**) and the GMP and WA (r = 0.998**) and a strong positive correlation between the GMP and NCP (r = 0.632**). The very strong positive correlation of GMP with WUE and WA and the strong positive correlation of GMP with NCP are related to the growth of the plants. An increase in the ability to convert water to forage mass occurs when plants have more cladodes or larger cladodes than usual. This increases the water storage capacity and nutrient accumulation and consequently increases the photosynthetic efficiency of plants due to the utilization of rain water and nutrient extraction from the soil and the ability to convert these resources into forage mass (Pinheiro et al., 2014).

The widths of the plants were positively correlated with the GMP and DMP. The horizontal growth of the plants provided vegetative expansion and an increase in the GMP, DMP, WUE, WA, and NCP due to the relatively high capacity that each individual cladode has to store water and nutrients. The older cladodes serve as a basis to sustain the plant and the new cladodes lead to the growth of the plant (Silva et al., 2015).

Silva et al. (2010) evaluated the relation among morphological and productivity characteristics of 50 cactus pear clones in rainfed conditions and found moderate values (varying from 0.560** to 0.610**) of the positive correlations between the GMP and the HP and WP.

The heights of the plants were not correlated with the productivity characteristics, indicating that this characteristic was independent of the others. The exception was the lengths and diameters of the cladodes, because these measurements directly influence the sustentation of the plant.

The results found by Barbosa et al. (2018) were similar to those obtained by this study, indicating that there is a strong correlation among the dimensions of the cladode. The authors evaluated the morphological characteristics of three cactus pear clones and verified that the lengths, widths and diameters of the cladodes were highly correlated; the thicknesses of the cladodes, however, showed a slightly negative and nonsignificant correlation.

Consistent with the results of the present research, the study by Amorim et al. (2015), which evaluated the agronomic characteristics of 24 cactus varieties of the genera *Nopalea*, verified that there was a significant positive correlation between the agronomic (GMP, DMP, and NCP) and morphological (HP, WP, DC, TC, LC, and WC) characteristics and the production of forage mass among the cactus varieties.

To evaluate the discriminatory agronomic characteristics, the GMP, DMP, WUE, WA, SC, NCP, HPs, and WPs were used. The results were expressed in a dissimilarity dendrogram (Figure 2).

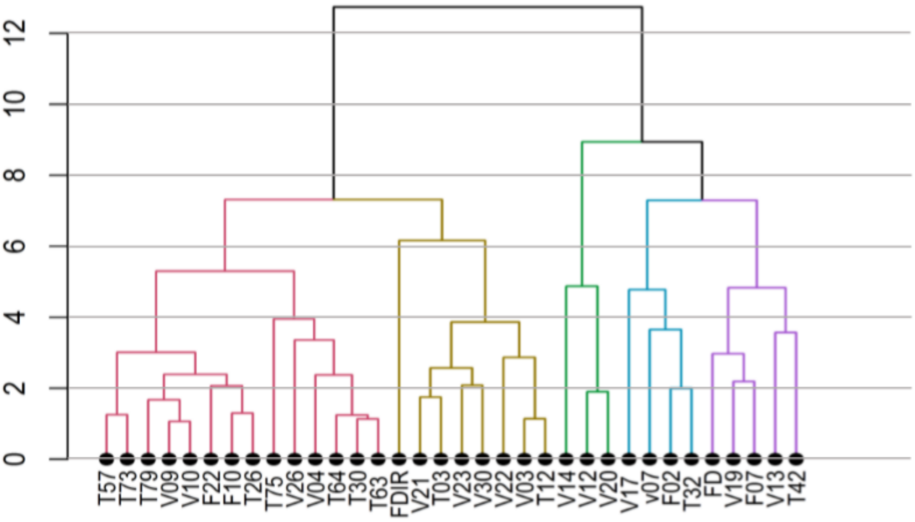

Figure 2. Dissimilarity dendogram of growing and yielding characteristics of 34 cactus genotypes.

Data source: Authors.

According to the dissimilarity dendrogram, there was variability in each group, indicating that some genotypes may stand out due to their agronomic characteristics.

In the descriptive analysis of the data, a hierarchical formation of five groups was observed, with 7% total dissimilarity. The formation of the groups took into account a Euclidian distance of 2% in relation to the genotypes (Table 5).

Group I consisted of the T42, V13, F07, V19, and FD genotypes; group II consisted of the T32, F02, V07, and V17 genotypes; group III consisted of the V20, V12, and V14 genotypes; group IV consisted of the T12, V03, V22, V30, V23, T03, V21, and FDIR genotypes; and group V consisted of the T63, T30, T64, V04, V26, T75, T26, F10, F22, V10, V09, T79, T73, and T57 genotypes.

Table 5. Descriptive statistic of growing and yielding characteristics of 34 cactus genotypes.

Groups		GMP[1]	DMP[2]	WUE[3]	WA[4]	SC[5]	NCP[6]	HP[7]	WP[8]
I	Average	185.1	23.2	39.5	161.9	572.8	58.7	83.3	104.1
	Maximum	223	30.8	52.6	197.1	761.3	59.3	86.3	114.7
	Minimum	153.3	17.6	30.1	135.7	435.8	57.7	78.3	91.7
	[9]VC (%)	20.8	29.4	29.4	19.6	29.4	1.5	5.2	11.2
II	Average	182.2	21.6	36.9	160.6	534.5	20.2	85.2	102.9
	Maximum	219.7	25.4	43.3	197.2	628.3	40.7	93.3	117.7
	Minimum	153.5	16.4	30	131.2	405.2	11	81.7	88.7
	VC (%)	16	17.5	17.4	18.9	17.5	69	6.4	11.6
III	Average	137	12.8	21.7	124.3	315.2	21.7	64.7	84.4
	Maximum	173.4	14.9	25.4	158.8	368.3	39	79	125.7
	Minimum	80.8	10.1	17.2	70.5	248.9	5.7	45	52.7
	VC (%)	26.6	18.5	18.5	27.8	18.5	64.3	19.8	34
IV	Average	95.7	9.9	17	85.7	245.8	9	93.8	72.3
	Maximum	128.8	13.4	22.8	119.5	330.1	14.7	111	114.7
	Minimum	30.7	4.3	7.3	26.4	105.7	5	78.3	37
	VC (%)	33.5	29.7	29.7	34.8	29.7	40.4	10.6	35.5
V	Average	32	4.7	8	27.2	116.5	7.1	71.8	54.9
	Maximum	58.7	9.2	15.6	49.5	226.6	19.3	87.3	88.7
	Minimum	14.7	1.8	3	13	43.6	4.3	51	17.3
	VC (%)	40	47.7	47.7	39.4	47.7	55.4	13.7	40.5

[1]GMP: green mass production (t ha^{-1}); [2]DMP: dry mass production (t ha^{-1}); [3]WUE: water use efficiency (kg MS mm^{-1}); [4]WA: water accumulation (t ha^{-1}); [5]SC: support capacity (quantity of animals); [6]NCP: number of cladode per plant (unity); [7]HP: height of the plant (cm); [8]WP: width of the plant (cm); [9]VC: variation coefficient (%).

Data source: Authors.

The grouping analysis identifies the variations that occur in each genotype. These variations are also expressed within each group, with higher homogeneity among the genotypes of a given group and higher heterogeneity among the genotypes of the other groups. From the point of view of the selection and identification of genotypes, this variation is favorable, as it indicates that the genotypes are different from each other, and provides the possibility of the comparison and selection of the genotypes that presented the desired characteristics, such as productivity and/or morphological characteristics (Ferreira et al., 2003).

As the grouping analysis shows, group I included genotypes with higher dry matter and green mass production, which was due to the genotypes in this group presenting relatively high WUE, WA, and heights.

These variables are related to the productivity characteristics; therefore, as one characteristic increases or decreases, the other dependent characteristics respond positively or negatively, depending on the type of correlation among the variables. The genotypes belonging to groups II, III, and IV had intermediate values relative to those of the genotypes of group I and the group V, which had relatively low productivity and morphological characteristics.

According to the classification, groups I and V had relatively low and high average values for the following variables, respectively: GMP, 32 and 185.1 t ha^{-1}; DMP, 4.7 and 23.2 t ha^{-1}; WUE, 8 and 39.5 kg DM mm^{-1}; WA, 27.2 and 161.9 t ha^{-1}; SC, 116.5 and 572.8 animals ha^{-1}; and NCP, 7 and 58.7 per plant.

The morphological characteristics, such as the heights and widths of the plants, were highly correlated with the productivity characteristics; as a plant increases its yield, it needs to expand its tissues by increasing the cladode dimensions and number, which also influences the height or width of the plant. Therefore, these morphological and productivity characteristics are interconnected, although cactus cultivation produces forage mass. Beyond the factors already described, the forage mass also depends on the edaphoclimatic characteristics and the density of the cultivation. All of these characteristics acting together (i.e., the environmental effect) with the genetic characteristics (i.e., the genetic effect) of the species will determine the response of the cactus to cultivation in distinct situations (Oelofse, Labuschagne, & Potgieter, 2006; Pinheiro et al., 2014).

Relatively short and tall plants were found in the genotypes belonging to groups II and III, with values from 64.7 and 85.2 cm, respectively. For the WPs, group V presented a relatively low value (54.9 cm), and group I presented a relatively high value (104.1 cm). The NCP presented relatively low and high variation for groups I and II, respectively, with a CV of 1.5% for group I and a CV of 69% for group II.

Conclusion

The genotypes with markedly different values were Negro Michoacan (V07), Tamazunchale (V12), California (V14), Orelha de Elefante Mexicana (V17), and Amarillo 2289 (T32). These genotypes presented greater forage yield, water accumulation, water-use efficiency and support capacity.

Acknowledgements

The authors express gratitude by the support of the Grupo de Estudos em Forragicultura (GEF), as well as the contribution of the Empresa Paraibana de Pesquisa, Extensão Rural e Regularização Fundiária (EMPAER), Instituto Agronômico de Pernambuco (IPA), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) by the financial support.

References

Association of Official Analytical Chemists [AOAC]. (1990). *Official methods of analysis*. (15th ed.). Washington, D.C.: AOAC.

Amorim, P. L., Martuscello, J. A., Araújo Filho, M. J. T., Cunha, D. N. F. V., & Jank, L. (2015). Morphological and productive characterization of forage cactus varieties. *Revista Caatinga*, *28*(3), 230-238. DOI: 10.1590/1983-21252015v28n326rc

Arantes, A. M., Donato, S. L. R., & Silva, S. O. (2010) Relação entre características morfológicas e componentes de produção em plátamos. *Pesquisa Agropecuária Brasileira*, *45*(2), 224-227.

Barbosa, M. L., Silva, T. G. F., Zolnier, S., Silva, S. M. S., Araújo Junior, G. N., & Jardim, A. M. R. F. (2018). The influence of cladode morphology on the canopy formation of forage cactus plants. *Revista Ceres*, *64*(5), 465-475. DOI: 10.1590/1983-21252018v31n121rc

Cavalcanti, F. J. A. (1998). *Recomendações de adubação para o Estado de Pernambuco – 2ª aproximação* (2a. ed.). Recife, PE: Instituto Agronômico de Pernambuco.

Costa, F. S., Suassuna, J. F., Melo, A. S., Brito, M. E. B., & Mesquita, E. F. (2012). Crescimento, produtividade e eficiência no uso da água em bananeira irrigada no semiárido paraibano. *Revista Caatinga*, *25*(4), 26-33.

Dubeux Júnior, J. C., Santos, M. V. F., Cavalcante, M., & Santos, D. C. (2013). Potencial da palma forrageira na América do Sul. *Cactusnet Newsletter*, *13*(esp.), 29-40.

Ferreira, C. A., Ferreira, R. L. C., Santos, D. C., Santos, M. V. F., Silva, A. J. A., Lira, M. A., & Molica, S. G. (2003) Utilização de técnicas multivariadas na avaliação da divergência genética entre clones de palma forrageira (*Opuntia ficus-indica* Mill.). *Revista Brasileira de Zootecnia*, *32*(6), 1560-1568. DOI: 10.1590/S1516-35982003000700004

Gebreegziabher, Z., & Tsegay, B. A. (2015). Efficacy of cactus pear (*Opuntia ficus-indica*) varieties as a source of food and feed in endamehoni district, Northern Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development*, *15*(5), 10406-10427.

Instituto Nacional de Meteorologia [INMET]. (2016). *Dados meteorológicos*. Retrieved on Jan. 6, 2017 from http://www.inmet.gov.br/portal/index.php?r=clima/normaisclimatologicas

Lüttge, U. (2010). Ability of crassulacean acid metabolism plants to overcome interacting stresses in tropical environments. *AoB Plants*, *201*, 1-15. DOI: 10.1093/aobpla/plq005

Mokoboki, K., & Sebola, N. (2017). Chemical composition and feed intake of Opuntia cladodes varieties offered to goats. *Journal of Animal & Plant Science*, *32*(1), 5096-5103.

Neder, D. G., Costa, F. R., Edvan, R. L., & Souto Filho, L. T. (2013). Correlations and path analysis of morphological and yield traits of cactus pear accessions. *Crop Breeding and Applied Biotechnology*, *13*(3), 203-207. DOI: 10.1590/S1984-70332013000300009

Oelofse, R. M., Labuschagne, M. T., & Potgieter, J. P. (2006). Plant and fruit characteristics of cactus pear (*Opuntia* spp.) cultivars in South Africa. *Journal of the Science of Food and Agriculture*, *86*(12), 1921-1925. DOI: 10.1002 / jsfa.2564

Pinheiro, K. M., Silva, T. G. F., Carvalho, H. F. S., Santos, J. E. O., Morais, J. E. F., Zolnier, S., & Santos, D. C. (2014). Correlações do índice de área do cladódio com características morfogênicas e produtivas da palma forrageira. *Pesquisa Agropecuária Brasileira*, *49*(12), 939-947. DOI: 10.1590/S0100-204X2014001200004

R Core Team (2018). *R: A language and environment for statistical computing*. Vienna, AU: R Foundation for Statistical Computing. Retrieved on Jan. 10, 2018 from https://www.R-project.org/

Rocha, R. S., Voltolini, T. V., & Gava, C. A. T. (2017). Características produtivas e estruturais de genótipos de palma forrageira irrigada em diferentes intervalos de corte. *Archivos de Zootecnia*, *66*(255), 363-371. DOI: 10.21071/az.v66i255.2512

Sales, A. T., Leite, M. L. M. V., Alves, A. Q., Ramos, J. P. F., & Nascimento, J. P. (2013). Crescimento vegetativo de palma forrageira em diferentes densidades de plantio no Curimataú Paraibano. *Tecnologia & Ciência Agropecuária*, *7*(1), 19-24.

Santos, D. C., Lira, M. D. A., Farias, I., Dias, F. M., & Silva, F. D. (2006). Assessment of forage cactus pear varieties for semi-arid conditions of Northeast, Brazil. *Acta Horticulturae*, *728*, 177-181. DOI: 10.17660/ActaHortic.2006.728.24

Scott, A. J., & Knott, M. (1974). A cluster analysis method for grouping means in the analysis of variance. *Biometrics*, *30*(3), 507-512.

Silva, N. G. M., Lira, M. A., Santos, M. V. F., Dubeux Júnior, J. C. B., Mello, A. C. L., & Silva, M. C. (2010). Relação entre características morfológicas e produtivas de clones de palma-forrageira. *Revista Brasileira de Zootecnia*, *39*(11), 2389-2397. DOI: 10.1590/S1516-35982010001100011

Silva, T. G. F., Primo, J. T. A., Morais, J. E. F., Diniz, W. J. S., Souza, C. A. A., & Silva, M. C. (2015). Crescimento e produtividade de clones de palma forrageira no semiárido e relações com variáveis meteorológicas. *Revista Caatinga*, *28*(2), 10-18.

Statistical Analysis System [SAS]. (2010). *User's guide: Statistics, Version 9.1*. Cary, NC: SAS Institute Inc.

Ward, J. H. (1963). Hierarquical grouping to optimize an objective function. *Journal of the American Statistical Association*, *58*(301), 236-244. DOI: 10.1080 / 01621459.1963.10500845