Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252019v32n326rc

FORAGE PRODUCTION AND PRESERVATION OF SPECIES BY ENRICHING CAATINGA WITH GRASSES AND THINNING AREAS INTO STRIPS[1]

JEFTE ARNON DE ALMEIDA CONRADO[2]*, ANA CLARA RODRIGUES CAVALCANTE[3], RAFAEL GONÇALVES TONUCCI[3], MARIA SOCORRO DE SOUZA CARNEIRO[2], MAGNO JOSÉ DUARTE CÂNDIDO[2]

ABSTRACT - The objective of this study was to evaluate the thinning into strips and the enrichment with exotic grasses in a Caatinga area in order to maintain and increase the biodiversity of native vegetable species and forage production. Two studies were carried out—one in an area of Caatinga thinned into strips and one in an unmanipulated Caatinga area—during the rainy and rainy-dry season transition periods in 2016. The production of herbaceous biomass was evaluated, and the diversity and equability of the two areas were assessed through Shannon-Weaver (H’) and Pielou (J’) indexes. The establishment of massai and buffel grasses at the center and edges of the area thinned into strips was also evaluated. During the rainy season, the production of herbaceous biomass in the area thinned into strips and the unmanipulated area was 1,228 kg ha^{-1} and 833.33 kg ha^{-1}, while during the rainy-dry transition period, it was 1,973 kg ha^{-1} and 836.00 kg ha^{-1}, respectively. The indexes remained similar: H’ (1.86) and J’ (0.74) for the area thinned into strips, and H’ (1.77) and J’ (0.85) for the unmanipulated area. The massai grass presented better establishment and development than that by the buffel grass in the center and edges of the area thinned into strips. Thus, thinning into strips increases the biodiversity of an area, and this combined with enrichment through grasses increases the biomass of herbaceous forage.

Keywords: Botanical composition. Massai grass. Buffel grass. Shading. Full sun exposure.

PRODUÇÃO DE FORRAGEM E PRESERVAÇÃO DE ESPÉCIES DA CAATINGA ENRIQUECIDA COM GRAMÍNEAS E RALEADA EM FAIXAS

RESUMO – O objetivo deste estudo foi avaliar o raleamento em faixas e o enriquecimento com gramíneas exóticas em uma área de Caatinga, de modo que fosse possível manter e ou aumentar a biodiversidade de espécies vegetais nativas, e intensificar a produção de biomassa de forragem. Dois estudos foram conduzidos em uma área de Caatinga raleada em faixas e em outra área de Caatinga não manipulada no período chuvoso e transição águas-seca no ano de 2016. Avaliou-se a produção de biomassa herbácea e, a diversidade e equabilidade pelos índices de Shannon-Weaver (H’) e Pielou (J’) das áreas raleada em faixas e não manipulada. Foi ainda avaliado o estabelecimento dos capins massai e búffel ao centro e na lateral da área raleada em faixa. Na época das águas a produção de biomassa herbácea na área raleada em faixas e não manipulada foi de 1.228 kg ha^{-1} e 833,33 kg ha^{-1}, enquanto o período de transição águas-seca 1.973 kg ha^{-1} contra 836,00 kg ha^{-1}, respectivamente. Os índices permaneceram próximos H’ (1,86) e J’ (0,74), para a área raleada e H’ (1,77) e J’ (0,85) para a não manipulada. O capim-massai apresentou melhor estabelecimento e desenvolvimento que o capim-búffel no centro e na lateral da área raleada em faixas. O raleamento em faixas aumenta a biodiversidade da área contribuindo juntamente com o enriquecimento no incremento de biomassa de forragem herbácea.

Palavras-chave: Composição botânica. Capim-massai. Capim-búffel. Sombreamento. Pleno sol.

*Corresponding author
[1]Received for publication in 08/10/2018; accepted in 07/10/2019.
Paper extracted from the master dissertation of the first author.
[2]Departmente of Animal Science, Universidade Federal do Ceará, Fortaleza, CE, Brazil; jefte_arnon@hotmail.com – ORCID: 0000-0002-9470-0416, msocorro@ufc.br – ORCID: 0000-0002-6887-7111, magno@ufc.br – ORCID: 0000-0003-3573-6053.
[3]Center of Forage and Grassland, Empresa Brasileira de Pesquisa Agropecuária Caprinos e Ovinos, Sobral, CE, Brazil; ana.clara@embrapa.br – ORCID: 0000-0002-9685-569X, rafael.tonucci@embrapa.br – ORCID: 0000-0002-7511-4956.

INTRODUCTION

The Caatinga biome is the main dry forest in Brazil, covering approximately 844,453 km² and representing 11% of the entire Brazilian national territory; it is also one of the most inhabited semiarid regions in the world (ALVES; ARAÚJO; NASCIMENTO, 2009). Agriculture is among the most exploited activities the region. However, due to its short rainy season (3 to 4 months) (GUERREIRO et al., 2013), shallow soils, and different levels of fertility, this biome is very prone to desertification (AQUINO et al. 2017).

Because it is more resilient than agriculture, livestock production is the main activity in this region; it also has high social and economic impact because it offers animal protein and leather as source of subsistence and income (CORREIA et al., 2013). However, wood extraction driven by itinerant agriculture has led to an increase in degradation indexes and the disappearance of native Caatinga species (SANTOS et al., 2010).

Thinning, developed in the 1980s by Embrapa, is a technique that aims to manipulate in a targeted way the woody stratum, maintaining a soil cover of 20% for areas used for agriculture and 40% for the those used for livestock (SCHACHT; MALECHEK, 1989). Araújo Filho et al. (2002) evaluated a thinned Caatinga area and observed that forage production increased by 76% and the area maintained its botanical composition. Among the biomes where thinning has been initiated (savanna, forest and strips), the savanna model has been the most exploited; but limitations have been observed, such as a high dependence on labor, low establishment of grasses in consortium with the woody stratum, and significant loss of vigor of the native species (CAMPANHA et al., 2011).

Thinning the area into strips appears to solve the problems above, considering that forest strips intersect with deforested areas, guaranteeing a vegetation cover of around 40% (ARAÚJO FILHO et al., 2002), and that it is possible to increase the herbaceous biomass production between the strips. Although this theoretical model exists, there are no studies that attest to the efficiency or benefits of this manipulation model, since part of the area must be deforested (FILHO; SILVA; CÉZAR, 2013). According to Seddaiu et al. (2013), the few studies aiming to evaluate interactions between woody and herbaceous strata have been limited to subtropical environments, and almost none have investigated semiarid regions.

Besides maintaining vegetation biodiversity, thinning into strips allows for the intensification of biomass production in the space between the strips, and for the annual herbaceous native pasture to become enriched with perennial grasses. The buffel grass is the most widely used forage species in these regions because it presents adaptive characteristics for dry lands. However, limitations have been reported, such as low seed quality and germination rate and the capacity of the native area for sustaining invasive species (MARSHALL; LEWIS; OSTENDORF., 2012). Recently another grass, the massai grass (*Megathyrsus maximus* 'Massai' syn. *Panicum maximum* 'Massai'), originally released for wetlands, has shown to be very promising and efficient for use in semiarid environments (CAVALCANTE et al. 2014).

Thus, the objective of this study was to quantify the impact of the thinning into strips method on the botanical composition of a Caatinga and to estimate the method's forage production potential when enriched with tropical forage grasses.

MATERIAL AND METHODS

Two trials were carried out at Embrapa (Goats and Sheep unit) in Sobral-CE, Brazil, from January to June of 2016, the first one in a Caatinga area thinned into strips (03° 44′ 35.71" S and 040° 21' 56.09" W) and an unmanipulated Caatinga area (Control) (03° 44′ 35.73" S and 040° 21' 56.06" W) and the second trial only in the area thinned into strips. Both areas were at an altitude of 83 m. The area was thinned into strips (East/West) in 2015, perpendicular to the slope (North/South) of the area. Each area was approximately 3 ha.

The climate of the experimental area is semiarid of BShw' type, according to the Köppen classification (CARVALHO et al., 2004), with a rainy season from January to June. The average annual temperature is 28 °C and the average precipitation is 759 mm per year. There were patches of Typical Luvisol Chromic Ortic (more prevalent) and Typical Luvisol Hypochromic Ortic (less predominant), with a clay texture in the areas (AGUIAR et al., 2006).

In the Caatinga area thinned into strips, intact native vegetation (15 × 250 m) and deforested area (20 × 250 m) intersected, maintaining 35-40% woody cover in the whole area (deforested and intact), as recommendation for savanna thinning (ARAÚJO FILHO et al., 2002).

A soil sampling was performed (0-10 cm deep) for the chemical composition analysis, with the following results: pH (5.4); O.M. (20.3 g kg^{-1}); P (9.0 mg dm^{-3}); K (162.0 mg dm^{-3}); Ca (36.0 mmol$_c$ dm^{-3}); Mg (43.0 mmol$_c$ dm^{-3}); H+Al (23.1 mmol$_c$ dm^{-3}); SB (85.0 mmol$_c$ dm^{-3}); CEC (108.0 mmol$_c$ dm^{-3}); V (78.0%). Due to the fertility of the soil, the foundation fertilization practice for the implantation of the second trial was not necessary.

The climatic data of temperature (maximum, average and minimum), average dew point, and precipitation (accumulated weekly) of the experimental site are presented in Figure 1. Precipitation data were collected from a pluviometer installed in the area, while the others were collected from a site in the INMET station in Sobral.

TRIAL 01:

The phytosociological survey, botanical composition and structural variables evaluation of the herbaceous and woody strata in the entire thinned -into-strips and control areas were all performed in two distinct periods: rainy season (Jan 07, 2016 to Mar 31, 2016) and rainy-dry transition (Apr. 01, 2016 to Jun. 30, 2016).

The herbaceous stratum considered all the species in a 0.250 m² frame up to 1 m high and the woody stratum, shrubs and trees whose height was greater than 1.0 m and had a diameter at the ground level (DGL) above 3 cm (RODAL; SAMPAIO; FIGUEIREDO, 2013).

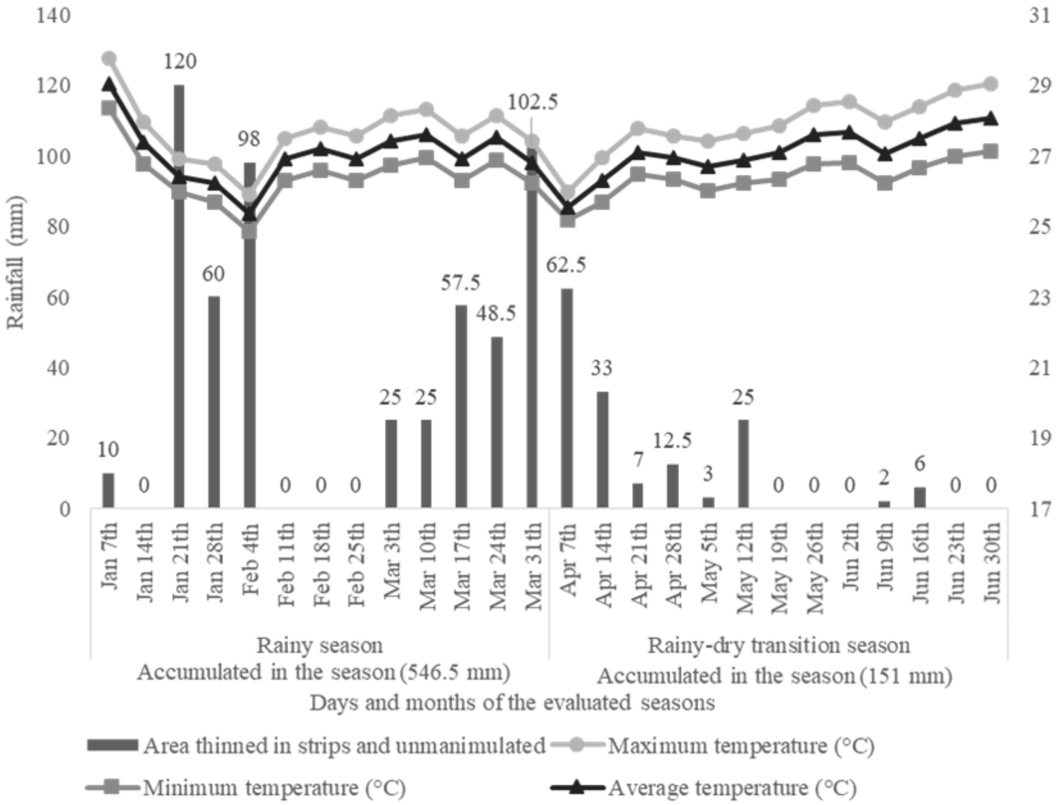


Figure 1. Maximum, average, and minimum temperature (°C); average dew point (°C); and precipitation (mm) accumulated during the week in the evaluated seasons.

The design adopted included completely randomized blocks in a split-plots arrangement, with repeated measures in time (where the plots were the thinned-into-strips or control areas and the subplots were in the rainy and rainy-dry transition seasons), with four replications, with each trip being considered a replication.

The evaluated phytosociological variables were density, cover, and frequency of herbaceous and woody species. Diversity indexes such as the Shannon-Weaver (H') and Pielou (J') were calculated using the equations described below. The herbaceous stratum was evaluated by the visual method (applying a percentage value), the total soil coverage (%), coverage by monocotyledons (%), herbaceous dicotyledons (%) and litter (%), and the absolute frequency (%).

$$\mathrm{A.F.}\,(\%) = \frac{N.\mathrm{S.S.}}{\mathrm{T.N.S.}} \,\mathrm{x}\, 100$$

, where A.F. is the absolute frequency, N.S.S. is the number of sample units in which the species occurred, and T.N.S is the total number of sample units.

$$\mathrm{S.D.}\left(\frac{\text{indivídual}}{\text{ha}}\right) = \frac{10.000}{\mathrm{A} \times \mathrm{N}}$$

, where S.D corresponds to the specific density, A is the sampled area, and N is the total number of individuals sampled.

$$\mathrm{R.D.}\,(\%) = \frac{\mathrm{S.D.}}{\mathrm{T.D.}}$$

, where R.D. is the relative density, S.D. is the specific density, and T.D. is the total density.

$$\mathrm{T.D.}\left(\frac{\text{plants}}{\text{ha}}\right) = \sum S.\mathrm{D.}$$

, where T.D is the total density and S.D the specific density.

$$\mathrm{H}' = -\sum_{\mathrm{i}=1}^{\mathrm{s}} \frac{\mathrm{ni}}{\mathrm{N}} \,\mathrm{x}\, \ln \frac{\mathrm{ni}}{\mathrm{N}}$$

, where H' is the diversity index of Shannon-Weaver (H'), ni is the number of individuals sampled for the i_{th} species, N is the total number of individuals sampled, and ln is the Napierian logarithm.

$$J' = \frac{H'}{\ln(S)}$$

, where J' corresponds to the equability index of Pielou, H' is the diversity index of Shannon-Weaver, ln is the Napierian logarithm, and S is the total number of species sampled.

For the quantification of the botanical composition of the native vegetation, vegetal species present in the experimental area were collected, herbalized, and identified according to the system protocol of APG III (APG, 2009). The species were grouped in forages (those recognized by animals) and non-forages (invasive, toxic, and low nutritive plants). The plants identified in this study received a number according to the work collection of the research project and were registered in the herbarium of Embrapa Goats and Sheep.

Structural variables of native pastures, especially the herbaceous stratum, were quantified. The total forage biomass (kg ha^{-1}) and litter biomass (kg ha^{-1}) in a frame of 0.25 × 1.0 m were collected using the following variables: height (cm), using a retractable graduated rod adapted from the type s*ward stick* (Barthram, 1984) along the pasture; leaf area index (LAI) and interception of photosynthetically active radiation (IPAR, %), using in agriculture analyzer PAR-LAI model Accupar LP -80, with the readings taken below and above the herbaceous canopy. All variables were measured in a minimum number of 24 points in the Caatinga area thinned into strips and in the control.

The variables for the woody stratum are as follows: diameter at the base (DB) at 0.30 m from the ground; diameter at breast height (DBH) at 1.3 m from ground; and height (m) of the trees present in the plots of 15 × 30 m (450 m²), collected using a Finn caliper.

TRIAL 2:

The establishment criteria for perennial forage plants in area thinned into strips was evaluated. Two grasses were planted: massai grass (*Megathyrsus maximus* 'Massai' syn. *Panicum maximum* 'Massai') and buffel grass (*Pennisetum ciliare* 'Áridus' syn. *Cenchrus ciliaris* 'Áridus'), in shaded conditions and in full sun.

The shaded plots of buffel and massai grasses were on the right and left sides of the area thinned into strips, while the full sun treatment plots were in the center of the area thinned into strips; the latter was considered parallel to the range of the shaded condition.

The minimum sowing rate (kg seeds ha^{-1}) was calculated based on the cultural value, which for massai and buffel grasses were 21 and 1.2, respectively.

The two grasses were cultivated in 35-cm-spaced rows in plots of 3 × 3 m (9 m²), at a depth of 2 cm for massai and 3 cm for buffel grass, when the soil was wet—indicating the beginning of the rainy season. The seedlings were fertilized with 67 g of nitrogen, equivalent to 300 kg ha^{-1}, with urea as the nitrogen source, at 16 days post germination in the low technological level condition (SFCST, 1999). To evaluate the establishment criteria, physiological and structural variables of massai grass and buffel grass were quantified.

The design was completely randomized, with four replications, where the experimental units were the plots in full sun or shaded.

Physiological variables were collected 60 days after germination (LOPES et al., 2013). Two devices were used: infrared gas exchange analyzer (IRGA) model LC-Pro-SD and chlorophyllometer model SPAD-502. Measurements were taken on the last newly expanded leaf of the plants in the intermediate growing position within the plot. The day before the measurements, a daily round was done every 2 h (06:00, 08:00, 10:00, 12:00, 14:00, and 16:00) to determine the maximum photosynthetic rate; 10:00 was used for the shading treatment and 08:00 for the full sun exposure treatment. The variables collected were leaf transpiration rate (E, mmol $m^{-2} s^{-1}$), photosynthetic rate (A, µmol $m^{-2} s^{-1}$), stomatal conductance rate (gs, mol $m^{-2} s^{-1}$), internal concentration of carbon dioxide (Ci, ppm), internal leaf temperature (T_{Leaf}, °C), carboxylation rate (A/Ci), intrinsic water use efficiency (A/E), and chlorophyll relative index (SPAD units).

The structural parameters were evaluated at 80 days post germination, at which point the establishment cut was made and the following variables were quantified: total biomass (kg of dry matter per hectare) and its fractions (leaf blade, stem and dead material kg ha^{-1}) cut at ground level, and population density of tillers (PDT, plants m^{-2}) by using a frame of 0.5 × 0.5 m (0.25 m²); height (cm); LAI and IPAR (%) by using the analyzer equipment PAR-LAI in the agriculture model Accupar LP-80, with the readings taken below and above the canopy of the massai and buffel grasses; and number of live leaves per tiller (NLL). Rainfall use efficiency (RUE) was also quantified and expressed in kg ha^{-1} mm^{-1}, according to the equation of Turner (2004):

$$RUE = \frac{TFB}{AR}$$

, where TFB is the total forage biomass and AR the accumulated rainfall.

A descriptive statistic was used for the phytosociological and botanical composition parameters. The other variables were submitted to a normality test by Shapiro-Wilk's test (P<0.05) and homoscedasticity by Bartlett's test (P<0.05). The structural and physiological characteristics data were submitted for analysis of variance (ANOVA). Interactions were designated as significant by the F test (P<0.05) and the means were compared by Tukey's test (P<0.05).

As a tool for statistical analysis, the MIXED procedure of the software SAS (SAS Institute, version 9.3) was adopted, treating the area manipulated in strips with the grass species as fixed effects.

RESULTS AND DISCUSSION

TRIAL 01:

The thinning of the Caatinga into strips promoted the emergence of herbaceous species during both seasons evaluated compared more than the control area did (Table 1). The thinning of the area into strips may contribute to increasing the carrying capacity of that area. According to Aguiar et al. (2013), an increase in plant biodiversity may contribute to the production of herbaceous biomass, favoring animal production. Smith, Gros and Robertson (2008) observed that heterogeneous environments are more resilient than homogeneous environments due to the fact that the species that grow there become more efficient at using natural resources, mainly nutrients and groundwater.

In the woody stratum, the area thinned into strips presented more botanical families (7) than that in the control area (5) (Table 1). Of these families, only Malvaceae (with the species *Pseudobombax marginatum* Hill.Juss. & Cambess.Robyns) and Rhamnaceae (with the species *Ziziphus joazeiro* Mart.) appeared exclusively in the area thinned into strips. These species are protected by law (ALBUQUERQUE et al., 2007) because they disappear with the succession process. One of the principles of thinning is to preserve the native species of the region protected by law, and our results suggest that this technique, besides boosting the production of biomass, also succeeds in protecting such native species.

The woody stratum species in the area thinned into strips that presented the highest A.F. (100%) and density (121 individuals ha^{-1}) was *Cordia oncocalyx* Allemão (Boraginaceae). Mendes et al. (2013a), evaluating *C. oncocalyx*, observed that the species was more resistant to drought in the thinned area than the unmanipulated one. This may be associated with the fact that trees in agroforestry systems keep their leaves for a longer period than that by plants in unmanipulated systems. According to Mendes et al. (2013b), this species has a root system that favors the supply of water to native and/ or cultivated herbaceous species, mainly by flowing through the trunk. This is associated with the increase in the photosynthetic rate of this species, which in thinned areas is superior to that in unmanipulated areas.

The thinning of the Caatinga into strips favored the appearance of functional species of forages during the two evaluated seasons (Table 1), with an increase of 21.2% during the rainy season and 73.2% during the rainy-dry transition season. This increase is mainly due to the emergence of species such as *Jacquemontia gracillima* Choisy. Hallierf, *Centrosema pubescens* Benth, *Mimosa caesalpiniaefolia* Benth, and *Phaseolus patyroides* Linnaeus, all of which appeared in the area thinned into strips. This response is an effect of the reduced competition for light and nutrients, which in turn is a result of the reduced tree density. According to Silva et al. (2017), an ideal woody cover in semiarid regions generates several benefits for the production system, such as reduced evapotranspiration of the species and increased energy flow of the system; both of these also increase the number of forage species and consequently biomass production. Aguiar et al. (2013) studied a thinned Caatinga area and observed an increment in herbaceous forage biomass production compared to the unmanipulated Caatinga area, and a production similar to that of a fully deforested area.

Some herbaceous species have appeared exclusively in the area thinned into strips. Among them, *Jacquemontia gracillima* Choisy. Hallierf stood out, with 12.5% A.F. during the rainy season and 25% during the rainy-dry transition season. According to Linhares et al. (2010), this species can produce 32 tons of green biomass ha^{-1} $year^{-1}$ and presents satisfactory nutritional levels in its protein, calcium and phosphorus compositions; this is reasonable considering that it adapted to the semiarid conditions. Another species that deserves to be highlighted is *Arachis dardani* Krapov. & Wing. Coutu. Gregory, which presented higher A.F. values in the Caatinga area thinned into strips during both rainy (51.40%) and rainy-dry transition (5.60%) seasons compared to those of the control area, which had values of 40.10 and 4.20%, respectively (Table 1). The appearance of the spontaneous form of that species in the area thinned into strips is important, since in Brazil it is used as a way to improve the nutritive quality of pastures (LUDWING et al., 2010).

Stylosanthes spp. in the legume family were observed in the area thinned into strips during the two evaluated seasons, but they were only observed in the control area during the rainy season. Forage legumes contribute to the recovery of the area since they have the capacity to fix nitrogen in the soil, favoring the sustainability of the production system (BARCELOS et al., 2008).

Table 1. Botanical identification (family and scientific name), absolute frequency (A.F.%) of species of the herbaceous stratum during two seasons (rainy and rainy-dry transition) and absolute frequency (A.F.%), specific density (S.D., individuals ha^{-1}) and total density (Total Dens. individuals ha^{-1}) of woody stratum species during the rainy season in the Caatinga area thinned into strips (Thinn.) and control area (Contr.) in Sobral/CE in 2016.

Family	N°	Scientific name	A.F (%)			
			Rainy		Rainy-dry trans.	
			Thinn.	Contr.	Thinn.	Contr.
Herbaceous stratum						
Amaranthaceae	01	*Alternanthera tenella* Colla Linnaeus	0.00	0.00	6.90	15.30
Amaranthaceae	02	*Froelichia lanata* Moq.	0.00	5.40	0.00	0.00
Asteraceae	03	*Bidens pilosa* var. Minor Blume Sherff.	0.00	0.00	18.10	0.00
Commelinaceae	04ǂ	*Commelina nudiflora* Linnaeus	4.20	37.50	5.60	13.70
Convolvulaceae	05	*Ipomoea asarifolia* Desr. Roem. & Schult	0.00	0.00	5.60	0.00
Convolvulaceae	06ǂ	*Jacquemontia gracillima* Choisy. Hallierf.	12.50	0.00	25.00	0.00
Combretaceae	07ǂ	*Combretum leprosum* Martius	0.00	2.80	0.00	1.40
Euphorbiaceae	08	*Croton sonderianus* Muell.Arg	25.00	5.60	22.20	25.00
Euphorbiaceae	09	*Cnidoscolus urens* Link. Arthur	27.80	0.00	0.00	0.00
Equisetaceae	10	*Equisetum hyemale* Lehm.	1.40	6.90	0.00	0.00
Fabaceae	11ǂ	*Arachis dardani* Krapov. & Wing. Coutu. Gregory	51.40	40.10	5.60	4.20
Fabaceae	12ǂ	*Canavalia brasiliensis* Mart. Benth.	15.30	15.30	15.30	0.00
Fabaceae	13ǂ	*Centrosema pubescens* Benth.	15.30	0.00	0.00	0.00
Fabaceae	14ǂ	*Leucaena leucocephala* Lam. Wit.	4.20	1.40	0.00	0.00
Fabaceae	15ǂ	*Mimosa caesalpiniaefolia* Benth.	4.20	0.00	15.30	0.00
Fabaceae	16ǂ	*Mimosa modesta* Martius.	38.90	25.00	33.30	29.20
Fabaceae	17ǂ	*Mimosa tenuiflora*. Wild. Poir.	6.90	0.00	0.00	15.30
Fabaceae	18ǂ	*Marsypianthes chamaedrys* Vahl. Kuntze.	0.00	18.10	4.20	18.10
Fabaceae	19ǂ	*Phaseolus patyroides* Linnaeus	11.10	0.00	0.00	0.00
Fabaceae	20	*Senna obtusifolia* Link. Irwin & Barneby	19.40	22.10	19.40	4.20
Fabaceae	21ǂ	*Stylosanthes* spp.	23.60	18.10	30.60	0.00
Fabaceae	22	*Senna trachypus* Benth. Irwin & Barneby	0.00	16.70	0.00	0.00
Hypoxidaceae	23	*Hypoxis decumbens* Lehm	26.40	29.20	37.50	0.00
Lamiaceae	24	*Hyptis suaveolens* Link. Poit	81.90	98.60	93.10	97.20
Malvaceae	25	*Herissantia tiubae* Schum. Brizicky	0.00	0.00	0.00	5.60
Malvaceae	26	*Wissadula spicata* Kunth. C.Presl	33.30	38.90	1.40	31.30
Malvaceae	27	*Waltheria americana* Linnaeus.	1.40	0.00	20.80	1.40
Oxalidaceae	28	*Oxalis divaricata* Mart. Zucc.	2.80	0.00	0.00	0.00
Oxalidaceae	29	*Oxalis glaucescens* Norl.	9.70	260	0.00	0.00

Identification number given to the species according to the alphabetical order of the family (N°)
ǂ *Forage species.*

Table 1 continued.

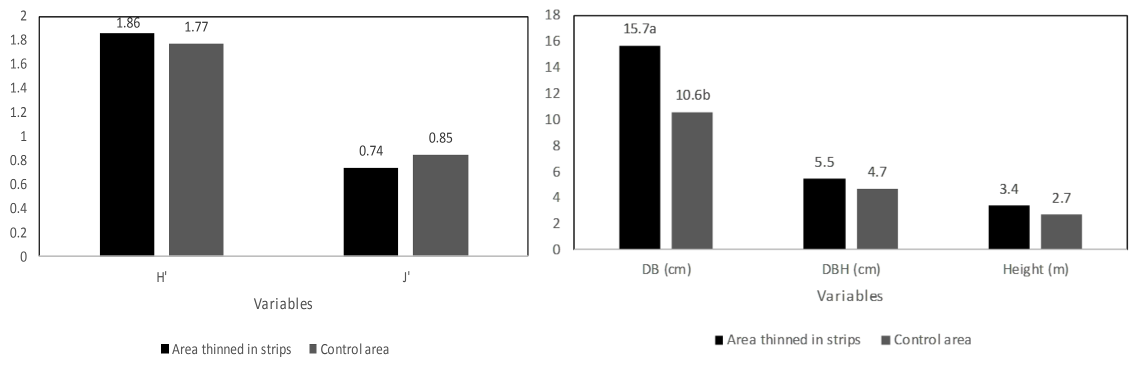
Family	N°	Scientific name	A.F (%)			
			Rainy		Rainy-dry trans.	
			Thinn.	Contr.	Thinn.	Contr.
Herbaceous stratum						
Poaceae	30ǂ	*Anthephora hermaphrodita* Link. Kuntze.	26.40	5.60	0.00	0.00
Poaceae	31ǂ	*Aristida adscencionis* Linnaeus.	0.00	0.00	9.70	0.00
Poaceae	32ǂ	*Brachiaria plantaginea* Link. Hitchc	41.70	45.80	10.90	2.80
Portulacaceae	33	*Portulaca oleracea* Linnaeus	0.00	1.40	1.40	0.00
Plantaginaceae	34	*Scoparia dulcis* Kuntze	4.20	0.00	0.00	0.00
Rubiaceae.	35	*Borreria verticillata* L. G. Mey	0.00	0.00	55.60	37.50
Verbenaceae	36	*Lippia sidoides* Cham.	00	0.00	11.10	0.00
Verbenaceae	37	*Lantana camara* Linnaeus.	45.80	91.70	8.30	1.40
Verbenaceae	38	*Lippia alba* Mill. Brown	0.00	9.70	0.00	0.00
Vitaceae	39	*Parthenocissus tricuspidata* Planch.	1.40	0.00	0.00	0.00
Turneraceae	40	*Turnera subulata* Smith.	0.00	0.00	8.30	0.00
Woody stratum			A.F. (%)		S.D. (individuals ha^{-1})	
			Thinn.	Contr.	Thinn.	Contr.
Apocynaceae	41	*Aspidosperma pyrifolium* Mart	41.70	75.00	8.00	22.00
Boraginaceae	42ǂ	*Cordia oncocalyx* Allemão	100.00	100.00	121.00	194.00
Combretaceae	43ǂ	*Combretum leprosum* Martius	75.00	50.00	14.00	17.00
Euphorbiaceae	44	*Croton sonderianus* Müll. Arg	75.00	100.00	37.00	217.00
Fabaceae	45	*Amburana cearensis* Allemão. Smith	41.70	0.00	6.00	0.00
Fabaceae	46	*Libidibia ferrea* Mart. Tui. Queiroz	91.70	75.00	19.00	28.00
Fabaceae	47ǂ	*Mimosa tenuiflora* Willd. Poir	66.70	100.00	25.00	94.00
Fabaceae	48ǂ	*Mimosa arenosa* Willd. Poir	91.70	100.00	49.00	72.00
Fabaceae	49ǂ	*Mimosa caesalpiniaefolia* Benth	100.00	100.00	96.00	83.00
Fabaceae	50ǂ	*Poincianella pyramidalis* Tui.	8.30	0.00	1.00	0.00
Malvaceae	51	*Pseudobombax marginatum* Hill. Robyns	8.30	0.00	1.00	0.00
Rhamnaceae	52ǂ	*Ziziphus joazeiro* Martius	25.00	0.00	2.00	0.00
Total Dens. (individuals ha^{-1})					379.00	728.00

Identification number given to the species according to the alphabetical order of the family (N°)
ǂ *Forage species.*

The Caatinga area thinned into strips presented Shannon-Weaver (H’) and Pielou (J’) diversity indexes than the control (Figure 2A). According to Drobnik et al. (2011), improved management strategies may favor the emergence of new species and promote the sustainability of the system.

A great advantage thinning an area into strips is that it maintains local biodiversity in addition to promoting a greater production of forage biomass. According to Versieux et al. (2011), when the Caatinga is manipulated in a disorderly way, it causes a reduction in floral biodiversity, which is illustrated in these indexes. The DBH and height variables were not different (P>0.05) between the thinned into strips and control areas (Figure 2B), demonstrating that thinning into strips maintained the structure of the trees.

Two species in the woody stratum with deciduous characteristics—*Croton sonderianus* Muell.Arg (217 individuals ha^{-1}) and *Cordia oncocalyx* Allemão (194 individuals ha^{-1}) (Table 1) in the control area—contributed to the variable litter coverage (Table 2). As there was a higher density of these species, they deposited a greater amount of this material in the area.



(A) (B)

Figure 2. Shannon-Weaver (H') and Pielou (J') Indexes (A) and structural variables (DB, DBH and height) (B) of the woody stratum in the Caatinga area thinned into strips and control area in Sobral/CE in 2016.

Means followed by different letters, inside each structural variable, differ by the Tukey's test ($P<0.05$).
Diameter at base height (DB, cm) and diameter at breast height (DBH, cm).
When the effect was not identified as significant, its corresponding letters were not included in the figure.

There was no interaction for manipulation × period among these variables: total soil coverage, mono and dicotyledons herbaceous (%) for both thinned into strips and control areas. However, there was a significant difference between the treatments ($P<0.0001$) in total soil coverage of the soil and monocotyledons according to the evaluated season; the rainy season presented the highest mean and the rainy-dry transition season the lowest (Table 2), which was due to the ephemeral character of monocotyledons (Table 1). According to Silva et al. (2017), the high evapotranspiration and temperatures, which are associated with low precipitation, promote a rapid disappearance of native herbaceous species, which contributes to them completing their growth cycle faster (ephemeral).

The monocotyledon species showed a lower absolute frequency (%) and contributed little to the production of total biomass (kg ha^{-1}). Highlighted in this fraction was the presence of *Brachiaria plantaginea* Link Hitchc in 10.9% of the frames thrown in the area thinned into strips and 2.3% in the control area (Table 1). These values add a new perspective to the increase in the number of those species over the time in the area thinned into strips, since this environment provides ideal conditions, such as the incidence of light and the rapid dispersion of seeds.

Total forage biomass (TFB) was superior in the area thinned into strips, with the highest production during the two seasons evaluated (rainy and rainy-dry transition) being 35% in the rain and 135% rainy-dry. This increase can be explained by the herbaceous plants using radiation more efficiently, which promoted an acceleration in the growth and biomass production rates (SILVA et al., 2009). Another factor that influenced TFB was the presence of herbaceous dicotyledons in the area thinned into strips, with an emphasis on the species *Hyptis suaveolens* Link. Poit. Pereira Filho et al. (2007) demonstrated that, besides increasing local biodiversity, the Caatinga thinning in their study lead to an 80% increase in the availability of herbaceous forage biomass harvested. That species was also mainly responsible for the significant difference ($P<0.0001$) in height of the herbaceous stratum—the lowest value was observed during the rainy season (25.33 cm) and the highest during the rainy-dry transition season (53.52 cm). This response was due to the increase in A.F. (%) in the area thinned into strips. According to Rodrigues et al. (2012), *H. suaveolens* grows and establishes itself rapidly in the area and can reach up to 2 m high.

Interaction (manipulation × period) occurred for the variables LAI and IPAR, both of which were significantly different ($P<0.0011$ for LAI and $P<0.0053$ for IPAR) between rainy and rainy-dry transition seasons. The thinning of the Caatinga into strips decreases the density of trees, and this is reflected in the lower LAI in our results. Shaded herbaceous plants tend to elongate their stems and alter their leaf angles, making them flatter to improve light uptake (LARCHER, 2006). For IPAR, the rainy-dry transition season presented the lowest mean for the area thinned into strips.

The high coefficients of variation (CV) observed in the research is due to the fact that this study was carried out in a rangeland located in a biome with rich biodiversity and variable climatic parameters.

Table 2. Coverage components, biomass, height, leaf area index and interception of photosynthetically active radiation of the herbaceous stratum in Caatinga area thinned into strips and control area in Sobral/CE in 2016.

Manipulation	Rainy season	Rainy-dry transition season	Mean
Total soil coverage (%) (CV = 30.24%)			
Thinned into strips	50.76	48.40	49.58
Control	66.87	43.82	55.35
Average	58.82^{a}	46.11^{b}	
Herbaceous monocotyledons coverage (%) (CV = 109.42%)			
Thinned into strips	6.74	1.53	4.13
Control	5.85	0.03	2.94
Average	6.29^{a}	0.78^{b}	
Herbaceous dicotyledons coverage (%) (CV = 38.29%)			
Thinned into strips	30.80	46.25	38.53
Control	33.04	29.10	31.10
Average	31.92	37.66	
Litter coverage (%) (CV = 95.14%)			
Thinned into strips	13.20^{Ba}	0.55^{Aa}	6.88
Control	27.99^{Aa}	12.64^{Ab}	20.31
Average	20.59	6.60	
Total forage biomass (TFB, kg ha^{-1}) (CV = 56.98%)			
Thinned into strips	1,128.98^{Ab}	1,973.61^{Aa}	1,551.29
Control	833.40^{Aa}	836.32^{Ba}	834.86
Average	981.19	1,404.96	
Litter biomass (LB, kg ha^{-1}) (CV = 133.00%)			
Thinned into strips	373.33^{Ba}	59.44^{Aa}	216.39
Control	1,490.55^{Aa}	253.33^{Ab}	871.94
Average	931.94	156.94	
Height of the herbaceous stratum (cm) (CV = 44.64%)			
Thinned into strips	21.16	51.71	36.44
Control	29.89	55.33	42.61
Average	25.53^{b}	53.52^{a}	
Leaf area index (LAI) (CV = 69.59%)			
Thinned into strips	3.67^{Ba}	0.74^{Ab}	2.21
Control	5.12^{Aa}	1.39^{Ab}	3.26
Average	4.40	1.10	
Interception of photosynthetically active radiation (IPAR, %) (CV = 34.79%)			
Thinned into strips	83.10^{Aa}	37.91^{Bb}	60.50
Control	89.81^{Aa}	55.70^{Ab}	72.75
Average	86.44	46.80	

Means followed by distinct letters, uppercase in the column and lowercase in the row, within each variable differ by Tukey's test (P<0.05).
When significant interaction was detected, the letters were left at the center of each variable and not in the mean; when no significant interaction was observed, the letters were left only in the mean.

TRIAL 02:

Buffel and massai grasses were established, but since the buffel grass did not germinate, only the massai grass was analyzed and the conditions of full sun exposure and shade were considered as treatments, the former being located in the center and the latter on the left and right sides of the area thinned into strips. The buffel grass did not germination at first probably because it was dormant. According Santos et al. (2013), climatic factors such as low rainfall or high temperatures, reduce the germination of this species, reducing the break of physiological dormancy.

Structural and production variables of the massai grass were not significantly different (P>0.05) (Table 3); that is, the thinning of the Caatinga into strips did not decrease forage biomass production, since 40% of the coverage was manipulated by removing some trees, aiming to enable herbaceous growth and avoid erosion. This response was possibly due to the North/South direction of the strips in the thinned area, which allowed the seedlings to receive at least 6 hours of solar radiation per day; this temporary shading was not characterized as a limiting factor to seed growth. Silva et al. (2012), evaluating seven forage species in a consortium with pinhão-manso (*Jatropha curcas* L.), cultivated an area of Caatinga in rows and observed that the massai grass was the species that presented the highest constancy of growth and a greater accumulation of dry matter. They were not limited by the shade provided by the above-mentioned arboreous species, since shading favors the mineralization of nitrogen by soil microorganisms.

The variables internal concentration of carbon dioxide (Ci), leaf transpiration rate (E), stomatal conductance rate (gs), photosynthetic rate (A), relative index of chlorophyll a and b (SPAD), rate of carboxylation (A/Ci), and intrinsic water use efficiency (A/E) were not significantly different (P>0.05). However, internal leaf temperature (T_{Leaf}) did (P<0.05)—it had the lowest mean in the massai grass exposed to full sun and the highest in the shaded condition (Table 3). This response can be explained by the time at which these variables were measured before a daily round, as mentioned in the material and methods section. The readings were carried out on the plants in full sun exposure at 08:00 and shaded plants at 10:00, and this may have contributed to the rise in T_{Leaf} of shaded plants and improved their photosynthetic efficiency. According to Mendes et al. (2013b), the coverage of trees in semiarid environments can promote some physiological changes in the sub-forest, among them a decrease in leaf transpiration.

Because the grass was cultivated in a region characterized by high climatic variation (Figure 1) during the rainy season, this factor was attributed to the CV's variation in the analyzed variables.

Table 3. Structural and physiological variables of Massai grass grown under full sun exposure and shaded conditions in the area of Caatinga thinned into strips in Sobral/CE during the rainy season of 2016.

Structural					
Variables	Full sun	Shaded	Mean	CV (%)	P-Value
TFB (kg ha^{-1})	1,445.00	772.80	1,108.70	73.20	0.2859
GLB (kg ha^{-1})	821.00	377.20	599.10	79.70	0.2366
GSB (kg ha^{-1})	341.70	149.60	245.70	101.50	0.3182
DFB (kg ha^{-1})	281.80	247.30	264.50	54.50	0.7457
PDT (plants m^{-2})	496.00	520.50	508.30	48.01	0.8917
NLL	3.00	2.80	2.90	10.00	0.5158
IPAR (%)	0.50	0.58	0.51	29.30	0.4087
LAI	1.30	1.32	1.30	64.90	0.9359
Height (cm)	33.30	22.10	27.70	29.30	0.0976
RUE	3.80	2.00	2.90	73.20	0.2860
Physiological					
Variables	Full sun	Shaded	Mean	CV (%)	P-Value
T_{Leaf} (°C)	32.50^{b}	40.60^{a}	------	4.36	0.0004
Ci (ppm)	167.00	220.80	193.90	48.8	0.4524
E (mmol m^{-2} s^{-1})	0.40	0.60	0.50	70.15	0.3674
gs (mol m^{-2} s^{-1})	0.03	0.01	0.02	70.35	0.3308
A (μmol m^{-2} s^{-1})	5.10	3.40	4.30	47.59	0.2780
SPAD	27.40	25.30	26.40	12.71	0.4037
A/Ci	0.04	0.02	0.03	70.39	0.1546
A/E	1.20	0.60	0.90	38.26	0.0582

Means followed by the same lowercase letter in the row do not differ statistically by the Tukey's test (0.05).
Number of live leaves per tiller (NLL); Total forage dry biomass (TFB); Green leaf dry biomass (GLB); Green stem dry biomass (GSB); Dead forage dry biomass (DFB); Population density of tillers (PDT); Leaf area index (LAI); Interception of photosynthetically active radiation (IPAR) and Rainfall use efficiency (RUE); Internal leaf temperature (T_{leaf}); Internal concentration of carbon dioxide (Ci); Leaf transpiration rate (E); Stomatal conductance rate (gs); Photosynthetic rate (A); Relative index of chlorophyll a and b; Rate of carboxylation (A/Ci) and Intrinsic water use efficiency (A/E).
When significant effect was detected, the letters were left in the table.

The coverage promoted by thinning into strips did not affect the production and physiology of the grasses, since it favored an increase of biomass. According to Pedreira, Pedreira and Lara (2015), integration systems that allow a transmittance of radiation to the herbaceous stratum ≤ 1,800 μmol photon m^{-2} s^{-1} are ineffective for the stability of the production system.

CONCLUSIONS

Thinning into strips is a management option for the Caatinga that favors a quantitative increase the biomass pasture and the botanical composition of native species. This technique favors a large number of monocotyledon and dicotyledon forage species; it also allows the establishment of exotic species such as the massai grass, independent of its planting position in the area thinned into strips, which increases the forage biomass produced throughout the year and maintains the biodiversity in the area.

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