NATIVE CAATINGA SPECIES FOR THE RECOVERY OF DEGRADED AREAS IN THE BRAZILIAN SEMIARID REGION

Jullyanna Nair de Carvalho[2*], Márkilla Zunete Beckmann-Cavalcante[3], Renato Garcia Rodrigues[4], André Paviotti Fontana[5] and Daniel Salgado Pifano[4]

[1] Received on 16.05.2021 accepted for publication on 17.01.2022.
[2] Universidade Federal de Lavras, Programa de Pós-Graduação Agronomia/Fitotecnia, Lavras, MG - Brasil. E-mail: <jullyannacarvalho@gmail.com>.
[3] Universidade Federal do Vale do São Francisco, Colegiado de Engenharia Agronômica, Petrolina, PE - Brasil. E-mail: <markilla.beckmann@univasf.edu.br>.
[4] Universidade Federal do Vale do São Francisco, Colegiado de Ciências Biológicas, Petrolina, PE - Brasil. E-mail: <renato.garcia@univasf.edu.br>and <danielguela@gmail.com>.
[5] Núcleo de Ecologia e Monitoramento Ambiental-NEMA, Petrolina, PE - Brasil. E-mail: <andrepaviotti@yahoo.com.br>.
*Corresponding author.

ABSTRACT – This study aimed to prospect, among the species that grow spontaneously in compacted landfills, native Caatinga plants with potential for ground cover in extremely impacted areas, with exposed soil. Initially, a general floristic survey was carried out in the four study areas. To prospect the species, data referring to the richness, coverage, and densification of plants in the herbaceous stratum were collected in each study area, using the method of plots. The selection was based on species-specific characteristics: origin, plant habit, life cycle, propagation, dispersion syndrome, coverage, densification, and allelopathic effect. The general floristic inventory revealed the presence of 73 species belonging to 63 genera and 26 botanical families. In the survey of the coverage and densification of the herbaceous stratum, 33 species belonging to 32 genera and 16 families were found, being the most representative: Fabaceae (5), Malvaceae (5), and Poaceae (5). As for the origin, 26 are native, one is naturalized, and six are exotic, of which 66.6% are in the Poaceae family. Moreover, most of these species are herbs, with an annual life cycle, dissemination through seeds, and present autochoric dispersion. The coverage and densification of these species ranged from 0.44% to 9.5% of the area and 1 to 4.44 of individuals/m^2, respectively. The species *Senna uniflora*, *Rhaphiodon echinus*, *Sida galheirensis*, *Mesosphaerum suaveolens*, *Hexasepalum teres*, *Waltheria rotundifolia*, *Trianthema portulacastrum*, and *Herissantia crispa* showed potential for use in recovery plans for degraded areas based on the results presented by each of them in the parameters analyzed, especially in coverage, densification, dispersion syndrome, and life cycle.

Keywords: Herbaceous stratum; Densification; Vegetation Cover.

ESPÉCIES NATIVAS DA CAATINGA PARA RECUPERAÇÃO DE ÁREAS DEGRADADAS NO SEMIÁRIDO BRASILEIRO

RESUMO – O objetivo deste estudo foi prospectar, dentre as espécies de crescimento espontâneo em aterros compactados, plantas nativas da Caatinga com potencial para cobertura de solo em áreas extremamente impactadas, de solo exposto. Inicialmente, foi realizado um levantamento florístico geral nas quatro áreas do estudo. Para prospectar as espécies, foram coletados, em cada área, dados referentes à riqueza, cobertura e ao adensamento das plantas do estrato herbáceo, utilizando-se o método de parcelas. A seleção balizou-se nas características espécie-específicas: origem, hábito, ciclo de vida, propagação, síndrome de dispersão, cobertura, adensamento e efeito alelopático. O inventário florístico geral revelou a presença de 73 espécies pertencentes a 63 gêneros e 26 famílias botânicas. No levantamento da cobertura e adensamento do estrato herbáceo, foram encontradas 33 espécies pertencentes a 32 gêneros e 16 famílias, sendo as mais representativas; Fabaceae (5), Malvaceae (5) e Poaceae (5). Quanto à origem, 26 são nativas, 1 naturalizada e 6 exóticas, das quais 66,6% na família Poaceae. Além disso, a maioria dessas espécies são ervas, com ciclo de vida anual, disseminação por meio de sementes e apresentam dispersão autocórica. A cobertura e o adensamento dessas

http://dx.doi.org/10.1590/1806-908820220000010

espécies variaram de 0,44% a 9,5% de área e 1 a 4,44 de indivíduos/m², respectivamente. As espécies ***Senna uniflora****,* ***Rhaphiodon echinus****,* ***Sida galheirensis****,* ***Mesosphaerum suaveolens****,* ***Hexasepalum teres****,* ***Waltheria rotundifolia****,* ***Trianthema portulacastrum*** *e* ***Herissantia crispa*** *apresentaram potencial para utilização em planos de recuperação de áreas degradadas baseado nos resultados apresentados por cada uma delas nos parâmetros analisados, especialmente na cobertura, adensamento, síndrome de dispersão e ciclo de vida.*

Palavras-Chave: Estrato herbáceo; Adensamento; Cobertura vegetal.

1. INTRODUCTION

Caatinga corresponds to a phytogeographic domain known as CPD – Caatinga Phytogeographic Domain (Moro et al. 2014), which harbors the most vulnerable ecological systems to climate change, is also poorly studied and protected (Silva et al. 2017). It is the largest, most continuous, and most diverse semiarid vegetation in the New World (Fernandes and Queiroz, 2018). Occupying 912,529 km^2 in Northeastern Brazil, the Caatinga is best described as a rich and complex socio-ecological system that houses a unique natural and cultural heritage of global importance (Silva et al. 2017; Fernandes and Queiroz, 2018).

This biome presents floristic, physiognomic, and ecologically distinct plant formations, with the steppe savanna being the predominant vegetation (Moro et al., 2014). This significant floristic heterogeneity reflects flora adaptations to local climate and soil conditions in the semiarid region. Plants have developed skills to survive adverse conditions that include irregular rainfall and recurrent droughts, with the most striking feature being deciduousness (Fernandes and Queiroz, 2018).

However, the Caatinga has been undergoing phytophysiognomic and structural changes related to anthropogenic processes that date back to the time of colonization in Brazil (Bezerra et al., 2014). The result is that at least 63.6% of the Caatinga was modified by human activities (Silva et al., 2017). The systematic elimination of vegetation cover and the inadequate and unsustainable use of the soil has caused severe environmental problems for the Caatinga, located almost entirely in the Brazilian semiarid region, reducing biodiversity, soil degradation, and desertification stand out (Bezerra et al., 2014). Around 94% of the Caatinga are at moderate to high risk of desertification, which can be further intensified due to the biome's climate vulnerability (Silva et al., 2017).

In the last few decades, the Northeast region of Brazil has received and has been receiving investments in infrastructure that have been improving the quality of life of rural people. Irrigation systems revolutionized agriculture in the lower middle São Francisco, generating employment and income in important urban centers, such as Petrolina, in the state of Pernambuco, and Juazeiro, in the state of Bahia. Obviously, pressure on remnants of Caatinga has also increased, and areas formerly with extensive native vegetation have given way to large grape and mango farms. More recently, PISF, the São Francisco Integration Project, has been taking water to Brazil's aridest areas through the country's largest infrastructure project, the transposition of the São Francisco River.

The present work was carried out in these areas directly affected by the PISF, which correspond to severe anthropic interventions (with heavy machinery). In other words, after the machines pass, the landscape is no longer the same. Therefore, the main objective is to prospect species that are capable of colonizing exposed, poor, and overturned soil, sometimes even areas of waste disposal. The objective of the action is to move from a scenario of exposed soil (without vegetation) to one of soil with vegetation cover, being, therefore, a recovery action and not a restoration action.

Thus, studies and recovery plans for these areas are essential for mitigating environmental impacts. The selection of species for use as vegetation cover in anthropic areas should be based on edaphic, climatic, and environmental factors and the plants' characteristics (Gris et al., 2012). Native species are the most suitable for covering areas without vegetation since, in addition to ensuring the preservation of the autochthonous gene bank, they make the environment closer to the original one and more ecologically balanced (Sousa and Sutili, 2017).

Then, this study aimed to prospect, among the species that grow spontaneously in compacted landfills, native plants from the Caatinga with potential for covering the soil in highly impacted areas and/or exposed soil in the Brazilian semiarid region.

2. MATERIAL AND METHODS

2.1. Study area

The study was carried out on slopes of compacted landfills distributed along the channels of the north and east axes, in the states of PE and CE, in the PISF work area (Integration Project of the São Francisco River). Four areas with older slopes were selected. Area I is located on the east axis and corresponds to the dark line on the right in the image, and areas II, III, IV are located on the north axis, the dark line on the left. (Figure 1).

Information about the four sampled areas is contained in table 1.

It is important to emphasize that the species surveyed were found on construction structures composed of compacted landfills with different physical and chemical structures from the soils present in the surrounding matrix.

2.2. Floristic survey

Initially, a floristic survey was carried out on all slopes of the study areas to verify their general floristic composition. The survey took place during November (dry season) of 2014 and February and March (rainy season) of 2015, with the identifications based on prior knowledge of the taxa, collecting botanical material only from plants found in the phenological stage reproductive system (Fidalgo and Bononi, 1989). The exsiccates of the collected material were deposited in the PISF botanical collection. Taxonomic identification was carried out through consultations with specialists and the literature. The classification of species followed APG IV (2016).

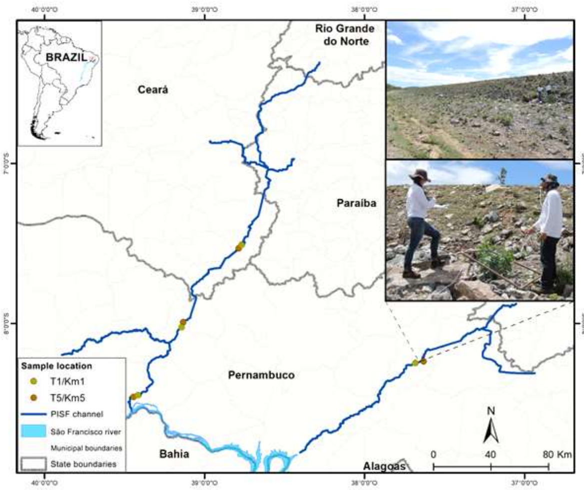

Figure 1 – Location of the PISF axes and areas with slopes sampled in the municipalities of Custódia (I), Cabrobó (II), Salgueiro (III), and Mauriti (IV).
Figura 1 *– Localização dos eixos do PISF e das áreas com taludes amostradas nos municípios de Custódia (I), Cabrobó (II), Salgueiro (III) e Mauriti (IV).*

Table 1 – Information from sampled areas I, II, III, and IV.
Tabela 1 *– Informações das áreas amostradas I, II, III e IV.*

		Area I	Area II	Area III	Area IV
Municipality		Custódia	Cabrobó	Salgueiro	Maurití
Geographic coordinates	initial	08°14’51’ ’S 37°40’58’’ W	08°26’52’’ S 39°24’54’’ W	08°01’25’’ S 39°08’37’’ W	07°31’48’’ S 38°47’12’’ W
	final	08°14’07’’ S 37°38’53’’ W	08°25’30’’ S 39°26’40’’ W	07°59’31’’ S 39°07’58’’ W	07°31’11’’ S 38°47’02’’ W
Elevation(m)		538	366	507	413
Temperature	average	23.4	24.8	23.8	24.5
(ºC)	minimum	18.9	19.8	19.1	19.7
	maximum	30.4	31.4	30.9	31.3
Precipitation(mm)		627	541	616	838
Relative humidity (%)		68.9	61.2	62.4	64.1
Aridity index (Hijmans et al., 2005)		0.39	0.31	0.36	0.50
Climate type		Hot semi-arid (BSh)	Hot semi-arid (BSh)	Hot semi-arid (BSh)	Hot semi-arid (BSh)
Type of soil (Embrapa, 2018)		Chromic Luvisol (CT)	Chromic Luvisol (CT)	Litholic Neosol (RL)	Neossolo Litólico (RL

2.3. Coverage survey and densification of the herbaceous layer

Weeds (including creeping herbs) and sub-shrubs were considered as part of the herbaceous strata (Oliveira et al., 2017). The plots method was used to collect data regarding the coverage and densification of plants in the herbaceous stratum. Sampling was carried out in the four areas (I, II, III, and IV), in a stretch of 5 km contiguous, with slopes totaling 20 km in length. At the beginning of each kilometer, a point was georeferenced at the base of the slope, and from this point, another five points 10 m apart from each other were also georeferenced, forming a line of 50 m. At each point of the line, a transect was established perpendicularly to the top of the slope. In each transect, plots of 1 m^2 (1 × 1 m) were placed, spaced 1 m apart from each other, and placed alternately on the right and left of the transect. Thus, the number of plots in each area varied depending on the height of the slopes. The number of plots in areas I, II, III, and IV were 94, 102, 134, and 51, respectively, totaling a sampled area of 381 m^2.

In each 1 m^2 plot, all individuals belonging to the herbaceous stratum were sampled, and the following data were collected: densification and percentage of coverage of each species. Densification was measured by counting the number of individuals of each species that occur in 1 m^2, considering only the plots where the species was present. Some species have underground stems that allow an extensive vegetative propagation, causing the aerial part to appear cespitose, making it difficult to measure and define what an individual is. Thus, any plant that did not show a connection with another at ground level was considered as a single individual, justifying the use of the term densification and not density.

The coverage percentage was performed through the visual estimation, supported by a 1 × 1 m plot, divided with nylon threads into 100 smaller squares, each representing 1% of the area. In order to make the visual estimate of the percentage of species coverage more accurate and due to the difficulties of sampling some of them because of their morphology and/or form of growth, we established the minimum coverage percentage of 1 percent for the herbaceous individuals. This approach also supports the adoption of the term densification instead of density.

2.4. Attributes for prospecting species

In this study, the following species-specific attributes were considered: origin, plant habit, life cycle, propagation, dispersion syndrome, coverage, densification, and allelopathic effect.

Species sampled were classified according to origin (native or exotic) and habit (grass or subshrub) (Andrade et al., 2020). The classification regarding life cycle (annual or perennial) and propagation (seed or seed/stolons) was based on Lorenzi (2014) and Silva et al. (2012). As regards the dispersion syndrome, the classification was based on Van der Pijl (1982), which is grouped into three basic groups: zoochoric (dispersed by animals), anemochoric (dispersed by the wind), and autochoric (self-dispersed).

The coverage and densification values were calculated from field survey data, obtaining the average of the coverage percentage and the number of individuals of each species in 1 m^2, respectively. For the calculations of both coverage and densification

Table 2 – Scoring scheme of attributes and classes considered for classification of plant species in the Caatinga.
Tabela 2 *– Esquema de pontuação dos atributos e classes considerados para classificação das espécies de plantas da Caatinga.*

Attributes	Weight	Class	Score
Origin		Native	
		Exotic	
Plant habit	1	Subshrub	1
		Herb/ Subshrub	2
		Herb	3
Propagation	1	Seed	1
		Seed/rooting	2
Life cycle	1	Annual	1
		Annual/perennial	2
		Perennial	3
Dispersion syndrome	1	Zoochoric	1
		Anemochoric	2
		Autochoric	3
Coverage	2	< 4%	1
		4 to 8%	2
		> 8,1%	3
Densification	3	< 2 individuals/m^2	1
		2 to 4 individuals/m^2	2
		> 4,1 individuals/m^2	3
Allelopathic effect		Total	0
		High	1
		Medium	2
		Low	3

of a species, only the plots in which the species was present were considered.

The allelopathic effect was evaluated according to Grisi et al. (2013), and extracts from the root, stem, and leaves were used to evaluate the germination of Lettuce (*Lactuca sativa* L.), a species commonly used as a test plant in allelopathy studies. The species whose extracts interfered with the germination of *L. sativa* were considered as low, medium, high, and totally allelopathic, resulting in germination percentages greater than 80%, between 80 and 60%, less than 60% and 0%, respectively. The final score for each species was obtained from the average of leaf, stem, and root extracts.

The score for each native species, since exotic species are not the focus of this study, resulted from the sum of the products (weight × score) of the attributes of the plant habit, propagation, life cycle, dispersion syndrome, coverage, and densification. The allelopathic effect was evaluated for species with the highest score concerning the attributes mentioned above, and these allelopathic scores were added to the previously obtained (Table 2).

Therefore, a list of species with potential for land cover in extremely impacted areas was obtained.

3. RESULTS

3.1. Floristic survey

The general floristic survey, including all forms of life and origin, carried out in the four slope areas (I, II, III, and IV), indicated 73 species belonging to 63 genera and 26 botanical families. The most representative families, that is, with the highest number of species were Fabaceae (13 species), Poaceae (9 species), Malvaceae (8 species), Euphorbiaceae (6 species), and Apocynaceae (4 species), corresponding to 54.79% of the total species surveyed in this study (Table 3).

In addition to species from the herbaceous stratum (grass and sub-shrubs), shrub and creeping phanerogams were found, as well as woody species in the form of seedlings, probably arising from natural regeneration and colonization of the slopes.

3.2. Coverage survey and densification of the herbaceous layer

In the survey of densification and coverage of plants belonging to the herbaceous stratum, 33 species were found, distributed in 32 genera and 16 families. The families with the highest species richness were Fabaceae (5), Malvaceae (5), and Poaceae (5) (Table 4).

Of the 33 species sampled, 26 were considered natives, one naturalized, and six exotics, with 66.6% belonging to the Poaceae family. Thus, even though the Poaceae family is among the most representative of the herbaceous stratum, its species were of little importance because they are mostly exotic, thus opposing the focus of the study, which are native species. These species are African in origin but already well-established in the Caatinga, with a few already being classified as naturalized by some authors. Such exotic species have a high power of infestation since they reproduce by caryopsis-type fruits (epizoochory or anemochory) and have rhizomes or other underground stems that help vegetative propagation. Therefore, they present a high degree of biological invasion. However, the diversity (richness) found, apparently induces competition and establishment, ending up biologically controlling the infestation.

In terms of plant habit, 21 species were classified as grasses (the creepers included here), nine as sub-shrubs, and three as grass/sub-shrubs. Regarding the life cycle, 17 species are annual, 13 are perennial, and three can be perennial/annual depending on the environment since herbaceous plants in the Caatinga can present variable growth patterns depending on water availability (Table 4).

Concerning propagation, all species are disseminated through seeds (Table 4). However, two of these species (*Commelina erecta* and *Dactyloctenium aegyptium*), in addition to propagating through seeds, can also reproduce through stolons (thin aerial stems that have horizontal growth, originating new plants). In addition, most species (63.6%) have autochoric dispersion, that is, through mechanisms of the plant itself, and 36.4% need external agents to disperse, whether wind (anemochoric) or animals (zoochoric) (Table 4).

The coverage area ratio per individual ranged between 0.44% and 9.57% (Table 4). The species that presented the lowest cover percentages were *Tridax procumbens*, *Spigelia anthelmia*, *Oxalis glaucescens*, and *Hexasepalum teres*, while the highest percentages of cover were *Trianthema portulacastrum* (9.57%) and *Senna uniflora* (8.18%). Regarding densification,

Table 3 – List of species found in study areas I (Custódia), II (Cabrobó), III (Salgueiro) and IV (Mauriti).
Tabela 3 *– Lista das espécies encontradas nas áreas de estudo I (Custódia), II (Cabrobó), III (Salgueiro) e IV (Mauriti).*

Family/Species	Family/Species
Amaranthaceae	Lamiaceae
Alternanthera pungens Kunth	*Marsypianthes chamaedrys* (Vahl) Kuntze
Alternanthera tenella Colla	*Mesosphaerum suaveolens* (L.) Kuntze
Amaranthus viridis L.	*Rhaphiodon echinus* (Nees & Mart.) Schauer
Astronium urundeuva (M.Allemão) Engl.	Loganiaceae
Aizoaceae	*Spigelia anthelmia* L.
Trianthema portulacastrum L.	Malvaceae
Apocynaceae	*Corchorus argutus* Kunth
Aspidosperma pyrifolium Mart. & Zucc.	*Herissantia crispa* (L.) Brizicky
Calotropis procera (Aiton) W.T.Aiton	*Melochia tomentosa* L.
Cryptostegia grandiflora R.Br.	*Sida ciliaris* L.
Ibatia nigra (Decne.) Morillo	*Sida cordifolia* L.
Asteraceae	*Sida galheirensis* Ulbr.
Tridax procumbens L.	*Waltheria albicans* Turcz.
Boraginaceae	*Waltheria rotundifolia* Schrank
Euploca procumbens (Mill.) Diane & Hilger	Molluginaceae
Cactaceae	*Mollugo verticillata* L.
Xiquexique gounellei (F.A.C.Weber) Lavor & Calvente	Nyctaginaceae
Capparaceae	*Boerhavia diffusa* L.
Neocalyptrocalyx longifolium (Mart.) Cornejo & IItis	Oxalidaceae
Cleomaceae	*Oxalis glaucescens* Norlind
Tarenaya aculeata (L.) Soares Neto & Roalson	Passifloraceae
Tarenaya longicarpa Soares Neto & Roalson	*Passiflora foetida* L.
Commelinaceae	Poaceae
Commelina erecta L.	*Cenchrus ciliaris* L.
Convolvulaceae	*Cenchrus echinatus* L.
Jacquemontia corymbulosa Benth.	*Chloris barbata* Sw.
Ipomoea asarifolia (Ders.) Roem. & Schult.	*Dactyloctenium aegyptium* (L.) Willd.
Cyperaceae	*Digitaria ciliaris* (Retz.) Koeler
Cyperus surinamensis Rottb.	*Digitaria* sp.
Euphorbiaceae	*Echinochloa colona* (L.) Link
Astraea surinamensis (Miq.) O.L.M. Silva & Cordeiro	*Eragrostis pilosa* (L.) P.Beauv.
Cnidoscolus urens (L.) Arthur	*Melinis repens* (Willd.) Zizka
Croton blanchetianus Baill.	Portulacaceae
Euphorbia adenoptera Bertol.	*Portulaca elatior* Mart. ex Rohrb.
Jatropha mollissima (Pohl) Baill.	*Portulaca oleracea* L.
Jatropha ribifolia (Pohl) Baill.	Rubiaceae
Fabaceae (Symbiosis *Rhizobium* spp)	*Hexasepalum teres* (Walter) J.H.Kirkbr.
Desmodium sp.	*Richardia grandiflora* (Cham. & Schltdl.) Steud
Indigofera microcarpa Desv.	Solanaceae
Indigofera suffruticosa Mill.	*Nicotiana glauca* Graham
Mimosa ophthalmocentra Mart. ex Benth.	*Solanum capsicoides* All.
Mimosa pudica L.	Turneraceae
Parapiptadenia zehntneri (Harms) M.P.Lima & H.C.Lima	*Piriqueta sidifolia* (Cambess.) Urb.
Prosopis juliflora (Sw.) DC.	Vitaceae
Rhynchosia sp.	*Clematicissus simsiana* (Schult. & Schult.f.) Lombardi.
Senna occidentalis (L.) Link	Zygophyllaceae
Senna uniflora (Mill.) H.S.Irwin & Barneby	*Kallstroemia tribuloides* (Mart.) Steud.
Stylosanthes sp.	*Tribulus terrestris* L.
Tephrosia purpurea (L.) Pers.	
Zornia sericea Moric.	

Table 4 – Characteristics of the herbaceous stratum species surveyed in the study areas (Custódia), II (Cabrobó), III (Salgueiro) and IV (Mauriti).
Tabela 4 *– Características das espécies do estrato herbáceo levantadas nas áreas de estudo (Custódia), II (Cabrobó), III (Salgueiro) and IV (Mauriti).*

Species	Origin	Plant habit	Life cycle	Propagation	Dispersion syndrome	Coverage/ individual (%)	Densification (Individuals/m²)	Allelopathic effect Leaf	Stem	Root
Alternanthera tenella	Native	Subshrub	Annual/perennial	Seed	Anemocoric	1.54	3.89			
Amaranthus viridis	Exotic	Herb	Annual	Seed	Anemocoric	5.00	2.00			
Tridax procumbens	Naturalized	Herb	Annual	Seed	Anemocoric	0.44	4.17			
Commelina erecta	Native	Herb	Perennial	Seed/stolons	Zoochoric	3.50	1.00			
Evolvolus cordatus	Native	Herb	Annual	Seed	Autochoric	4.92	1.83			
Astraea surinamensis	Native	Herb	Annual	Seed	Autochoric	1.00	1.00			
Euphorbia adenoptera	Native	Herb	Annual	Seed	Autochoric	1.00	1.00			
Indigofera microcarpa	Native	Herb/subshrub	Perennial	Seed	Autochoric	1.25	1.33			
Mimosa pudica	Native	Subshrub	Perennial	Seed	Autochoric	4.35	1.35			
Senna uniflora	Native	Herb	Annual	Seed	Autochoric	8.18	2.20	low	low	low
Tephrosia purpurea	Native	Subshrub	Perennial	Seed	Autochoric	5.17	2.19			
Zornia sericea	Native	Subshrub	Perennial	Seed	Autochoric	2.00	1.00			
Rhaphiodon echinus	Native	Herb	Perennial	Seed	Autochoric	1.32	3.79	medium	medium	low
Mesosphaerum suaveolens	Native	Subshrub	Annual	Seed	Autochoric	1.92	4.41	high	medium	low
Spigelia anthelmia	Native	Herb	Annual	Seed	Zoochoric	0.63	4.00			
Herissantia crispa	Native	Herb/Subshrub	Perennial	Seed	Autochoric	5.89	1.38	high	high	low
Melochia tomentosa	Native	Subshrub	Perennial	Seed	Autochoric	3.07	1.97			
Species	Origin	Plant habit	Life cycle	Propagation	Dispersion syndrome	Coverage/ individual (%)	Densification (Individuals/m²)	Allelopathic effect Leaf	Stem	Root
Sida cordifolia	Native	Subshrub	Perennial	Seed	Autochoric	6.10	1.75			
Sida galheirensis	Native	Subshrub	Perennial	Seed	Autochoric	4.02	2.10	high	medium	low
Waltheria rotundifolia	Native	Subshrub	Perennial	Seed	Autochoric	3.09	3.40	low	medium	low
Glinus radiatus	Native	Herb	Annual	Seed	Autochoric	9.57	1.56	total	total	low
Mollugo verticillata	Native	Herb	Annual	Seed	Autochoric	1.80	1.97			
Boerhavia diffusa	Exotic	Herb	Perennial	Seed	Zoochoric	1.38	2.54			
Oxalis glaucescens	Native	Herb	Perennial	Seed	Autochoric	0.67	1.50			
Cenchrus ciliaris	Exotic	Herb	Annual	Seed	Zoochoric	2.40	1.67			
Chloris barbata	Native	Herb	Annual/perennial	Seed	Zoochoric	1.51	3.15			
Dactyloctenium aegyptium	Exotic	Herb	Annual/perennial	Seed/stolons	Zoochoric	1.13	4.44			
Echinochloa colona	Exotic	Herb	Annual	Seed	Zoochoric	1.80	1.25			
Melinis repens	Exotic	Herb	Annual	Seed	Anemocoric	6.71	2.86			
Portulaca oleracea	Native	Herb	Annual	Seed	Autochoric	2.28	1.79			
Hexasepalum teres	Native	Herb	Annual	Seed	Autochoric	0.77	4.00	low	medium	low
Richardia grandiflora	Native	Herb/subshrub	Annual	Seed	Autochoric	1.33	1.50			
Tribulus terrestris	Native	Herb	Annual	Seed	Zoochoric	6.00	1.44			

the species that have more individuals inhabiting the same m², therefore greater aggregation capacity, are: *Dactyloctenium aegyptium* (4.44), *Mesosphaerum suaveolens* (4.41), *Tridax procumbens* (4.17), and *Hexasepalum teres* (4.00). The lowest densification values (1.00) were from *Commelina erecta*, *Astraea surinamensis*, *Euphorbia adenoptera*, and *Zornia sericea*. Except for *Tridax procumbens*, all the others are native, showing the importance of intercropping between plants of different origins in the colonization of the slopes.

3.3. Selected species

The species selected for the vegetation cover of degraded areas, according to the evaluation of the attributes of origin, plant habit, life cycle, propagation, dispersion syndrome, cover, densification, and allelopathic effect, were: *Senna uniflora*, *Rhaphiodon echinus*, *Sida galheirensis*, *Mesosphaerum suaveolens*, *Hexasepalum teres*, *Waltheria rotundifolia*, *Trianthema portulacastrum*, and *Herissantia crispa*.

Assessing the allelopathic effect of the leaf, stem, and root of the selected species (Table 4), we found that only *Senna uniflora* had low allelopathy in the leaf, stem, and root, with 85%, 85%, and 94% of germination of the tested plant (Lettuce), respectively. On the other hand, *Trianthema portulacastrum* proved to be a completely allelopathic species for leaf and stem, both with 0% germination and low allelopathy for root (83% germination).

4. DISCUSSION

Considering floristic studies with smaller life forms (habits), 73 species is a relevant richness value. Nevertheless, 33 species in slope areas with high human-modified impacts, poor, shallow, and stony soil are also significant. In a study compiling floristic and phytosociological literature on plant diversity in the Caatinga Phytogeographic Domain (CPD), Moro et al. (2014) found that the families Fabaceae, Euphorbiaceae, Malvaceae, Asteraceae, Convolvulaceae, Poaceae, Bignoniaceae, Cyperaceae, Rubiaceae, and Apocynaceae are the ten families with the most outstanding richness in the domain.

The Fabaceae family is the best represented in the Caatinga and has the most significant number of endemic species (Córdula et al., 2014). The predominance of Fabaceae may be associated with the fact that these species have different survival strategies in xeric environments, such as root nodules, compound pinnate leaves, and pulvinus, in addition to extrafloral nectaries that help in the transpiration and the protection of the plant in general. (Córdula et al., 2014). Probably species belonging to this family are more resistant to the stressful conditions of the environment and, therefore, more adapted, a fact that is justified by the significant irradiation of these families in the Quaternary period (Klein, 1975). In addition, *Senna uniflora* (Fabaceae) proved to be the most important species in this study, with the best values in the evaluated attributes, especially in coverage, densification, and dispersion syndrome. This species has as its main characteristic the ability to fix atmospheric nitrogen through a symbiotic relationship with diazotrophic (nitrogen-fixing) bacteria (Neves et al., 2017). Furthermore, they present rapid growth and regrowth capacity, making them suitable for recovering degraded areas (Neves et al., 2017). Therefore, Pereira and Rodrigues (2012) highlight that Fabaceae play an important role in the dynamics of ecosystems, presenting enormous potential for recovery and, therefore, they are systematically used in environmental projects.

Considering the objective of the work, we have a universe of 33 species, that is, those found on the slopes. It is imperative to highlight the high percentage of native species (78.9%) compared to exotic (18.9%). As previously mentioned, most of these exotics belong to the Poaceae (Graminae) family and are originally from Africa, being quite aggressive in the colonization processes of exposed soil. According to Carpanezzi (1998), the rehabilitation of local biodiversity is an expected consequence of actions to recover degraded areas, so the selected species should preferably be native to the recovering environment, though some exotic species, such as the grasses mentioned above, also can be beneficial in primary succession and colonization of exposed soil.

The high floristic richness of native species adds value to the results since little is known about their potential in succession processes in the Caatinga (Moro et al., 2014). They attract fauna with their flowers, fruits, and extrafloral nectaries, in addition to being a shelter for the rest of the fauna that does not use them for food (Araújo and Silva, 2017). The sum of these attributes accelerates the biological interactions and, with that, there is the advancement of succession (Rodrigues et al., 2009). Furthermore, in the natural succession process, pioneer species are generally ruderal herbaceous plants, which enrich the soil, allowing the establishment of late species (Guariguata and Ostertag, 2001).

Additionally, among the 33 species, eight were selected mainly based on coverage and densification values. Namely, they are: *Senna uniflora*, *Rhaphiodon echinus*, *Sida galheirensis*, *Mesosphaerum suaveolens*, *Hexasepalum teres*, *Waltheria rotundifolia*, *Trianthema portulacastrum*, and *Herissantia crispa*. *Sida galheirensis* and *Waltheria rotundifolia* are two Malvaceae species that are very common shrubs in the Caatinga, presenting a high degree of cespitose, therefore, with significant coverage and densification in communities where they are dominant. *Rhaphiodon echinus* (Lamiaceae) and *Herissantia crispa* (Malvaceae) are creeping plants, that is, herbaceous vines devoid of gripping structures. Consequently, they have a high coverage value and are also widely distributed in the CPD. On the other hand, *Mesosphaerum suaveolens* (Lamiceae) and *Hexasepalum teres* (Rubiaceae) are shrubby-herbaceous plants with low tillering with ample dispersive capacity, since their seeds are small and have autochoric dispersion. Moreover, the dispersion syndrome is the attribute that comes next in the sequence of relevance concerning the prospection objective of this study.

Species with different forms of dispersal syndrome are important for recovery and degraded areas. The advantage of autochory is that there is no need for dispersing agents (Van der Pijl, 1982). Anemochory is considered a specialization, that is, adaptation to unfavorable environments, in addition to being important in open environments (Fenner and Thompson, 2005). On the other hand, zoochory has the advantages of distancing the seeds from the surroundings of the mother plant and the colonization of gaps in degraded areas (Araújo and Silva, 2017). However, in areas with severe levels of degradation, such as those commonly found in PISF areas, the presence of fauna is modest. Therefore, most of the 33 species (63.6%) found to have autochoric dispersion is a result that cannot be neglected. Indeed, the non-dependence of biological actors in seed dispersal is vital in degraded places and distant from islands of diversity, such as the present case.

All eight species selected in this study are considered spontaneous and pioneer plants presenting large seed production as a survival mechanism, with efficient dispersion and longevity (Lorenzi, 2014). According to Rodrigues et al. (2009), the use of fast-growing pioneer species is fundamental in recovery programs, as it facilitates the beginning of the successional dynamic, mainly due to shading and nutrient incorporation, primarily covering the soil, incorporating organic matter, and inhibiting the development of exotic species invasive (Alves et al., 2018). In addition, ruderal herbaceous-shrub plants are more aggressive and pioneer, making them suitable for the base of the secondary succession process (Holanda et al., 2015).

The eight species selected are eudicots, which have axial or pivoting roots, which are more profound, and lateral ramifications that can be more or less developed depending on the species (Judd et al., 2015). This type of root system can extract nutrients found in deeper soil layers, which will be made available after decomposition and incorporation of the plant into the soil (Favero et al., 2000).

The greater the coverage and densification, the greater the biomass production. In this sense, the highest percentages of coverage were of *Trianthema portulacastrum* (9.57%) and *Senna uniflora* (8.18%). Concerning densification, the species that have more individuals inhabiting the same square meter, therefore greater aggregation capacity, are: *Dactyloctenium aegyptium* (4.44), *Mesosphaerum suaveolens* (4.41), *Tridax procumbens* (4.17), and *Hexasepalum teres* (4.00). The only exotic one is *Dactyloctenium aegyptium*, and the others are all common and widely distributed species within the CPD, that is, with easy propagation management and construction of germplasm banks. Even so, only *Senna uniflora* was already studied from the ecological perspective of conservation.

Favero et al. (2000) and Ferreira et al. (2013) concluded that *Senna uniflora* could promote the same effects of land cover, biomass production, and nutrient cycling as species introduced or cultivated for green manure, in addition to having forage potential. Carrying out herbaceous vegetation cover in exposed soil with potentially suitable species tends to accelerate the process of natural regeneration and establishment of secondary and late species. This occurs because, despite the occurrence of natural succession processes in degraded environments, where herbaceous, shrub and arboreal species are gradually added to the community, in space and in time (Coe and Souza, 2014), the efficiency of this process depends on several factors, such as the availability of propagules in the soil, the coverage capacity of pioneer species and the level of impact on the soil (Coe and Souza, 2014).

In this perspective, two species potentially suitable for vegetation cover in degraded areas, *Senna uniflora* and *Rhaphiodon echinus*, prospected in this study, are being tested in soil vegetation cover methodologies in the PISF Degraded Area Recovery Plans, the fundamental scope of the Basic Environmental Plan (PBA) 09. PBA is a condition required by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) to the Ministry of Regional Development for the environmental licensing of the PISF's operating license. *Rhaphiodon echinus* became the target of this action for being easily accessible concerning seed collection and vegetative propagation compared to the others.

The exotic species found in this study can be classified, considering the family, in Poaceae and other families. Only two non-Poaceae species were recorded, *Amaranthus viridis* (Amaranthaceae) and *Boerhavia diffusa* (Nyctaginaceae), both with low to moderate degree of invasion, because they do not have underground structures for vegetative propagation and present autochory and epizoochory dispersal, respectively. However, for the Poaceae family, the scenario is different. They are all species with a high degree of invasion due to their aforementioned characteristics. Nonetheless, in the study area, they apparently do not threaten the community, since the richness found was significant (33 species).

Although studies of prospecting species for recovery, mainly in the Caatinga, are pretty scarce, what is evidenced in this work is that there are native species suitable for use in methodologies of Degraded-Area Recovery Projects (PRADs).

5. CONCLUSION

The species *Senna uniflora*, *Rhaphiodon echinus*, *Sida galheirensis*, *Mesosphaerum suaveolens*, *Hexasepalum teres*, *Waltheria rotundifolia*, *Trianthema portulacastrum* and *Herissantia crispa* have potential for use as vegetation cover for exposed soil in degraded areas. Through their species-specific attributes, such species showed that they have interesting characteristics of high propagation, coverage and densification. Planting these species can also initiate the natural regeneration processes of the impacted area, either through facilitated dispersion, nitrogen fixation and/or soil protection.

AUTHOR CONTRIBUTIONS

The manuscript is part of the master's thesis of the first author. R.G.R, M.Z.B.C and D.S.P contributed to the study conception and design. The data collection was performed by J.N.C and A.P.F and the analysis by J.N.C, R.G.R, A.P.F and D.S.P. The first draft of the manuscript was written by J.N.C and all authors commented on previous versions of the manuscript and gave final approval for publication. R.G.R and D.S.P secured funding and logistic support.

6. ACKNOWLEDGEMENTS

We acknowledge funding by the Brazilian government from the Ministério do Desenvolvimento Regional (MDR) as part of the Projeto São Francisco environmental licensing requirements. We also thank all team of the NEMA by support.

7. REFERENCES

Alves APA, Pereira TMS, Marques AL, Moura DC, Melo JIM. Ecological succession in mineral exploration in the semiarid of the Paraiba state (Brazil). ACTA Geográfica. 2018;12(29):75-93. doi: 10.5654/acta.v12i29.5020

Andrade LE, Forzza RC, Walter GZ, Filardi FLR. Brazilian Flora 2020: Innovation and collaboration to meet Target 1 of the Global Strategy for Plant Conservation (GSPC). Rodriguésia. 2020;69(4):1513-1527. doi:10.1590/2175-7860201869402

Chase MW, Christenhusz MJM, Fay MF, Byng JW, Judd WS, Soltis DE, et al. APG IV. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Botanical Journal of the Linnean Society. 2016;181(1):1-20. doi:10.1111/boj.12385

Araújo HFP, Silva JMC. The Avifauna of the Caatinga: Biogeography, Ecology, and Conservation. In: Silva, J. M. C.; Leal, I. R. & Tabarelli, M. eds. Caatinga: The largest tropical dry forest region in South America. Switzerland: Springer International Publishing; 2017. p. 181-210. ISBN: 9783319683393

Bezerra AMR, Lazar A, Bonvicino CR, Cunha AS. Subsidies for a poorly known endemic semi-arid biome of Brazil: non - volant mammals of an eastern region of Caatinga. Zoological Studies. 2014;53(16):1-13. doi: 10.1186/1810-522X-53-16

Carpanezzi AA. Espécies para recuperação ambiental. In: Galvão APM. Espécies não tradicionais para plantios com finalidades produtivas e ambientais. Colombo: Embrapa Florestas; 1998 [cited 2022 January 22]. p.43-53. Available from: http://www.alice.cnptia.embrapa.br/handle/doc/307861

Coe HHG, Souza LOF. The brazilian "Caatinga": ecology and vegetal biodiversity of a semiarid region. In: Dry forests: ecology, species diversity, and sustainable management. Nova publishers; 2014. 201 p. ISBN: 9781633212916

Córdula E, Morim MP, Alves M. Morphology of fruits and seeds of Fabaceae occurring in a priority area for the conservation of Caatinga in Pernambuco, Brazil. Rodriguésia. 2014;65(2):505-516. doi: 10.1590/S2175-78602014000200012

Favero C, Jucksch I, Costa LM, Alvarenga RC, Neves JCL. Biomass productivity and nutrient accumulation by spontaneous and leguminous species used for green manure. Revista Brasileira de Ciência do Solo. 2000;24(1):171-177. doi: 10.1590/S0100-06832000000100019

Fernandes MF, Queiroz LP. Vegetação e flora da Caatinga. Ciência e Cultura. 2018;70(4):52-56. doi: 10.21800/2317-66602018000400014

Fenner M, Thompson K. Seed ecology. 2ª. ed. London: Chapman and Hall; 2005. ISBN 978-0521653688

Ferreira LL, Almeida DG de, Ribeiro TS, Montenegro INA, Porto VNC. Capacidade de absorção de fósforo e de potássio por espécies espontâneas em unidades de produção de base ecológica no Brejo Paraibano. Scientia Plena. 2013;9(5):1-8.

Fidalgo O, Bononi VLR. Técnicas de coleta, preservação, e herborização de material botânico. São Paulo: Instituto de Botânica; 1989.

Gris D, Temponi LG, Marcon TR. Native species indicated for degraded area recovery in Western Paraná, Brazil. Revista Árvore. 2012; 36(1):113-125. doi: 10.1590/S0100-67622012000100013

Grisi PU, Gualtieri SCJ, Ranal MA, Santana DG de. Allelopathic influence of aqueous extract of *Sapindus saponaria* L. root on barnyardgrass and morningglory. Bioscience Journal. 2013; 29(3):760-766.

Guariguata MR, Ostertag R. Neotropical secondary forest succession: changes in structural and functional characteristics. Forest Ecology and Management. 2001;148:185-206. doi: 10.1016/S0378-1127(00)00535-1

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology. 2005;25:1965-1978. doi:10.1002/joc.1276

Holanda AC, Lima FTD, Silva BM, Dourado RG, Alves, AR. Vegetation structure caatinga in remaining from different with historical disturbance in the region of Cajazeirinhas - PB. Revista Caatinga. 2015;28(4):142 – 150. doi: 10.1590/1983-21252015v28n416rc

Judd WS, Campbell CS, Kellogg EA, Steven, PF, Donoghue MJ. Plant Systematics: a phylogenetic approach. 4ª. ed. EUA: OUP; 2015. ISBN 978-1605353890.

Klein, R.M. Southern Brazilian phytogeographic features and the proble influence of upper quaternary climatic changes in floristic distribuition. Boletim Paranaense de Geociências. 1975;33:67-88.

Lorenzi H. Manual de identificação e controle de plantas daninhas. 7ª. ed. Nova Odessa: Platarum;

2014. ISBN 9788586714450.

Moro MF, Lughadha EN, Filer DL, Araújo FS de, Martins FR. A catalogue of the vascular plants of the Caatinga phytogeographical domain: a synthesis of floristic and phytosociological surveys. Phytotaxa. 2014;160(1):1-118. doi: 10.11646/phytotaxa.160.1.1

Neves AM, Costa PS, Coutinho MGS, Souza EB, Santos HS, Silva MGV, et al. Chemical characterization and the antimicrobial potential of species of the genus *Senna* Mill. (Fabaceae). Rev. Virtual Quim. 2017;9(6):2506-2538.

Oliveira EVS, Prata APN, Pinto AS. Characterization and attributes of herbaceous vegetation in a Caatinga fragment in the State of Sergipe, Brazil. Hoehnea. 2017;45(2):159-172. doi: 10.1590/2236-8906-70/2017

Pereira JS, Rodrigues SC. Growth of tree species used on the recovery of degraded area. Caminhos de Geografia. 2012;13(41):102–110.

Rodrigues RR, Lima RAF, Gandolfi S, Nave AG. On the restoration of high diversity forests: 30 years of experience in the Brazilian Atlantic Forest. Biological Conservation. 2009;142(6):1242-1251. doi:10.1016/j.biocon.2008.12.008

Silva CM, Silva CI da, Hrncir M, Queiroz RT, Imperatriz-Fonseca VL. Guia de plantas: visitadas por abelhas na Caatinga. Fortaleza: Fundação; 2012. ISBN 978-85-98564-09-0.

Silva JMC da, Leal IR, Tabarelli M. Caatinga: the largest tropical dry forest region in south America. Spinger; 2017. ISBN 978-3-319-68339-3.

Sousa RS, Sutili FJ. Aspectos Técnicos das Plantas utilizadas em Engenharia Natural. Ciência & Ambiente. 2017;46/47:31-71.

Van der Pijl L. Principles of dispersal in higher plants. 3ª. ed. Berlin: Springer; 1982. ISBN: 9783642879272.