

Articles

Seed bank in a restoration area with topsoil transposition in the Caatinga

Banco de sementes em área de restauração com transposição de solo superficial na Caatinga

Letícia de Brito Rodrigues¹ , Raphaela Aguiar de Castro¹ ,
Daniela Cristine Mascia Vieira¹ , Renato Garcia Rodrigues¹ ,
Marcos Vinicius Meiado^{II} 

¹Federal University of São Francisco Valley , Petrolina, PE, Brazil

^{II}Federal University of Sergipe , Itabaiana, SE, Brazil

ABSTRACT

Soil transposition is a nucleating technique that promotes successional dynamics with seed bank transfer. The study evaluated the efficiency of soil transposition in the arrival of new species from the soil seed bank of a Caatinga area undergoing recovery. Plots (32 m²) were established with three treatments—I) no soil translocation (ST); II) soil translocation on 15% of the area (T15%); and III) translocation on 30% of the area (T30%)—with eight replicates each. Two years later, soil was collected from each plot. Eight random samples were also collected from the preserved Caatinga area (positive reference)—the source of the translocated soil. The eight samples from each treatment were placed in a greenhouse and irrigated. We performed the analyses every 15 days, for 150 days, counting the emerged seedlings, species and number of individuals. We subjected the richness, density, and diversity index data to statistical comparison tests. We tested the similarity between the areas using ANOSIM. We also calculated phytosociological parameters. The areas T15% (8.25 ± 0.90 species) and T30% (11 ± 0.53 species) showed greater richness, with a statistical difference between ST and T30% (p = 0.0003). T30% also showed higher density (p = 0.009; average of 393.88 ± 46.63 individuals/m²). According to ANOSIM, the areas are not similar to each other (p < 0.05). Herbaceous species showed higher values of importance indexes (IV) in all areas. For the study site, soil translocation, applied to 30% of the area as a conditioning technique for degraded land, proved promising, enriching the seed bank of the area undergoing restoration.

Keywords: Brazil; Ecological succession; Herbs; Semiarid; Topsoil

RESUMO

A transposição do solo é uma técnica nucleadora que promove a dinâmica sucessional com transferência de banco de sementes. O estudo avaliou a eficiência da transposição do solo na chegada de novas espécies do banco de sementes do solo de uma área de Caatinga em recuperação. Foram estabelecidas parcelas (32 m²) com três tratamentos — I) sem translocação de solo (ST); II) translocação de solo em 15% da área (T15%); e III) translocação em 30% da área (T30%) — com oito repetições cada. Dois anos depois, coletou-se solo de cada parcela. Também foram coletadas oito amostras aleatórias da área de Caatinga preservada (referência positiva), onde coletamos o solo que foi transposto. Colocamos o solo em casa de vegetação, com irrigação. Realizamos as análises a cada 15 dias, durante 150 dias, contando as plântulas emergidas, espécies e número de indivíduos. Submetemos os dados de riqueza, densidade e índice de diversidade aos testes comparação estatística. Testamos a similaridade entre as áreas usando ANOSIM. Também calculamos parâmetros fitossociológicos. As áreas T15% ($8,25 \pm 0,90$ espécies) e T30% ($11 \pm 0,53$ espécies) apresentaram maior riqueza, com diferença estatística entre ST e T30% ($p = 0,0003$). T30% também apresentou maior densidade ($p = 0,009$; média de $393,88 \pm 46,63$ indivíduos/m²). Segundo a ANOSIM, as áreas não são semelhantes entre si ($p < 0,05$). As espécies herbáceas apresentaram maiores valores de índices de importância (IV) em todas as áreas. Para a área deste estudo, a translocação de solo em 30% da área, como técnica de condicionamento para áreas degradadas, mostrou-se promissora, enriquecendo o banco de sementes da área em recuperação.

Palavras-chave: Brasil; Sucessão ecológica; Herbáceas; Semiárido; Solo superficial

1 INTRODUCTION

The Caatinga, a seasonally dry tropical forest located mainly in the northeast region of Brazil, has a history of degradation results from excessive land use and the reduction or abandonment of the necessary fallow periods for maintaining productivity (Sá; Angelotti, 2009). Combined with these factors, there is the imminent concern about the expansion of semi-arid areas in desertification processes that increase the need for adequate restoration methods (Vieira et al., 2020). Also driven by the United Nations Decade on Ecosystem Restoration, ecosystem restoration is increasingly visible (Ribeiro; Massi, 2025).

Restoration projects currently prioritize the recovery of ecological processes over merely planting tree species (Socolowski et al., 2021). In this context, topsoil transposition emerges as a viable alternative. It can be applied as a strategy to improve soil conditions by incorporating organic matter, nutrients, macrofauna, and microflora, all of which are essential for soil restructuring and fertilization (Brancalion et al., 2015). Additionally, it facilitates the transfer of the native seed bank present in the soil and

litter, which plays a crucial role in enhancing plant cover and increasing biodiversity in the area under restoration.

The use of soil seed banks (SSB) has been recommended for ecological restoration due to its potential to reestablish an area, based on the species present (Garwood, 1989). This approach also reduces the costs associated with extracting soil from nearby remnant areas. According to Martins et al. (2017), SSB serves as one of the primary regeneration mechanisms, playing a crucial role in the colonization of natural or anthropogenic clearings, as well as in the recovery of large abandoned areas. Moreover, it facilitates the initiation of the successional process.

The seed bank comprises all viable seeds present in the soil, forming a dynamic system influenced by the influx of new seeds through seed rain and dispersal mechanisms (Vieira, 2004). Analyzing the seed bank allows for assessing the potential composition and diversity of the area.

Given the capacity of topsoil transposition to introduce new species through seeds and improve soil conditions, this study aimed to evaluate whether the topsoil transposition technique facilitates the emergence of new flora species to enrich the seed bank in an area undergoing recovery in the Caatinga. The study also aimed to compare vegetation responses to two levels of translocated soil cover, assess floristic similarity among regions, and characterize community structure.

2 MATERIALS AND METHODS

2.1 Area of study and experimental design

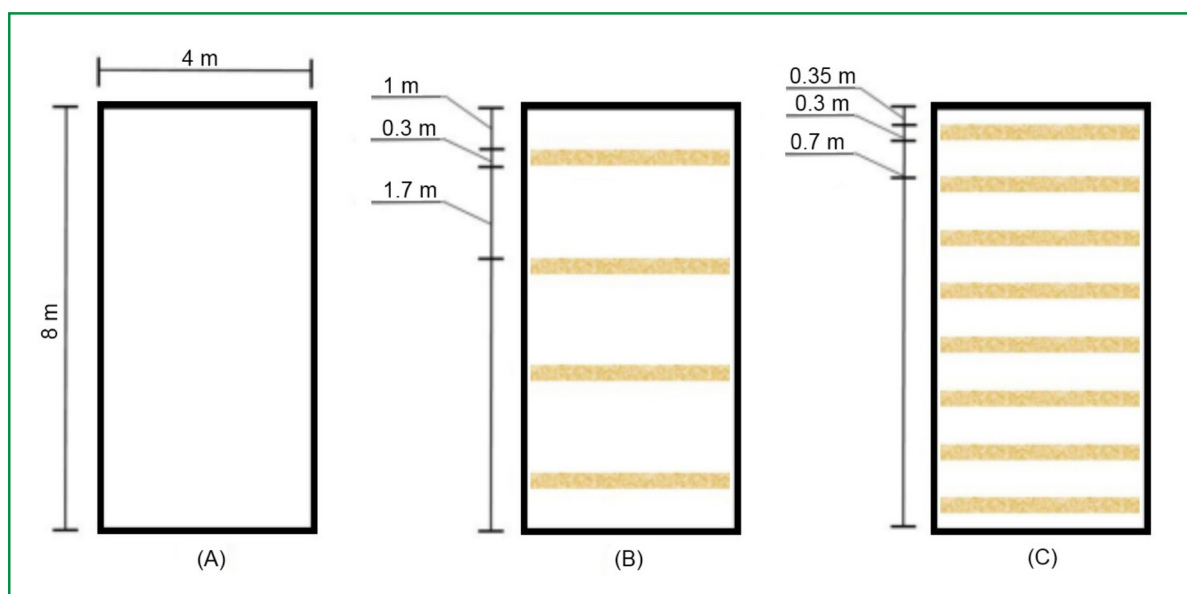
We conducted this research in an experimental area at the Federal University of São Francisco Valley (UNIVASF) in Petrolina, Pernambuco. According to Köppen's climate classification, the study area has a tropical semi-arid climate (BSh), with an average annual temperature ranging from 24°C to 28°C and an average annual rainfall of 535.5 mm (Teixeira, 2010). A total of 219 mm of precipitation was recorded in the year of field soil translocation, and 519 mm was recorded in the year of seed bank sampling. The area has experienced at least 18 years of degradation, during which the

topsoil was removed for the construction of an internal road on the university campus. Before the recovery intervention, the site was in an advanced state of degradation, characterized by compacted soil and the absence of native vegetation.

Soil designated for translocation was collected from 20 sampling points within the reference area and homogenized to obtain a composite sample. This area was also assessed for the impacts of soil removal as part of a complementary study. From this composite sample, we extracted the required amount of soil for each plot. The Caatinga areas from which the soil was translocated, measuring 4.8 and 4.1 ha, respectively, were designated as positive reference areas (AR). These areas were located approximately 400 and 920 m, respectively, from the restoration site.

We organized the experimental area into plots measuring 4 m x 8 m (32 m²), applying soil transposition in strips measuring 4 m x 0.3 m x 0.05 m. The experiment comprised three treatments with eight replicates each (Figure 1): I) C No soil transposition (ST). II) Soil transposition with four strips, representing 15% of the total plot area (T15%). III) Soil transposition with eight strips, representing 30% of the total plot area (T30%). Before implementing the soil transposition, we cleared the area and loosened to a depth of at least 30 cm to reduce compaction.

Figure 1 – Experimental design of soil transposition treatments



Source: Authors (2025)

In where: A - no soil transposition (ST); B - transposition in 15% of the plot through the application of four soil strips (T15%); C - transposition in 30% of the plot through the application of eight soil strips (T30%).

2.2 Data collection and analysis

At the end of the dry season, 2 years and 8 months after the implementation of soil translocation, soil samples were collected to characterize the established soil seed bank. A single sample was collected randomly from each experimental replicate, resulting in eight samples per treatment (ST, T15%, and T30%) and eight additional samples from the reference area. One sample was collected at each of eight randomly selected sampling points within the reference area. Within each plot, sampling was performed using a 30 × 20 × 5 cm frame. A total of 3 L of soil was collected from each plot and transferred to polypropylene trays (43.5 × 29.6 × 7.5 cm) equipped with drainage holes. We placed the trays in a greenhouse under a fine shade screen (30%). We irrigated the trays daily for 30 minutes using suspended micro-sprinklers. Additionally, we set up eight trays containing substrate as a methodological control to identify any spontaneous species originating from the greenhouse. We excluded any species that appeared. We evaluated the samples every 15 days, recording the species that emerged and their abundance.

Data collection continued for 150 days after the beginning of the experiment, by which time seedling emergence in the trays had stabilized. We therefore considered this period sufficient to capture the entire germinable fraction of the soil seed bank under the experimental conditions. We identified the species by comparing them with specimens in the Herbarium of Reference of the Northeastern Backlands (HRSN) and consulting herbarium specialists. To facilitate identification, we transplanted the unidentified seedlings to allow them to grow and be identified.

We removed the identified and counted seedlings from the trays to prevent shading and possible seed dispersal within the trays. Based on the floristic list, we classified the species by habit and origin according to the “Flora and Fungi of Brazil” (2020). Using the richness and abundance of the emerged species, we calculated the diversity using Fisher’s Alpha index (Fisher et al., 1943). We assessed the normality of the richness, density, and diversity data using the Shapiro–Wilk test. The richness and diversity data followed a normal distribution. Richness and density was analyzed using one-way analysis of variance (ANOVA), followed by Tukey’s post hoc test for pairwise

comparisons. As the density data did not follow a normal distribution, we fitted a generalized linear model (GLM) with a quasipoisson distribution, followed by Duncan's multiple range test for pairwise comparisons. We also performed a similarity analysis (ANOSIM) (Clarke; Green, 1988) between treatments and plotted the similarity cluster between areas using the Bray-Curtis dissimilarity index with UPGMA (average linkage).

We analyzed the phytosociological parameters for each area. For each species, we calculated the absolute and relative values of density and frequency. We calculated these parameters using the methods proposed by Mueller-Dombois and Ellenberg (1974), as showed in equations (1), (2), (3) and (4).

$$\text{Absolute Frequency (AF)} = \frac{\text{Number of plots with occurrence of the species}}{\text{Total number of plots}} \quad (1)$$

$$\text{Relative Frequency (RF)} = \frac{\text{Absolute frequency of the species}}{\sum \text{FA espécies amostradas}} \times 100 \quad (2)$$

$$\text{Absolute Density (AD)} = \frac{\text{Total number of individuals of the species}}{\text{Total area}} \quad (3)$$

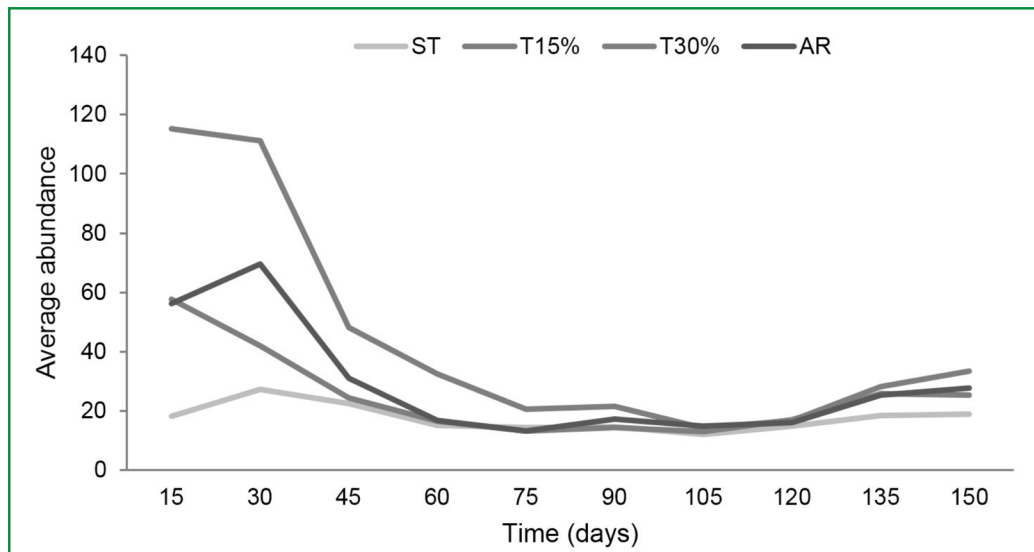
$$\text{Relative Density (RD)} = \frac{\text{Number of individuals of the species}}{\text{Total number of individuals}} \times 100 \quad (4)$$

In addition to the parameters mentioned above, we calculated the importance value (IV) by summing the relative frequency and relative density of each species, as proposed by Fabricante *et al.* (2016). We performed statistical analyses using the software R (R Development Core Team, 2013) and STATISTICA 13 (STATSOFT, 2012).

3 RESULTS

The first seedlings emerged in the trays in the first few weeks of irrigation (Figure 2), demonstrating the rapid germination response of the species in the Caatinga.

Figure 2 – Average abundance of individuals emerged in the trays during 150 days



Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area.

A total of 7090 individuals emerged, with 760 in the trays with samples from the area without soil transposition (ST), 1413 from the area with 15% soil transposition (T15%), 3151 from the area with 30% transposition (T30%), and 1766 from the positive reference area (AR). These individuals were distributed across 19 families, 38 genera, and 66 species. Among the species found, 13 were not identified and were considered indeterminate, five were identified at the family level, and seven were identified at the genus level, as presented in Table 1.

Table 1 – List of species that emerged from the seed bank, including their respective families, habits, abundance by area of occurrence and origin

Family/Specie	Habit	Areas				Origin
		ST	T15%	T30%	AR	
Asteraceae						
<i>Ageratum conyzoides</i> L.	Herbaceous/ Subshrub	0	0	0	3	N
<i>Centratherum punctatum</i> Cass.	Herbaceous/Subshrub	0	3	0	8	N
<i>Eclipta</i> sp.	Herbaceous	0	1	0	0	N
<i>Gamochaeta americana</i> (Mill.) Wedd.	Herbaceous	0	0	0	4	N

To be continued ...

Table 1 – continuation

Family/Specie	Habit	Areas				Origin
		ST	T15%	T30%	AR	
Boraginaceae						N
<i>Euploca procumbens</i> (Mill.) Diane & Hilger	Herbaceous/Subshrub	1	0	2	3	N
Burseraceae						
<i>Commiphora leptophloeos</i> (Mart.) J.B.Gillett	Shrub /Tree	0	0	0	1	N
Cleomaceae						N
<i>Physostemon lanceolatum</i> Mart. & Zucc.	Herbaceous	0	1	11	1	N
Cyperaceae						N
<i>Cyperus fugax</i> Liebm.	Herbaceous	51	280	674	643	N
<i>Cyperus squarrosus</i> L.	Herbaceous	6	43	225	207	N
<i>Cyperus subsquarrosus</i> (Muhl.) Bauters	Herbaceous	20	150	409	540	N
<i>Cyperus surinamensis</i> Rottb.	Herbaceous	4	0	0	0	N
<i>Eleocharis geniculata</i> (L.) Roem. & Schult.	Herbaceous	1	30	45	0	N
<i>Eleocharis</i> sp.	Herbaceous	22	16	42	1	N
<i>Fimbristylis dichotoma</i> (L.) Vahl	Herbaceous	12	6	56	5	N
<i>Scleria</i> sp.	Herbaceous	4	17	93	8	N
Cyperaceae sp.		0	0	7	4	
Eriocaulaceae						
<i>Eriocaulon</i> sp.	Herbaceous	0	2	0	7	N
Euphorbiaceae						N
<i>Euphorbia hirta</i> L.	Herbaceous	62	6	20	26	N
Fabaceae						
<i>Mimosa tenuiflora</i> (Willd.) Poir.	Tree/Shrub / Subshrub	0	0	0	3	N
Lythraceae						
<i>Ammannia latifolia</i> L.	Herbaceous	0	0	0	1	N
<i>Cuphea circaeoides</i> Sm. ex Sims	Subshrub	0	8	0	4	N
Lythraceae sp.		0	1	1	3	
Malvaceae						
<i>Sida galheirensis</i> Ulbr.	Subshrub	0	1	0	0	N
Microteaceae						
<i>Microtea celosioides</i> Moq. ex Sennikov & Sukhor.	Herbaceous	0	2	1	6	N

To be continued ...

Table 1 – continuation

Family/Specie	Habit	Areas				Origin
		ST	T15%	T30%	AR	
Molluginaceae						
Mollugo verticillata L.	Herbaceous	17	33	24	9	N
Onagraceae						
Ludwigia erecta (L.) H.Hara	Shrub	1	70	132	120	N
Ludwigia octovalvis (Jacq.) P.H.Raven	Subshrub/Shrub	0	0	1	0	N
Phyllanthaceae						
Phyllanthus niruri L.	Herbaceous/Subshrub	11	0	5	4	N
Plantaginaceae						
Bacopa gratioloides (Cham.) Edwall	Herbaceous/Subshrub	0	0	1	17	N
Monopera micrantha (Benth.) Barringer	Herbaceous	0	5	5	2	N
Scoparia dulcis L.	Herbaceous/Subshrub	26	139	63	7	N
Stemodia foliosa Benth.	Herbaceous/Subshrub / Shrub	0	18	5	16	N
Plantaginaceae sp1.		0	2	5	7	
Plantaginaceae sp2		0	0	1	0	
Poaceae						
Aristida adscensionis L.	Herbaceous	72	145	149	4	EI
Cenchrus echinatus L.	Herbaceous	244	46	190	1	N
Chloris sp.	Herbaceous	0	2	0	0	N
Dactyloctenium aegyptium (L.) Willd.	Herbaceous	2	3	3	0	EI
Digitaria sp1.	Herbaceous	3	31	22	1	N
Digitaria sp2.	Herbaceous	4	0	0	3	N
Eragrostis cf. maypurensis (Kunth) Steud.	Herbaceous	0	1	0	0	N
Eragrostis ciliaris (L.) R.Br.	Herbaceous	0	0	3	0	EI
Eragrostis pilosa (L.) P.Beauv.	Herbaceous	0	0	0	1	EI
Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	Herbaceous	0	1	0	1	EI
Panicum trichoides Sw.	Herbaceous	0	0	0	22	N
Pappophorum pappiferum (Lam.) Kuntze	Herbaceous	0	0	0	2	N
Poaceae sp.		95	29	114	13	
Portulacaceae						
Portulaca elatior Mart. ex Rohrb.	Herbaceous	101	275	792	9	N
Portulaca oleracea L.	Herbaceous	0	0	0	3	EI

To be continued ...

Table 1 – conclusion

Family/Specie	Habit	Areas				Origin
		ST	T15%	T30%	AR	
Rubiaceae						
<i>Richardia brasiliensis</i> Gomes	Herbaceous	0	0	1	0	N
<i>Staelia virgata</i> (Link ex Roem. & Schult.) K.Schum.	Herbaceous/Subshrub	0	37	39	5	N
Solanaceae						
<i>Schwenckia americana</i> Rooyen ex L.	Herbaceous	0	3	3	29	N
<i>Solanum caatingae</i> S. Knapp & Särkinen	Herbaceous	0	4	2	1	N

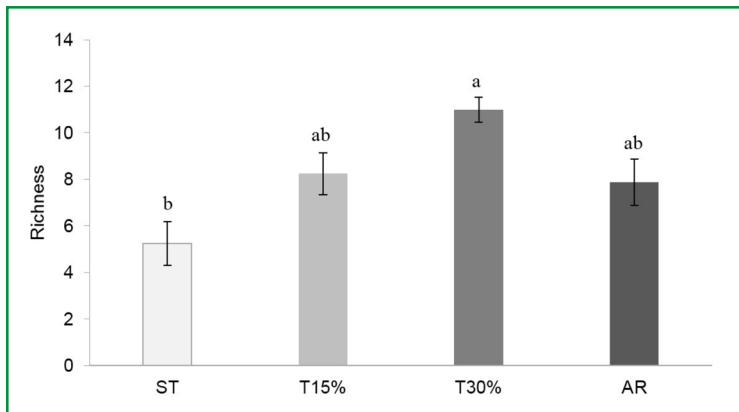
Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area; N - species native to Brazil; EI - invasive exotic species.

The most representative families were Poaceae and Cyperaceae, with greater richness in all study areas. The Plantaginaceae family was also well represented. For habit, 70.83% of the identified species are herbaceous. The herbaceous/shrub habit (14.58%) and the shrub habit (4.17%) were the second and third most representative habits, respectively (Table 1). *M. tenuiflora* and *C. leptophloeos* make up the tree stratum of the seed bank, emerging only in the positive reference area (Table 1), representing 4.17% of the identified species. For average species richness, the data presented normal distribution ($p = 0.2055$) and showed a statistically significant difference between the ST and T30% areas ($p = 0.0003$). The average richness observed in the ST, T15%, T30% and AR areas was 5.25 ± 0.94 ; 8.25 ± 0.90 ; 11 ± 0.53 ; and 7.88 ± 0.99 , respectively (Figure 3).

For density (individuals/m²), the data presented non-normal distribution ($p = 0.004$) and showed a statistical difference between the treatments ($p = 0.009$), with the area with the highest percentage of soil transposition (T30%) being different from the others. The densities in the ST, T15%, T30% and AR areas were 738.15 ± 231.56 individuals/m², 1372.32 ± 307.81 individuals/m², 3060.41 ± 362.33 individuals/m² and 1715.23 ± 699.82 individuals/m², respectively (Figure 4).

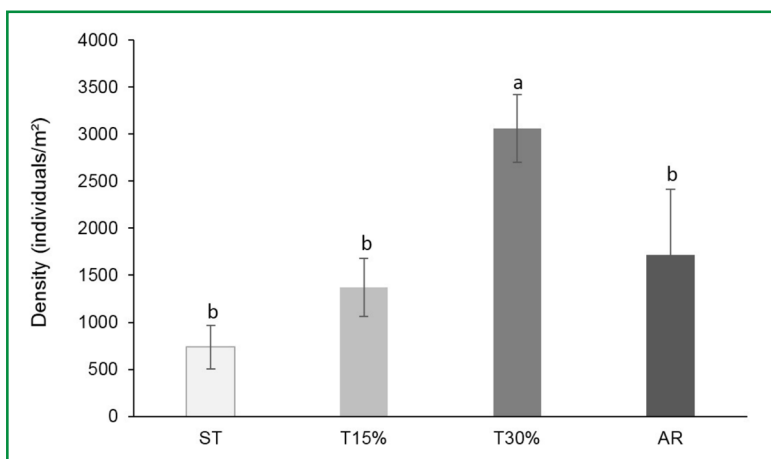
Figure 3 – Average species richness emerged from the soil seed bank in the study areas



Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area. Means followed by the same letter do not differ from each other according to the Tukey test ($p < 0.05$).

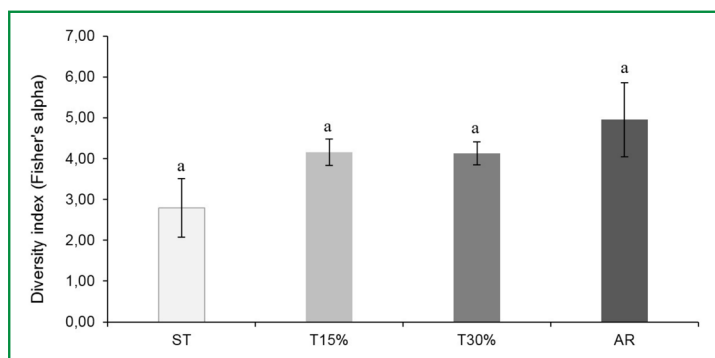
Regarding diversity, the data presented normal distribution ($p = 0.3175$). The diversity index (Fisher's alpha) showed no statistical difference between the study areas ($p = 0.1224$). The average diversity for the ST, T15%, T30% and AR areas was 2.79 ± 0.72 ; 4.15 ± 0.32 ; 4.13 ± 0.28 ; and 4.95 ± 0.91 , respectively (Figure 5). The similarity analysis (ANOSIM) demonstrated that the areas are not similar to each other, as shown in Table 2.

Figure 4 – Average species density (individuals/m²) from the soil seed bank in the study areas

Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area. Means followed by the same letter do not differ from each other according to the Duncan test ($p < 0.05$).

Figure 5 – Average diversity index (Fisher's alpha) from the soil seed bank in the study areas



Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area. Means followed by the same letter do not differ from each other according to the Tukey test ($p < 0.05$).

Table 2 – ANOSIM results (p-values and R-squared values) between the study areas

	ST	T15%	T30%	AR
ST	-	p: 0.016	p: 0.001	p: 0.001
T15%	R: 0,25	-	p: 0.037	p: 0.020
T30%	R: 0,47	R: 0,133	-	p: 0.003
AR	R: 0,5	R: 0,22	R: 0,46	-

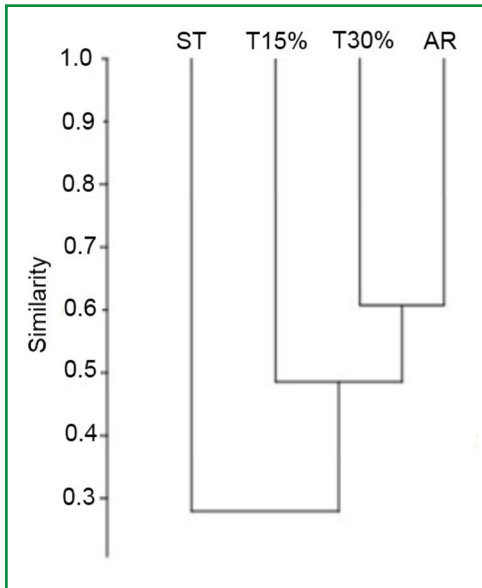
Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area.

Although ANOSIM indicates that the study areas have distinct compositions, the dendrogram based on the Bray-Curtis dissimilarity index (Figure 6) showed that the areas that received soil transposition are more similar to each other and more similar to the positive reference area.

For phytosociological analysis, ST, T15% and T30% were similar regarding the species with the highest importance values (considering the first 10), which included *P. elatior*, *C. fugax*, *C. echinatus*, *A. adscensionis*, *C. subsquarrosus*, and *Poaceae* sp. (Supplementary material). The families *Poaceae* and *Cyperaceae* were responsible for 60%, 60% and 70% of the 10 species with the highest IV in the ST, T15% and T30% areas, respectively (Supplementary material).

Figure 6 – Dendrogram of similarity between the study areas using the Bray-Curtis dissimilarity index



Source: Authors (2025)

In where: ST - no soil transposition; T15% - area with 15% soil transposition; T30% - area with 30% soil transposition; AR - positive reference area.

In the AR area, IV was distributed differently from the other areas (Supplementary material). The three species with the highest IV belong to the Cyperaceae family: *C. fugax*, *C. subsquarrosus* and *C. squarrosus*. *P. elatior* was the most successful species inhabiting the environment in T15% and T30%, with relative densities of 19.5% and 25.13%, respectively, followed by *C. fugax*, which had 19.8% and 21.39%, respectively. Another common species in both areas regarding IV was *C. subsquarrosus*, with 10.6% of the species in T15% and 12.98% in T30%. In ST, the highest IV was attributed to *C. echinatus* (0.40), representing 20% of the species, *P. elatior* (0.23), Poaceae sp. (0.19), *E. hirta* (0.17) and *A. adscensionis* (0.15). In positive reference area, the highest IVs were represented by *C. fugax* (0.43), *C. subsquarrosus* (0.37), *C. squarrosus* (0.18), and *L. erecta* (0.11).

4 DISCUSSIONS

The rapid emergency response of individuals in the nursery has also been observed in other studies on seed germination in the Caatinga (Ribeiro *et al.*, 2017). The rapid response of seeds to favorable conditions may represent a strategy for Caatinga plants to ensure higher survival and establishment rates during a short rainy season (Souza, 2021). The presence of tree species such as *M. tenuiflora* and *C. leptophloeos* indicates potential for transposition. These species are pioneer trees adapted to the Caatinga and play an important role in the ecological succession of degraded areas (Carvalho, 2009; Pessoa *et al.*, 2022).

It is also important to highlight that the seed bank observed at the time of sampling reflects a dynamic process involving the initial translocation of seeds, germination, mortality, subsequent propagule production, seed rain, and changes in vegetation structure and composition throughout the study period. Thus, the establishment and persistence of a soil seed bank are governed by multiple interacting ecological processes operating over time. According to Almeida (2016), these factors include seed production, viability periods, dormancy, dispersal processes, competition, predation, and the presence or absence of propagule sources. For Costalonga (2006), seed banks are predominantly composed of propagules from species that produce large quantities of seeds and have long longevity, characteristics commonly found in pioneer species. According to the author, secondary and climax species generally form seedling banks due to high predation rates and low viability. Therefore, it is more difficult to observe the arrival of these species in areas undergoing early succession. The colonization of environments depends on the presence of propagules, spatial patterns in the environment, existing vegetation, and biotic and abiotic factors (Pillar, 1994).

The predominance of herbaceous species and the lower emergence of tree species were also observed in other studies on seed banks in the Caatinga (Ferreira *et al.*, 2014; Ribeiro *et al.*, 2017; Sousa *et al.*, 2020). Herbaceous species are essential

in the succession process, playing a crucial role in the initial phase of colonization in altered environments and providing a microclimate favorable for the establishment of other species. They protect the soil, reduce solar incidence, maintain soil moisture, and alter fertility (Ferreira et al., 2014). The greater richness and abundance in the T30% area can be explained by the presence of a larger amount of transposed soil and, probably, seeds. Soil translocation can also introduce organic matter, soil macrofauna, microorganisms, and nutrients, which can improve soil conditions and structure and, consequently, facilitate the establishment of new species (Brancalion et al., 2015).

The study area exhibited a high degree of degradation and lacked topsoil layers; therefore, herbaceous species are expected to drive local changes that, over time, create an environment suitable for the arrival and persistence of other shrub and tree species. Combining the translocation technique with the seeding and planting of these species may also be necessary to foster succession in areas of this type.

It is important to note that areas that was subjected only soil preparation (ST) also showed emerging species. In the same study area, an *in-situ* analysis of species by Castro et al. (2024) found that areas with and without transposition exhibited similar richness and density. Although the seed bank differs with transposition, the local edaphoclimatic conditions still do not allow this bank to germinate completely. Schneider et al. 2023 also demonstrated that active restoration techniques are preferred. Sousa et al. (2020) compared the results from the degraded area with those from the area with topsoil transposition and found that the recovering area had greater vegetation cover, increased microbial activity, and larger mesofauna populations. Sousa et al. (2020) successfully implemented the soil transposition technique to recover an area in the Caatinga within the Seridó desertification nucleus. They observed a new and diverse seed bank in the study area, which stimulated ecological succession.

Factors such as the availability of material for translocation and the feasibility of transporting it should be considered when applying this technique. The impacts of soil removal from reference areas for translocation were also assessed in a parallel study,

which found that species richness and vegetation cover in the source areas recovered to pre-removal levels within less than one year.

Regarding diversity, Fisher's Alpha index relates the number of species to the number of individuals in a community (Fisher et al., 1943). The equality in diversity between areas may be attributed to the fact that Fisher's Alpha index gives importance to rare species, represented by a single individual. Thus, increases in species richness and abundance observed in some treatments did not necessarily result in a statistically significant increase in Fisher's alpha, indicating that changes in richness and abundance were not necessarily reflected in the estimated diversity of the seed bank.

For Phytosociological analysis, Poaceae and Cyperaceae, the most representative families in this study, were generally like those found in other studies related to seed banks in the Caatinga (Sousa et al., 2021; Pessoa et al., 2022). Sousa et al. (2020), in a study on the transposition of seed banks as a strategy to facilitate the ecological restoration of a degraded area in a desertification-prone region, identified 17 families. The most representative of these, in decreasing order of species, were Fabaceae, Poaceae, Euphorbiaceae, Malvaceae, Asteraceae, Convolvulaceae, and Cyperaceae. The occurrence of the three species with the highest importance index values belonging to the Cyperaceae family can be explained by the cosmopolitan distribution of the family and the fact that its species have varied reproductive strategies that can adapt to different habitats. Species from this family colonize disturbed environments and store their seeds in seed banks until environmental conditions become favorable (Leck; Schutz, 2005).

Poaceae is one of the most representative families of herbaceous plants, with most species considered invasive aliens, originating from Africa, well established in semiarid conditions due to their high degree of biological invasion (Parente et al., 2013). *A. adscensionis* is an invasive alien species that needs to be monitored frequently due to its high flammability and fire risk (Luz et al., 2023). In this study, the species occurred in all treatments and is among the top 10 in importance value

indexes. The species *E. ciliares*, *E. pilosa*, *E. tenella*, *P. oleracea*, and *D. aegyptium*, invasive aliens, also appeared, but presented low relative frequency (RF), relative density (RD) and importance value (IV). Additional field analyses of these species should be conducted to determine whether there will be an increase in density and potential negative consequences for the ecosystem and the need for management. However, it is important to emphasize the importance of sourcing soil for translocation from areas free from invasive alien species.

5 CONCLUSIONS

The topsoil transposition technique, used to condition degraded areas of the Caatinga, has shown promise by enriching the seed bank of the area undergoing restoration. In the field, this seed bank can create favorable conditions for ecological succession in the degraded area.

The 30% transposition treatment was the only one that stood out in terms of richness, promoting enrichment of the germinable seed bank and resulting in a significant number of individuals compared to areas without transposition. It was also the treatment that showed the greatest similarity to the reference areas. Therefore, for highly degraded areas like the one in this study—which lack vegetation but have available material and viable transport options—soil transposition is an approach worth considering. A cost-benefit analysis should be conducted on a case-by-case basis to determine the feasibility of using this technique.

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Authorship Contribution

1 Letícia de Brito Rodrigues

Bachelor's in Biological Sciences

<https://orcid.org/0009-0003-0524-6739> • leticia.brito0107@gmail.com

Contribution: Conceptualization; Data curation; Methodology; Project administration; Software; Validation; Visualization; Writing – original draft preparation; Writing – review & editing

2 Raphaela Aguiar de Castro

Agricultural Engineering, Doctor's in Ecology and Conservation, Senior Environmental Analyst

<https://orcid.org/0000-0002-4678-8118> • rapha.aguiarcastro@gmail.com

Contribution: Conceptualization; Data curation; Methodology; Project administration; Software; Supervision; Visualization; Writing – review & editing

3 Daniela Cristine Mascia Vieira

Ecologist, Doctor's in Biological Sciences, Director of Research and Planning

<https://orcid.org/0000-0001-9103-6161> • daniela.mascia.vieira@gmail.com

Contribution: Conceptualization; Methodology; Supervision; Visualization; Writing – review & editing

4 Renato Garcia Rodrigues

Bachelor's and Licentiate's degree in Biological Sciences Ecologist, Doctor's in Ecology and Conservation, University professor and coordinator

<https://orcid.org/0000-0001-5576-8621> • renato.garcia@univasf.edu.br

Contribution: Conceptualization, Funding Acquisition, Methodology, Resources, Supervision, Visualization, Writing – Review & Editing

5 Marcos Vinicius Meiado

Bachelor's in Biological Sciences, Doctor's in Plant Biology, Professor

<https://orcid.org/0000-0002-9334-5985> • marcos_meiado@yahoo.com.br

Contribution: Conceptualization, Data Curation, Formal Analysis, Methodology, Supervision, Visualization, Writing – Review & Editing

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Prof. Dr. Alex Guimarães Sanches, *Section Editor*

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Miguel Favila, *Managing Editor*