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Richness and Abundance of Soil Seed Bank in Different Agroecosystems in Central Veracruz, Mexico
Riqueza y Abundancia del Banco de Semillas en Diferentes Agroecosistemas en la Zona Centro de Veracruz, México

Arturo Pérez-Vázquez[1], Carlos Nahin Castro-Jose[1‡], Ana Lid del Angel-Pérez[2], and Mónica de la Cruz Vargas-Mendoza[1]

[1] Colegio de Postgraduados, Campus Veracruz. Carretera Xalapa-Veracruz km 88.5, Predio Tepetates. 91690 De Manlio F. Altamirano, Veracruz, México; (A.P.V.), (C.N.C.J.), (M.C.V.M).
[‡] Corresponding author: castro.carlos@colpos.mx
[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Carretera libre Veracruz-Córdoba km 34.5, Localidad La Esperanza. Apdo. Postal 429. 91700 Medellín de Bravo, Veracruz, México; (A.L.A.P.).

SUMMARY

The soil seed bank is key to plant succession. However, agricultural activities have had a great impact on the vegetation and its composition. The aim was to determine the soil seed bank in different grazing agroecosystems in the central part of Veracruz state, Mexico. Richness, abundance, diversity, equity, dominance and similarity of the species were quantified and compared among four agroecosystems (silvopastoral, pasture-trees, traditional grazing, and Acahual or secondary vegetation) in Veracruz, Mexico during the year 2017. Samples were collected. of soil at two depths (0-5, > 5-10 cm). A statistical difference was found in the seed bank ($P < 0.05$) in silvopastoral at both depths, 0-5 (H' = 2.13) and 5-10 (H' = 1.86). Equity and dominance were higher for this agroecosystem (0.86) and for Acahual (0.58) with statistical differences ($P < 0.05$). No statistical differences were found at sites between depths ($P > 0.05$). Similarity was greater than 50% at all sites and increased with soil depth. The evidence suggests that the greatest diversity of the seed bank was in silvopastoral from 0 to 5 cm deep. The seed bank has potential for the restoration of vegetation, mainly herbaceous, and can promote the development of shrubs and trees, despite the management of cattle ranching sites.

Index words: *disturbance, paddock, pasture, plant succession, restoration.*

RESUMEN

El banco de semillas del suelo es clave para la sucesión vegetal. Sin embargo, las actividades agrícolas han tenido un gran impacto en la vegetación y su composición. El objetivo fue determinar el banco de semillas del suelo en diferentes agroecosistemas de pastoreo en la parte central del estado de Veracruz, México. Se cuantificó y comparó la riqueza, abundancia, diversidad, equidad, dominancia y similitud de las especies entre cuatro agroecosistemas (silvopastoril, pastos-árboles, pastoreo tradicional, y Acahual o vegetación secundaria) en Veracruz, México durante el año 2017. Se recolectaron muestras de suelo a dos profundidades (0-5, > 5-10 cm). Se encontró diferencia estadística del banco de semillas ($P < 0.05$) en silvopastoril en ambas profundidades, 0-5 (H'= 2.13) y 5-10 (H´ = 1.86). La equidad y la dominancia fueron mayores para este agroecosistema (0.86) y para Acahual (0.58) con diferencias estadísticas ($P < 0.05$). No se encontraron diferencias estadísticas en sitios entre profundidades ($P > 0.05$). La similitud fue mayor al 50% en todos los sitios y aumentó con la profundidad del suelo. La evidencia sugiere que la mayor diversidad del banco de semillas estuvo en silvopastoril de 0 a 5 cm de profundidad. El banco de semillas tiene potencial para la restauración de la vegetación, principalmente herbácea y puede promover el desarrollo de arbustos y árboles, a pesar del manejo de sitios para la ganadería.

Palabras clave: *perturbación, ganadería, pasto, sucesión vegetal, restauración.*

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INTRODUCTION

Mexico is one of the countries with high biodiversity due to the orographic variability, which generates different types of climates due to the altitudinal gradient in relatively short distances (Martínez-Meyer, Sosa, and Álvarez, 2014). The Veracruz state represent the diversity of ecosystems, agroecosystems, and species adapted to the different environmental conditions. However, it is also one of the states strongly affected by anthropogenic activities, such as land use change due to agricultural activities and extensive livestock production. These activities have transformed broad areas of land where the original vegetation was totally or partially removed with strong impact on its structure, as well as the soil seed bank and the potential to recovery the original vegetation (Zhang, Shi, Shen, and Chen, 2012; Martínez-Meyer *et al.,* 2014; Reid, Holl, and Zahawi, 2015).

Gliessman *et al.* (2007) pointed out that an agroecosystem is defined as a modified ecosystem towards a farm production. Therefore, the agroecosystem is the product of the original vegetation transformation into productive land mainly for food production. Livestock is one of the main activities in Veracruz state, which extensive changes and different management generate substantial changes in the local ecosystems with huge impact on vegetation diversity and soil seed bank (Guevara and Laborde, 2012). Then the elimination of natural vegetation, and the transformation through grass monocultures (pastures), mainly exotic, and the simplification of cultivated species (Del Ángel-Pérez, Villagómez, Mendoza, and Rebolledo, 2006). Therefore, landscape fragmentation hasten species loss, biodiversity changes and alterations on ecosystem functioning (Trilleras, Jaramillo, Vega and Balvanera, 2015).

The seed bank is a reservoir in the soil that contributes to the natural vegetation succession when the latency is broken, and favourable conditions trigger seeds germination (Erfanzadeh, Hamzeh, Azarnivand, and Pétillon, 2013; Williams-Linera, Bonilla, and López, 2016), especially in ecosystems with regular disturbances. The importance of soil seed bank is close related to the conservation and restoration of threatened ecosystems (Ottewell, Bickerton, and Lowe, 2011). The change in land use has an important effect on soil seed bank (Cano-Salgado, Zavala, Orozco, Valverde, and Pérez, 2012) and for local vegetation conservation. Therefore, soil seed bank is an important component of ecosystem resilience (Ge, Wang, Zhang, Song, and Liu, 2013) and key for successional process (Cui *et al.,* 2016; Anju, Warrier, and Kunhikannan, 2022). Therefore, the aim of this study was to determine the soil seed bank in different grazing agroecosystems in the central part of Veracruz state, Mexico.

MATERIAL AND METHODS

Field study. The study was conducted in Loma Iguana, Municipality of La Antigua, Veracruz. The community is located between the coordinates 96° 18' 40" W, 19° 14' 50" N and at an elevation altitude ranging from 27 to 46 meters of altitude. The study area is characterized by Aw_2 climate, warm subhumid with summer rains (Soto and Giddings, 2011). The average annual rainfall ranges from 1400 to 1600 mm, and rainy season is from June until September. The average annual temperature is 28 °C, and the lowest and highest is 20.3 °C and 30.7 °C. The field study is low-lying sandy clay hillocks formed by consolidated dunes with flat areas, and hills with some flood areas.

Agroecosystems under study. The study was carried out at the beginning of the rainy season (June) until December (2017). In the study area different paddock grazing exist, such as: 1) Silvopastoral system (Sps), 2) Traditional grazing system (Tgs), 3) Pasture and tree system (Pts), and 4) Acahual (Ac), or secondary natural vegetation. A brief description of each agroecosystem under study is showed below:

Silvopastoral system (Sps): It is a six-year established agroecosystem with timber species such as cedar (*Cedrela odorata* L. (1759)), mahogany (*Swietenia macrophylla* King.), oak tree (*Tabebuia rosea* (Bertol.) DC. (1845)), melina (*Gmelina arborea* Roxb.), and solerillo (*Cordia alliodora* Ruiz & Pav.) which integrate the tree canopy, while the herbaceous stratum was dominated by star grass (*Cynodon sp.*), and native grasses (Figure 1a).

Pasture and tree system (Pts): It is a grazing system with an arboreal canopy with more than 20 years ages with quebrache trees (*Diphysa robinioides* Benth.) spread almost homogeneously throughout the land. The site presents an herbaceous stratum dominated by Poaceae family, which are more evident under the tree canopies. Species of the families Malvaceae and Euphorbiaceae grow in clearings spots (Figure 1b). This site has been dedicated to cattle ranching activities for 20 years.

Traditional grazing system (Tgs): In this system grows low-altitude natural vegetation to feed the cattle. The species in the herbaceous stratum are broadleaf-like and vines. In addition, part of the land is used to enclose and grazing calves and sometimes for adult cattle. The soil has stony outcrops in some areas, and it is a bit bare due to overgrazing in some spots (Figure 1c). This piece of land was used for agricultural production, especially maize during 30 years ago.

Acahual (Ac): This is the typical ecosystem in the region called deciduous lowland forest or secondary vegetation. This secondary vegetation has approximately 50 years old without change until now (Figure 1d). The shrub vegetation is between two and five meters high, while the arboreal vegetation exceeds ten meters.

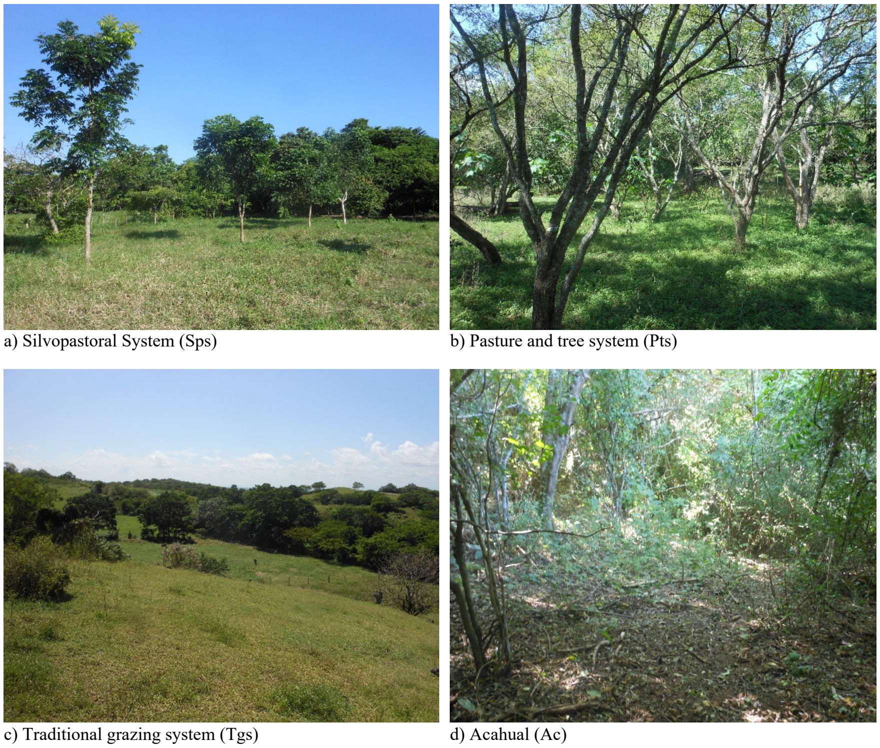

Figure 1. General view of the for studied agroecosystems.

Soil sampling. In June 2017, the soil samples were taken after a rainy event. In each of the agroecosystems, six points were chosen by using random numbers. The soil samples were collected at two depths (0 to 5 cm, > 5 to 10 cm) to evaluate the soil seed bank. The soil samples were kept in their structure and placed in plastic trays of 18 cm × 20 cm × 10 cm wide, long and deep. At the bottom of the trays, 1-cm thick layer of sand was placed to facilitate drainage. The trays were placed on 1-meter high of iron tables and covered with shading mesh to avoid the over exposition to the sunlight and reducing the impact of the rain.

Soil samples were collected at each sampling site for physicochemical analysis. Soil samples for biological determinations were taken at depths of 0-10 and >10-20 cm. In both cases, the soil samples were placed in polyethylene bags and taken to the laboratory for processing.

Trays handling. Trays containing the soil samples were irrigated with a rain-type hose to maintain a constant humidity (65%) to allow seeds germination and seedlings growth. Soil moisture was recorded with a Field Soil moisture meter (TDR 100 model). Just in case of rain events, irrigation was omitted. The trays were kept under observation for seven months (June to December, 2017). All plants were collected for botanical identification.

Recorded variables. Environmental conditions such as temperature and relative humidity were recorded. For the physical analysis of soil, it was determined: texture (Bouyoucos procedure). For chemical analysis was determined: nitrogen (nitrites), phosphorus, and potassium (Hanna Instruments photometric method), organic matter (Walkley-Black method), pH and electrical conductivity (with potentiometer). All soil analysis were carried out according to the NOM-SEMARNAT-2000 (SEMARNAT, 2002). For the edaphic macrofauna, soil samples were spread out on a table and revised thoroughly with a magnifier in the lab.

For soil seed bank, the following variables were estimated: Species richness (the total number of germinated species), the total abundance of species (is a measure of the relative abundance of each species), Shannon-Wiener diversity index (the proportional abundance of each of the registered species), equity (whose value close to 1 suggests that all species are represented according to their relative abundances), dominance (where a value close to 1 suggests that the vegetation is dominated by a single species), the Species evenness or Jaccard distance or similarity index estimator (is a metric used to measure the dissimilarity between two samples or communities based on their species presence or absence). Below all formulas are included. The germinated plants were herborized for taxonomic determination to compare with specimens deposited in the herbarium of the Institute of Ecology Civil Association (XAL Herbarium).

Species richness (SR)=TNS/TA
Where SR is the number of species in the sample
TNS is the total number of species
TA is the total area

Jaccard distance
SJ=ScS1+S2−Sc
where Sc is the number of species
divided common to both communities

Shannon-Wiener diversity index= H´
$H' = -\sum_{i=1}^{S} p_i \ln^{p_i}$,
where *pi* is the probability to find *ni=Npi*
Npi individuals in the *i*-th species (∑Si=1pi=1).

Relative abundance
= Isi/∑Nsi
Where Isi is the Total Number of Individual species by Total Number of Species Population (∑Nsi)

Information analysis. In accordance with the data, it was assumed that they do not have a normal distribution, so their analysis was made through inferential statistics and non-parametric tests. The comparison of the species richness and abundance between sites was made by calculating 95% confidence intervals. The diversity, equity and dominance were compared using the non-parametric Kruskal-Wallis test ($\alpha = 0.05$). Statistical differences for similarity were also established by calculating confidence intervals at 95%. All statistical analyses were performed using the XL-STAT add-ins for Microsoft Excel®, except for the similarity analysis, which was performed with the Estimate S program (Colwell, 2013).

RESULTS AND DISCUSSION

Weather Parameters

The average temperature from May to December was 26 °C with maximum and minimum values of 28.0 and 20.9 °C. The maximum value of relative humidity (69.1%) was recorded in December, being on average 63.9% (Figure 2). The average monthly precipitation followed the typical seasonal pattern, occurring the first rains at early June, with sporadic rainfall from July to the end of September of 140 and 225 mm monthly and a tendency to decrease as the winter season approached. The study area has a Aw2-climate considered the wettest of the subhumid group.

Soil Physical and Chemical Properties

Table 1 shows the soil analyses. The soil of the different sites had sandy-loam texture with smaller percentages of clay in the Tgs with 5.95% and a bit higher in the Ac with 11.98%. The silt content was 4% lower in the Pts and 18% higher in the Sps. The soil organic matter (OM) was in a range of 2.4 to 3.1%. The highest OM contents were at less depth (0-5 cm) and lowest at > 5-10 cm. The highest OM contents were recorded in the Ac (3.1.) and lower in the Sps (2.9), Tgs (2.6) and Pts (2.4). The lowest OM value was at > 5-10 depth in the Pts. The pH values were slightly alkaline with values of 7.3 to 7.7. The values of electrical conductivity (EC) were on a low scale with values from 0.3 to 0.6, without significant effects of salinity. The results situate the soils as mid-class for non-volcanic soils, according to the Official Mexican Standard NOM-021-SEMARNAT-2000.

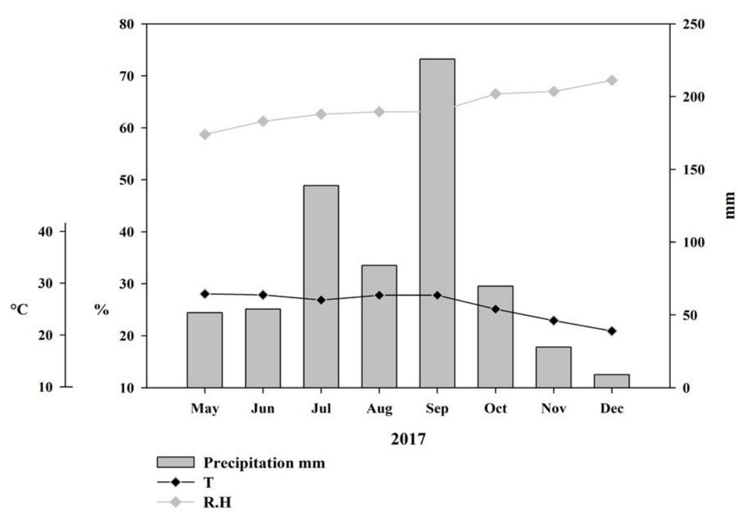

Figure 2. Environmental conditions in the area where the observations of the seed bank were made. T = means average temperature; R.H. = Relative humidity.

Table 1. Soil physicochemical properties of the different study sites.

Variable	Unit	Sps		Pts		Tgs		Ac	
		0-5	> 5-10	0-5	> 5-10	0-5	> 5-10	0-5	> 5-10
pH	pH	7.6	7.7	7.4	7.3	7.5	7.6	7.4	7.5
CE	$dS\ m^{-1}$	0.6	0.4	0.5	0.3	0.5	0.3	0.4	0.4
OM	%	2.9	2.2	2.4	1.3	2.6	2.0	3.1	2.4
Texture	Type								
		- Sandy-Loam -							
Nitrite	$mg\ L^{-1}$	2.5	4.5	8.0	7.0	40.0	19.0	11.0	6.0
Phosphorus	$mg\ L^{-1}$	6.5	4.5	5.0	2.5	2.5	1.0	2.0	2.0
Potassium	$mg\ L^{-1}$	160	200	80	69	88	22	80	42

Soil analysis reported no significant differences in any of the variables. The site with the least disturbance was the AC where the organic matter content was 3.1, and was low in the Pts (2.4). All sites are considered as mid-class because of non-volcanic soils according to the Official Mexican Standard NOM-021-SEMARNAT-2000: the range is between 1.6 and 3.5. It is reported that factors such as soil pH (Henig, Eshel, and Ne'eman, 1996), soil sun exposure due to lack of cover (Snyman and van Wyk, 2005), and the amount of sunlight (Trabaud and Renard, 1999) are factors that trigger seed bank germination.

The values for nutrients content (nitrites, phosphorus and potassium) found in each of the sites were higher in potassium and nitrite in the Sps and in the Tgs, with values of 200 and 40 mg L^{-1}. These higher contents with respect to the rest of sites, for the Sps, may be due to the application of potassium-rich fertilizers, which, according to the owner of the site, it has been done occasionally, and trees were planted five years ago. There was also greater amount of nitrites in the Tgs with about 40 mg L^{-1}. This value is high as compared to the other agroecosystems, and is due to the continuous contribution of cattle excreta (manure and urine). It is not only used for the grazing of adult cattle, but also for keeping calves. Whitmore (2000) points out that cattle manure generates nitrates and during the multi-stage process of nitrification, the efficiency of the transformation of nitrates into nitrites is reduced when high levels of organic matter are present at the site. It is evident by the content of 2.6% of organic matter, so this may generate remains of N in the form of nitrite in the soil in the Tgs.

It was expected to find lower contents of nutrients in the Tgs as the soil showed signals of erosion by overgrazing, compacted and with little vegetation. Huang, Wang, and Wu (2007) mentioned the processes of overgrazing might cause problems of desertification, where organic matter and nitrogen are the main components affected, and these are related to the loss of soil silt particles. In addition, overgrazing introduces disturbance, which can negatively affect the size and composition of pastures seed bank, spatially and temporally (Skoglund, 1992; Bekker *et al.,* 1997; Snyman and van Wyk, 2005). In this case, although the Tgs seemed to be the most affected due to livestock activities, it had silt content of 14.2%, taking it into the same textural classification as the other agroecosystems. The physical and chemical analyses showed that it has not been affected, but rather, the contribution of organic matter from the cattle generate a considerable amount of nutrients in the soil, organic matter and small quantities of silt particles in the soil.

Soil Seed Bank

It was found a total 23 families and 79 species in the different sites and depths. 16 families were recorded in Sps (Figure 3), 17 in Pts (Figure 3), 15 in Tgs (Figure 4), and 15 in Ac (Figure 4). The figures indicate the total number of germinated seeds.

The largest number of taxonomic families was found in the Pts at the depth of 0-5. The greatest number of plant species was found in the Tgs at both depths. In terms of richness, it was greater at 0-5 cm depth (Table 2). When species richness was compared among depths, Pts differed significantly from the rest of the sites. When it was considering both depths (0-10), Tgs stands out with a total of 45 species and Pts with 32. An overview of each site at a unique depth of 0-10 the same variable the Tgs system stands out with a maximum of 45 species, and Pts with a minimum (32).

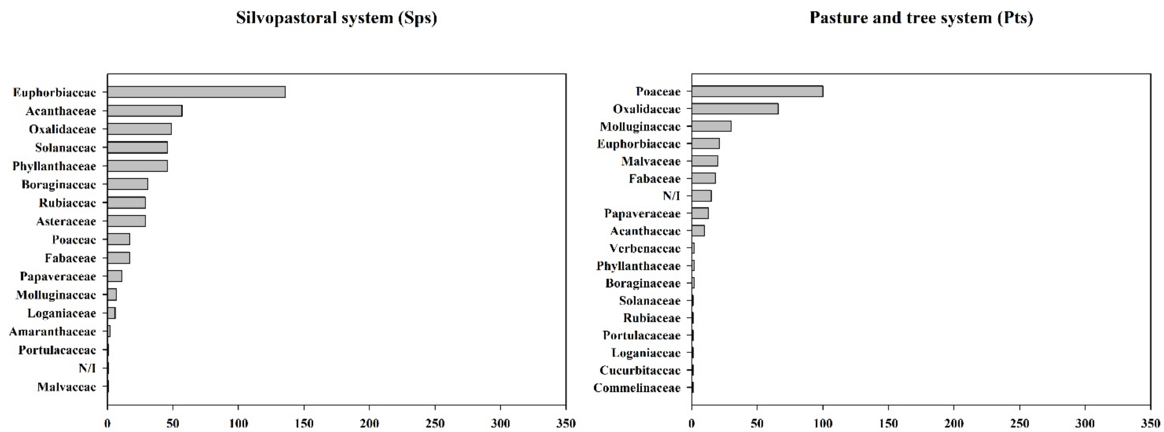

Figure 3. Total abundance of the soil seed bank in the silvopastoral system and pasture and tree system.

The nonparametric test of Kruskal-Wallis indicated significant differences between the diversity of the Sps and the Ac, being greater in the first. These differences occurred in a similar way in each of the depths in which the observations were made, except in the depth of > 5-10 cm, where the pasture with trees also presented significant differences with the diversity of the Ac.

When a measure is established for the biodiversity in different sites, the values can vary considerably according to the type of agroecosystem that is being considered. For example, Oosterhoorn and Kappelle (2000) found that the Shannon index showed values between 3 and 4 when they evaluated plant diversity and regrowth in a gradient that went from the interior of a tropical forest to a pasture, finding the biggest difference between the forest and pasture with greater intensity of management. The highest values were found inside the forest, contrary to what was observed between the Ac and the Sps, where although the values of the Shannon-Wiener index were lower than reported, they were higher for the Sps. It should be noted that the high index values obtained by the authors is due to the fact that tropical forests are ecosystems with one of the highest biodiversity in the world, which may influence the values of the studied areas.

The results presented are closely related to what it was found by De los Angeles-Cárdenas, Posada, and Vargas (2002) with the highest values of the Shannon index (1.94) obtained in sites with high disturbances due to intensive grazing and decrease with an intermediate disturbance. Being the Shannon index of Sps (2.13) higher than in Tgs (1.79). The difference between these two sites lies in the level of disturbance that it presents, since Tgs is recognized as the site with the greatest disturbance.

Regarding the difference between the diversity values of the Sps, it was not observed that the Ac species were found within the Sps although the sites are continuous to each other. This supports the approaches by Lin and Cao (2009) who mention a decrease of woody species as the distance of the wooded area increases towards the pastures.

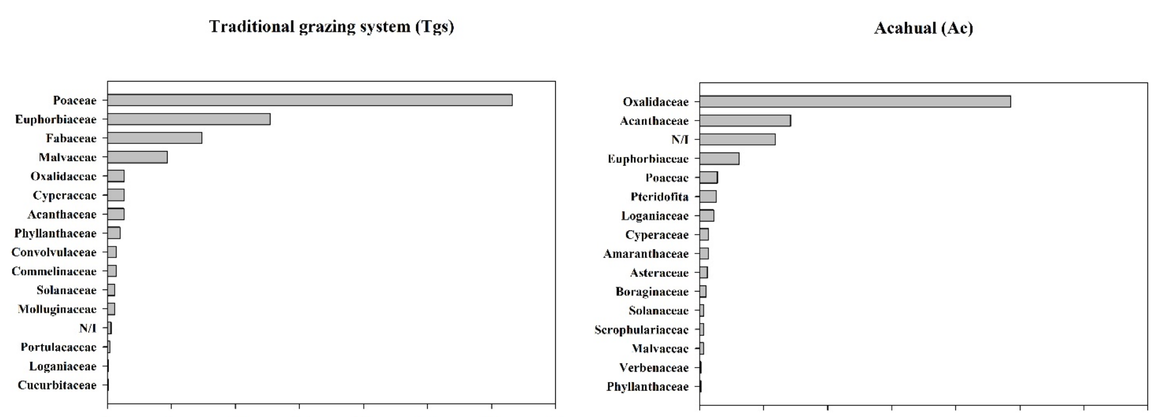

Figure 4. Total abundance of the soil seed bank in the traditional grazing system and acahual.

Table 2. Plant species richness from the seed bank in four different grazing systems at different soil depths.

	Total Richness				Average Richness			
Depth	Sps	Pts	Pts	Ac	Sps	Pts	Tgs	Ac
cm								
0-5	28	29	34	30	12±2.42 a[†]	9±2.42 a	11.8±3.25 a	9.5±1.94 a
> 5-10	25	19	29	19	8.83±1.92 a	5.5±1.40 b	7.83±3.05 ab	6.50±1.94 ab
0-10	34	32	45	33	15.5±2.95 a	11.5±4.37 a	15.6±4.27 a	12.5±2.88 a

[†] Average values with different letters show significant difference with α = 0.05 according to the calculations for confidence interval.

The Tgs and Pts presented diversities slightly higher than Ac, with values of 1.79 and 1.74, respectively, although the differences were not statistically significant. It could be inferred that these two agroecosystems are subject to processes by which the arrival and establishment of seeds is favoured, for better light conditions, incorporation by cattle through their droppings or the contribution of birds, insects (ants) and the wind for the arrival of seeds in the case of pasture with trees.

The abundance at 0-5 cm depth, showed significant statistical differences according to Kruskal-Wallis test (P = 0.011) between Tgs and Pts (Table 3). The values of total abundance of species at 5-10 cm did not have significant differences (P = 0.631) among study sites. In the case of the total abundance of species per site in both depths, there were significant statistical differences (P = 0.026) between Sps and Tgs.

A total of 23 families and 79 species were identified in the four sites. The largest number of families (16) belonged to the Pts, followed by the Sps (14), Ac (14) and Tgs (13). Regarding to the number of species, the greatest number was found in Tgs (34) followed by Ac (30), Pts (29) and Sps (28), all these at 0 to 5 cm depth. The largest number of species in the first few centimetres of soil depth coincides with other authors (Mall and Singh, 2014; Santín-Montanyá, Martín, Zambrana, and Tenorio, 2016), who suggest that it is possible to find the largest source of seeds due to plant regeneration in the first two centimetres on the soil surface. Ma, Zhou and Du (2010) mentioned that species richness tends to decrease as depth increases, a similar situation found in the four agroecosystems under study.

The Sps showed the greatest richness of species germinated in Tgs. As for richness of species, Tgs showed a greater impact, mainly on Poaceae, Fabaceae, Euphorbiaceae and Malvaceae families, which contributed with the 70% of total richness in terms of relative abundance. The rest species recorded did not have the same contribution since their relative abundance was lower and belonged to different families and species. This site had the highest species richness despite not showing a big difference over the other sites.

Olff and Ritchie (1998) mentioned that this may be due to the fact that herbivores often increase the vegetation diversity of a pasture through local disturbances and selective grazing. In addition, the effects of the impact on biomass and reproduction of dominant species, the density and type of regeneration of the site, as well as the source of propagules of other plants. The contribution that bovines have to the enrichment of the soil seed bank could only be appreciated when their presence was limited in the collected soil samples, since the trampling does not allow the development of the seedlings (Sione, Ledesma, Rosenberge, Galliussi, and Sabattini, 2015). Once the grazing restricted the species sheltered in the soil, seed bank may emerge. In this constant changes within the grazing systems, the changes on the vegetation might be by the soil seed bank (Ma *et al.,* 2010).

Table 3. Plant species abundance from the seed bank in four different grazing agroecosystems at different soil depths.

	Total Abundance				Average Abundance			
Depth	Sps	Pts	Tgs	Ac	Sps	Pts	Tgs	Ac
cm								
0-5	284	194	489	281	47±28.31 a[†]	32±2.8.71 a	82±3.25 ab	47±14.41 a
>5-10	202	111	157	197	33.6±17.72 a	18.50±12.77 a	26.16±17.83 a	32.83±31.04 a
0-10	486	305	646	478	81±44.94 a	50.83±19.63 a	107.66±46.60 ab	79.66±37.40 a

[†] Average values with different literals show significant difference according to the Kruskal-Wallis test with a corrected significance level of Bonferroni = 0.0083.

Cattle have a beneficial effect through the dispersion of seeds by moving from one site to another, but it depends on the environment. Authors such as Jeddi and Chaieb (2010) suggest that restricting grazing in arid areas contributes to soil improvement as well as the restoration of vegetation. Although this diversity is not appreciated in the field due to foraging and constant trampling, it was possible to confirm high diversity of seeds in the soil. Despite the different characteristics of the agroecosystems, species richness was not very different depending on soil depths. However, highest number of species was found in Tgs at 0-10 cm depth.

The main species in the Sps belonged to the families Phylantaceae, Euphorbiaceae, Acantaceae, Boraginaceae, Asteraceae and Rubiaceae with most common species such as: *Phyllanthus amarus, Euphorbia hirta, Euphorbia imbricata, Heliotropium angiospermum, Tridax procumbens, Spermacoce Assurgens*. These species belong to the herbaceous stratum and had the highest values of relative abundance.

It is important to reminder that the germinated seeds appeared once the plant cover and the organic matter in the soil were removed, and animals were restricted to grazing. Gross, Mittelbach, and Reynolds (2005) suggest that the reduction of plant cover is important for the recruitment of species, since they found similar responses in grasslands where there was a quick germination of species sheltered in the soil by removing the vegetation. A similar effect was obtained with the organic matter accumulated in the soil, which can be very high, as well as a wide canopy determines the vegetation development (Holl 2002; Xiong *et al.,* 2003). Although there was not a very large tree canopy, the large amount of biomass produced by the grass restricted the sunlight down to the soil, which not allowed seeds germination.

Baskin and Baskin (2014) mention that the soil seed bank rarely contains the same species that occur in standing vegetation. This difference between the soil seed bank and the standing vegetation has been documented by any other authors (Ma *et al.,* 2010; Ge *et al.,* 2013), either by the dominance of certain species such as pastures, or by lack of any disturbance in the soil that allows germination of seeds. In Ac, a total of 30 species were documented at 0-5 cm, belonging to the following families: Oxalidaceae, Acanthaceae, Euphorbiaceae, Loganiaceae, Amaranthaceae, and species such as *Oxalis corniculata, Euphorbia imbricata, Euphorbia sp., Spigelia anthelmia* e *Iresine diffusa*. The most representative species of each of these families relate to the herbaceous stratum, with fit with Chia, Min, Wang, and Tzeng (2022) that most soil seed bank is mainly composed of herbaceous for > 90% of the seed reserves.

The richness in Ac was greater than that described for earlier successional stages. González-Rivas, Tigabu, Castro-Marín, and Odén (2009), mentioned that the species richness increases as the succession period steps forward, with a maximum of 9 species in a site with 14 years of abandonment, where the species integrated the tree stratum mainly. The presence of shrub and arboreal species was insignificant, which may be due to the age of the site, with approximately 50 years and covering almost 100% of the soil surface by the tree canopy. This observation aligns with Bossuyt, Heyn, and Hermy (2002), who noted a decrease in seed density as plant succession advances. This finding is supported by Bossuyt *et al*. (2002) who mention that as plant succession goes on, seeds density decline. Another factor that may explain this find is that tree species have a low production of seeds and fecundity, as well as a short viability (no more than one year). The limitations of light with changes on solar radiation make up the canopy to generate microclimatic conditions that can affect the survival of seedlings and shoots, and therefore the processes of vegetation succession.

In the Pts, the botanical families Oxalidaceae, Poaceae, Fabaceae, Malvaceae, Papaveraceae and Euphorbiacea were recorded with species such as *Oxalis corniculata, Digitaria bicornis, Dactyloctenium aegyptium, Desmodium triflorum, Malvastrum coromandelianum, Argemone mexicana and Euphorbia hirta* as the main species for each family. As in Pts had the greatest relative abundance of the species mentioned above, although some other species were present. The contributions of the rest of the species in terms of abundance were lower, as these were represented only by one plant in some cases.

In this site, although there is a canopy consolidated by *Diphysa robinioides*, the presence of species was different from Ac, because the species of the family Poaceae was higher there, along with other herbaceous. It is clear that the presence of a large number of individuals belonging to the gramineae family responds to the fact that, although the canopy is large, the high sunlight reaching the ground, with a continuous input of seeds, encouraged the development of different species in the herbaceous layer. This information matches that observed by Menezes and Salcedo (1999) in earlier studies who noted that the biomass of the herbaceous vegetation is usually smaller under the tree canopy of species such as *Zyziphus joazeiro, Spondias tuberosa* and *Prosopis juliflora*.

In the case of Pts, it is taken into account that a very closed tree canopy interferes with the development of the vegetation on the buttom, and although this site may be fulfilling functions such storing seeds of different species, either through anemochory or zoochory when trees perform as perches for birds and bats (Guevara, Laborde, and Sánchez, 2005). The shade, as in the Ac, may be interfering the expression of diversity of seed bank sheltered in the soil.

Indicators of Plant Diversity of Seed Bank in Four Grazing Agroecosystems

For the specific richness, it was found no statistical differences per site according to depths. The highest and lowest diversity indicators of Shannon-Wiener were obtained in Sps and in Ac, with significant statistical differences for these sites in the three depths of soil (Table 4).

The highest value of the Shannon-Wiener diversity index was recorded for the silvopastoral system at the depth of 0-5, > 5-10 and 0-10. The Kruskal-Wallis test indicates that there were significant differences (P = 0.018) between Sps and Ac at the depth of 0 to 5 cm, the Pts and the Tgs. Although there were no differences with the Sps, a lowest value of Shannon-Wiener index was recorded, but superior to Ac. The values of the Shannon-Wiener index in the depth of > 5-10 cm were lower as compared to 0-5 cm for all sites. At this depth, significant differences were found between Sps with Ac (P = 0.016) and Pts (P = 0.010). The analysis considering the depth of 0-10 cm, shows higher Shannon-Wiener index for Sps as compared to Ac with a significant difference (P = 0.002).

Equity values were higher and lower in Sps and Ac, respectively, for the depth of 0-5 and 0-10, with statistically significant differences among Sps with Tgs and Ac (P = 0.005). Equity was similar at the depth of > 5-10 for all sites. In terms of dominance, the highest and lowest values were for Ac and Sps in the three depths, showing statistically significant differences (P = 0.004), as in Sps with Pts (P = 0.007) and Ac (P = 0.004) at the depth of > 5-10 and 0-10.

Seed Bank Similarity Index

The similarity index of Sorensen showed a similarity between sites over 50% with the exception of Tgs with Ac, which similarity index was 44% (Figure 5). These similarities are influenced because the first centimetres of the soil tend to accumulate the greatest number of new seeds, with greater germination capacity and greater organic matter, which contributes to germination.

Comparing the similarity among sites, it was found at >5-10 cm depth, that was greater than 50%. However, the lowest similarity was found between Tgs and Ac, being similar at the first depth. The index of similarity between sites at 0- 5 cm depth was from 0.44 (± 0.53) to 0.74 (± 0.45), without significant statistical differences. For the depth > 5 to 10, the index was from 0.61±(0.29) to 0.93±(0.31) in each site.

Table 4. Biodiversity indicators for soil seed bank in different grazing agroecosystems.

Indicator	Agroecosystem	Depth		
		0-5	> 5-10	0-10
Richness	Sps	28	25	33
	Pts	29	19	32
	Tgs	34	29	45
	Ac	30	19	33
H´	Sps	2.13 a†	1.86 a	2.36 a
	Pts	1.74 ab	1.23 b	1.85 ab
	Tgs	1.79 ab	1.70 ab	2.10 ab
	Ac	1.46 b	1.27 b	1.59 b
Equity	Sps	0.86 a	0.85 a	0.87 a
	Pts	0.80 ab	0.74 a	0.77 ab
	Tgs	0.73 b	0.85 a	0.77 ab
	Ac	0.64 b	0.73 a	0.63 b
Dominance	Sps	0.27 a	0.29 a	0.20 a
	Pts	0.36 a	0.57 b	0.39 b
	Tgs	0.42 ab	0.38 ab	0.33 ab
	Ac	0.58 b	0.57 b	0.55 b

† Bold letters are statistically different (α = 0.05) according to the nonparametric Kruskal-Wallis test.

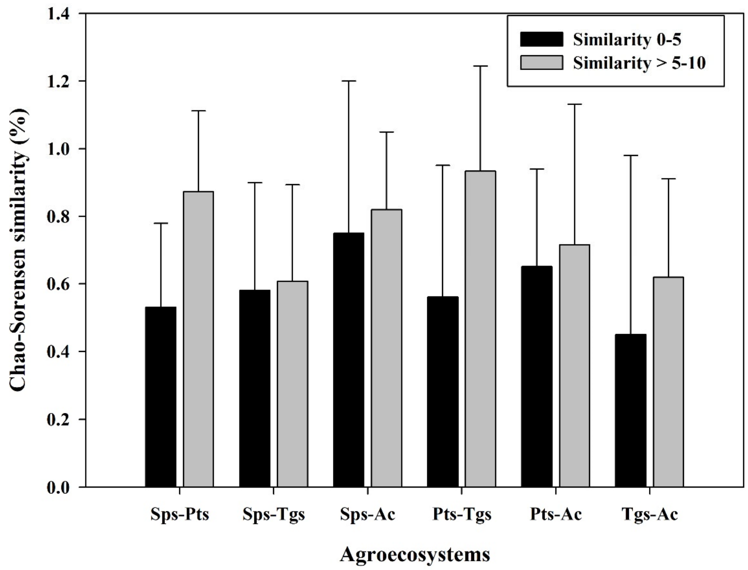

Figure 5. Similarity of the soil seed bank between different type of agroecosystems.

The results indicated a difference between the total abundance of species of the Tgs and the Pts, at the depths of 0-5 cm and 0-10 cm. In the Tgs, the greatest number of individuals was for a morphotype of Poaceae family with 175 individuals, followed by species from the families Fabaceae, Euphorbiaceae and Malvaceae. Tessema, de Boer, Baars, and Prins (2012) mentioned that in pastures with light grazing, they found the greatest abundance of germinated seedlings from the seed bank, among which the pastures, herbs and a single woody species and a density of 2061 seeds m^2 and 1302 seeds m^2 for the site with less grazing activity. In this case, the density of seeds of the highest grazing plot was 326 seeds m^2 and the lowest was 129 seeds m^2. The Tgs shows a high level of grazing, which is added to the history of grazing on a smaller scale in previous years, when the site was not used for the confinement of cattle, with a total of 489 seedlings, number below what was found by the author. Dölle and Schmidt (2009) do not support this information. They consider that a level of disturbance, in this case through ploughing, promotes a greater germination up to 30 000 seeds on average. When the succession period increases, the regeneration of vegetation is considerably reduced.

The lowest total abundance of species occurred in the Pts, at the depth of 0-5 cm and 0-10 cm. The families Oxalidaeae, Poaceae, Fabaceae, Malvaceae, Papaveraceae were recorded. The most significant of these was the highest abundance of germinated seedlings of: *Oxalis corniculata, Digitaria bicornis, Dactyloctenium aegyptium, Desmodium triflorum, Malvastrum coromandelianum* and *Argemone mexicana*. Most of the recorded species belonged to the herbaceous stratum, only two species of shrubs were recorded (*Ricinus communis*), an unidentified morphospecies, and a tree (*Gliricidia sepium*).

Recent studies such as that by Holl (2002) identified that under the canopy of medium-sized young shrubs, most of the vegetation belongs to the herbaceous stratum and determined the establishment of seedlings of arboreal species such as *Ardisisa sp., Cecropia sp., Dendropanax sp., Heliocarpus sp., Inga sp*., among others. In addition, this is favoured by the light conditions under the canopy of the bushes and the little pasture competition. In this study, the main species that formed tree canopy are just over twenty years old and about ten meters high. The shadow is sometimes quite closed, which is why this is probably the cause of the null presence of species of the tree stratum. Ortega-Pieck, López, Ramírez and García (2011) documented similar situations in relation to the effect of pastures on the germination and development of tree species in pastures near the mesophilic forest. The total number of species was similar in all sites at two different depths. At the depth of 0-10 centimetres, it was found the greatest number of species in Tgs and Sps and the lowest in Ac and Pts. The abundance of species showed significant difference only between Tgs and Pts, and this recorded the lowest number of individuals. The species richness was not very different among them. However, there was a greater abundance for a reduced number of species in the four sites that are characteristic of each one, mostly pioneer species.

According to the Kruskal-Wallis test, significant differences were found for the equity between Sps and Ac, with values of 0.86 and 0.64, respectively. These values are very similar when the depths of 0-5 and 0-10 are taken into account. Despite the highest percentage in *P. amarus*, the equity value of 0.86 that was obtained suggests that the relative abundances of the rest of the species are represented in a similar way. In the case of Ac, the equity value was 0.64, which indicates a greater difference in terms of the relative abundances of the species registered in this site. In this case, about 57% of the total individuals registered for the Ac were represented by two species (*O. corniculata* and an unidentified morphotype), differing with the rest of the species, which in some cases managed to register species with a single individual.

In the Pts and the Tgs, although there were no significant differences with respect to the two previous agroecosystems, the equity values were lower, and the relative abundances fell to the pasture with trees on: *O. corniculata, D. bicornis and D. aegyptium*. In the Tgs, the species with the highest relative abundances were from an unidentified morphotype of the family Poaceae, *D. triflorum* and *E. undivided*.

For the dominance of species, the Kruskal-Wallis test was applied in the same way. In the depth from 0 to 5 cm, the differences were statistically significant for Sps and Pts compared to Ac (Kruskal-Wallis 0.05), with values of 0.27, 0.36 and 0.58, respectively. The lower values of dominance for the Sps can be explained with the number of individuals, in this case for *P. amarus, E. hirta, E. imbricata, Euphorbia sp, H. angiospermun* and *T. procumbens*, which even though they were greater than the rest of the species, they do not reflect the dominance of a specific species.

The functionality that the seed bank can have related to the restoration of vegetation in cattle settings must be taken into account. These species are elements of the first successional stages, that initiate the colonization of a site prior to the establishment of woody species, and may be indicating a degree of disturbance which cannot be attributed to a single factor. This is the result of elements such as the characteristics of the site, the intensity and the type of land use (Guariguata and Osterbag, 2001).

For the depth of 0 to 5 cm, when comparing each of the sites with each other, similarity values are greater than 50%, with the exception of Tgs and Ac, with a similarity of 44%. The confidence intervals calculated for the comparison between the sites show that there is no significant difference between the similarities of the sites. Amiaud and Touzard (2004) found high similarities of up to 72% for a pasture seed bank and a site with advanced succession status, and mentioned that few grassland species can be found in older seed bank and sensible to rainfall (Eskelinen, Elwood, Harrison, Beyen, and Gremer, 2021). However, in the present study the similarity between Sps and Ac was high (74%) which seems to indicate that in both sites there is the presence of similar species, corresponding to the herbaceous stratum.

The lowest similarity between agroecosystems was found between Tgs and Ac (44%). The reason is because the sites are highly contrasting in several aspects, such as agricultural management conditions, particularly the grazing of cattle and the characteristics of the vegetation.

It is important to mention that the high similarity between some sites does not represent a specific functionality when considering the species that make up each of these. As it was mentioned, sites such as Tgs and Sps show a greater richness and diversity than Ac.

The high similarity between sites at the depth of > 5 to 10 may be due to different factors. For example, to the characteristics of the seed bank, as mentioned by Baskin and Baskin (2014), pastures have more persistent seeds than tropical forests, for example. The fact that the similarity at a greater depth is high can also be influenced by the activities previously carried out in the area, because according to the information obtained from the owners, before the Sps, the Pts and the Tgs were established as they are currently., the entire area was used for the extensive grazing of cattle which was moved constantly for food.

It should be noted that to establish the similarity of the seed bank of the different agroecosystems, the use of the Chao-Sorensen index was considered, a modification of the Sorensen index developed by Chao, Chazdon, Colwell, and Shen (2005). The purpose of this is to reduce the subsampling bias through estimation and compensation for the effects of shared species not observed. The authors recommend its use if there are samples of different sizes, when it is known or suspected that there was a subsampling or when it is probable that there are several species considered as rare. These authors mention that their use improves the interpretations of the similarity between sites, because the Sorensen classic index assumes that the data of the samples are complete and real representations of the evaluated composition.

CONCLUSIONS

It can be concluded that the largest number of families was for the silvopastoral system in the depth of 0-5 cm. More than 50% of the total seeds were found in the first 5 cm of depth, within the traditional grazing system with the highest number of individuals. Silvopastoral system was the one that presented outstanding characteristics in terms of the richness, diversity and abundance of plant species. The values of equity (0.86) and dominance (0.27) of this site suggest that the plant communities generated by the seed bank will be more heterogeneous than in the other agroecosystems. Considering the high similarity of the botanical composition of the seed bank, the management of the sites is likely to be determinant for their expression and development. Soil seed bank in cattle areas can function as a key element for the restoration of vegetation to increase the diversity of pastures. However, it is important to consider that, since the soil seed bank generates only species of the herbaceous stratum, some considered as pioneers, the restoration of the vegetation must be complemented with management activities that propitiate the development of shrub and arboreal species. Although there are nearby sources of seeds capable of establishing themselves, the dominance of pastures or the overlap, combined with its short period of viability, may limit its establishment. Indeed, herbaceous from soil seed bank will increase due to hot climate.

ETHICS STATEMENT

This study did not include people directly, but it did interview farmers with their consent. It also did not include animal studies or any animal abuse. The data from this study formed part of the corresponding author's thesis research. In addition, it was one of the chapters of his Master of Science thesis. All data collected were analyzed using software under institutional license.

CONSENT FOR PUBLICATION

The authors of this manuscript declare that it has not been sent to any other Journal for its publication and that its content has not been published in whole or in part. As authors we give our consent to the Editor and the Terra Latinoamericana Journal the rights of publication and the right to reproduce this contribution for the purposes of this Journal.

AVAILABILITY OF SUPPORTING DATA

Data availability is not applicable to this article as no new data were created or analyzed in this study. However, the complete data and details of the research are included in the corresponding author's thesis, which is registered in the Postgraduate College thesis repository.

COMPETING INTERESTS

All authors declare that they have no conflicts of interest.

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AUTHORS' CONTRIBUTIONS

Designed the methodological proposal of the research in collaboration: A.P.V. and C.N.C.J. Both contributed to sampling and collecting data in the field. Carried out part of the statistical analysis: C.N.C.J. and A.L.A.P. Carried out the statistical analysis of biodiversity metrics: M.C.V.M. and C.N.C.J. Reviewed the final manuscript and corrected the final version: A.P.V.

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