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Soil weed seed bank *in situ* and *ex situ* at a smallholder field in Maranhão State, northeastern Brazil

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ABSTRACT. The objective of this research was to assess the density, floristic composition, phytosociology and diversity of a soil weed seed bank *ex situ* by germination in a greenhouse and *in situ* by weed sampling on a smallholder corn field located in Lago Verde County, Maranhão State. Fifteen pairs of 25 m^2 plots were designated. In half of these plots, 90 soil samples were collected with an open metal template measuring 25 x 16 x 3 cm and placed in a greenhouse to germinate. In the other half, 90 weed samples were collected using the same metal template. We recorded a total of 1,998 individuals from 40 species, 31 genera and 16 families, from which 659 individuals germinated in *situ* and 1,339 *ex situ*. Density was higher *ex situ,* with 372 plants m^{-2}. The Cyperaceae family had the highest floristic richness with nine species, followed by the Poaceae with six. The dominant species based on the Importance Value Index were *Lindernia crustacea* (IVI 27.7%) *in situ* and *Scleria lithosperma* (IVI 37.0%) *ex situ*. Floristic diversity was higher *ex situ,* with H' = 2.66 nats ind^{-1}. These results could help predict infestation potential and could lead to improved weed management strategies in corn-growing areas on smallholdings in Maranhão State, northeastern Brazil.

Keywords: cyperaceae, competition, biological invasion, phytosociology, smallholder farmers.

Banco de sementes de plantas invasoras no solo *in situ* e *ex situ* em área de agricultura de subsistência no Estado do Maranhão, Nordeste do Brasil

RESUMO. O objetivo desta pesquisa foi avaliar a densidade, composição florística, fitossociologia e a diversidade no banco de sementes do solo *ex situ* pelo método de germinação em casa de vegetação e *in situ* em área de cultivo de subsistência de milho no município de Lago Verde, Estado do Maranhão. Quinze pares de parcelas de 25 m^2 foram alocadas. Na metade destas parcelas, 90 amostras de solos foram retiradas com um gabarito de metal vazado de 25 x 16 x 3 cm e colocadas para germinar em casa de vegetação. Na outra metade, 90 amostras de plantas invasoras foram retiradas com o mesmo gabarito. Foi registrado o total de 1.998 indivíduos de 40 espécies, 31 gêneros e 16 famílias, dos quais 659 indivíduos de 29 espécies germinaram *in situ* e 1.339 individuos de 29 espécies *ex situ*. A família Cyperaceae teve a maior riqueza florística com 9 espécies, seguida pela família Poaceae com seis. As espécies dominantes baseado no índice de valor de importância foram *Lindernia crustacea* (IVI 27,7%) *in situ* e *Scleria lithosperma* (IVI 37,0%) *ex situ*. A diversidade florística foi maior no banco de sementes do solo *ex situ* com H' = 2,66 nats ind^{-1}. Estes resultados podem ajudar na previsão de infestações e contribuir para melhorar estratégias de manejo de plantas invasoras em areas de cultivo de subsistência no Maranhão.

Palavras-chave: cyperaceae, competição, invasão biológica, fitossociologia, pequenos agricultores.

Introduction

Weeds are a major biological constraint for smallholders. They cause adverse impacts on crop yields by interfering with crop growth and development through allelopathy and competition for water, nutrients, light and space. In corn fields, the uncontrolled growth of weeds can reduce yields by 41% (BALBINOT JUNIOR et al., 2003).

The production of a large number of small seeds is an important survival strategy developed by weeds to survive control methods. After their dispersal, the seeds might remain on the soil surface or be buried by various biotic and abiotic agents, thus forming a soil seed bank that becomes the primary source of weeds in agroecosystems.

Several factors affect weed seed germination, including variations in soil temperature and moisture, light levels, and various physiological aspects of the seeds, particularly their dormancy requirements. When favorable conditions occur, the seeds germinate. The resulting plants produce new propagules, enriching the soil seed bank and the future population of weeds. In spite of the potential ecological and economic importance, the status of the soil weed seed bank in the tropics, specifically on smallholder corn fields in Maranhão State in northeast Brazil, is unknown. Moreover, very little data concerning invasive herbaceous vegetation is available. Therefore, there is a need to perform floristic surveys of weed species to determine their occurrence patterns in cropping fields. Studies on soil weed seed bank ecology in this region are crucial for improving control strategies.

Ecological studies on soil weed seed banks in agricultural fields, pastures and natural grasslands in the tropics have been conducted by several authors, including Silva and Dias Filho (2001), Maia et al. (2004), Lacerda et al. (2005), Begum et al. (2006), Lopes et al. (2006), Ikeda et al. (2008), Isaac and Guimarães (2008), Andrade et al. (2009), Costa et al. (2009) and Kamoshita et al. (2010). However, most of these studies were directed towards agribusiness, with no concern for generating scientific knowledge useful to smallholders.

Weed seed bank studies *in situ*, that is, the identification and enumeration of weed seedling emergence in the field, might provide a general indication of the composition of the weed flora in the seed bank. However, this method is not precise because seeds from many species can remain viable for long periods but do not germinate because they possess some degree of physical or physiological dormancy, while others germinate but do not emerge due to unfavorable environmental conditions.

However, weed seed bank study *ex situ*, that is, the identification and enumeration of weed seedling emergence from soil samples placed in trays in the greenhouse and irrigated daily for longer periods, is more efficient for assessing germination dynamics. Moreover, it is also possible to assess the potential size of the weed seed bank because many species are capable of extended fluxes of emergence over several weeks under favorable environmental conditions.

There is a need to understand soil weed seed bank germination dynamics and its relationship with invasive flora on smallholder fields in Maranhão State. This might contribute to the prediction of infestations and could lead to improved management strategies for minimizing the effects of the interference of invasive plants with crop growth and yields.

The objective of this research was to assess the density, florisitic composition, phytosociological structure and diversity of the soil weed seed bank both in the greenhouse and in the fields of a smallholder corn field in Lago Verde County, Maranhão State, in northeastern Brazil.

Material and methods

This research was conducted in a three hectare corn field, selected to represent the smallholder community located in Lago Verde County (4° 00' 01" S and 44° 54' 52" W), in the central portion of Maranhão State, in northeastern Brazil.

The climate in the region is of the Aw type, according to Köppen's classification, and is tropical, hot and humid with two well-defined seasons, one rainy, from January to June, and the other dry, from July to December. The average temperature is 25ºC, and the mean rainfall is approximately 1800 mm $year^{-1}$.

The region's relief is gentle and slightly undulating, with elevations varying between 16 and 25 m, with the presence of some hills with occasional modest altitudes. These forms range in shape as siltstones, sandstones in a clay matrix, argillites and shales, which are part of the Itapecuru Formation lithology, thought to belong to the Lower Cretaceous (IBGE, 1997). This formation extends over almost all of the northern portion of Maranhão State, covering an area of approximately 50% of its territory (GEPLAN, 2002). This formation gave rise to plinthosols, argisols and, to a minor degree, the latosols, which are the region's most prevalent soils (EMBRAPA, 2008).

The most important economic activities in the region are livestock and subsistence farming, which are practiced in a slash and burn agricultural system.

Fifteen pairs of 25 m^2 plots were designated. In half of these plots, six soil samples per plot were acquired, using a 25 x 16 x 3 cm open metal template and keeping a minimum distance to the plot border of 1.0 m (weed seed bank *ex situ*). The template was inserted 3 cm deep into the soil, and all of the material enclosed by the internal perimeter was withdrawn. A total of 90 soil samples were collected.

This procedure was performed at the end of the dry season, in November 2008, one month before the planting of the corn. The samples were placed in black plastic bags, labeled and transported to the greenhouse at the Farm School at the Agrarian Sciences Center at Maranhão State University, in São Luís, where they were left to germinate in

25x16x5 cm aluminum trays in January, 2009, according to the methodology proposed by Forcella et al. (2003). The trays were perforated to facilitate drainage, and the soil samples were irrigated daily to promote seed germination.

Three aluminum trays with washed sand were added as controls because of the possibility of eventual contamination by seed rain from local weed species. During the experiment, no contamination was observed. Additionally, soil samples were collected at a depth of 0-20 cm, packaged in plastic bags and sent to the Soils Laboratory of the Agrarian Sciences Center, at Maranhão State University, in São Luís, for physical and chemical analysis according to the methodology described by Embrapa (1997).

The identification, counting and removal of weed seedlings from the trays were performed every 15 days over a period of 130 days. Sixty days after the start of the experiment, irrigation was suspended for two weeks and the soil was turned over to facilitate the germination of seeds located in the lower portion of the trays. Seven assessments were made, four before and three after the water restriction.

In the other half of the plots, six weed samples were taken per plot during the rainy season, 2009, using the same metal template soil sampler (weed seed bank *in situ*). Weed samples were collected one day before both the first and the second weedings of the corn field; there were three in January and three in February, 2009, totaling 90 weed samples.

Botanical material from each species was collected in triplicate whenever possible when preparing exsiccates. The species were prepared as herbarium specimens and were incorporated into the Rosa Mochel Herbarium at the Biology Study Nucleus of Maranhão State University, in São Luís, Brazil.

Botanical identification was performed by analyzing the external morphological characteristics of the vegetative and reproductive parts according to specialized literature, by comparison with other species and also by consulting experts. The species that could not be identified at sampling time were transplanted into plastic containers and cultivated until they reached the flowering stage. The floristic list was organized according to the classification system of the Angiosperm Phylogeny Group II (APG II, 2003).

Phytosociological structure was assessed using parameters such as the absolute and relative values of frequency, density, abundance and the Importance Value Index for each species (MULLER-DOMBOIS; ELLENBERG, 1974). Species data were organized in spreadsheets using Microsoft® Excel 2007. Computation was performed using the following equations:

Absolute Frequency = number of sampling units with species presence/total number of sampling units

Relative Frequency = species absolute frequency/sum of all absolute frequencies * 100

Absolute Density = species total number of individuals/total sampled area

Relative Density = species absolute density/sum of all absolute densities * 100

Absolute Abundance = species total number of individuals/total number of sampling units that contained the species

Relative Abundance = species absolute abundance/sum of all absolute abundances * 100

Index of Importance Value = Relative Frequency + Relative Density + Relative Abundance

Floristic diversity was assessed using the Shannon's Diversity Index (H') based on a natural logarithm that gives equal weight to rare and abundant species. It was assumed that the higher is the value of H', the greater is the floristic diversity (SHANNON; WEAVER, 1949). Shannon's Diversity Index was computed using the following formula:

$$H = -\sum_{I=1}^{S} pi \ln pi$$

where:

ln is the natural logarithm; pi = ni N^{-1}; ni is the number of sampled individuals of the species i; and N is the total number of sampled individuals.

Results

The physical and chemical attributes of the soil were as follows: organic matter = 20 g dm^{-3}; pH $CaCl_2$ = 5.6, P = 3 mg dm^{-3}; K^+ = 2.5; Ca^{2+} = 21; Mg^{2+} = 12; $H+Al^{3+}$ = 16; Na^+ = 4.3 and Al^{3+} = 0 $mmol_c$ dm^{-3}; sand = 76%; silt = 5% and clay = 19%.

The flora assessed from the weed seed bank, both in the greenhouse and in the field, was represented by 1,998 individuals from 40 species, 31 genera and 16 families (Table 1). Specifically, 659 individuals and 29 species were recorded in the field, and 1,339 individuals and 29 species were observed in the greenhouse (Table 1).

Table 1. List of taxa with respective number of individuals recorded in the weed seed bank assessed in the field and in the greenhouse from a smallholder corn field in Lago Verde County, Maranhão State, northeastern Brazil.

Families/species	Number of individuals	
	Field	Greenhouse
Amaranthaceae		
Alternathera tenella Colla	-	5
Asteraceae		
Ageratum conyzoides L.	23	5
Elephantoppus mollis Kunth	23	1
Emilia coccínea (Sims) G. Don	69	42
Erechtites hieracifolius (L). Raf. ex DC.	-	11
Porophyllum ruderale (Jacq.) Cass	50	6
Commelinaceae		
Commelina diffusa Burm. f.	3	-
Cyperaceae		
Cyperus compressus L.	79	-
Cyperus diffusus L.	-	185
Cyperus distans L. f.	27	-
Cyperus iria L.	38	40
Cyperus sphacelatus Roth	-	211
Fimbristylis dichotoma (L.) Vahl	13	-
Pycreus lanceolatus (Poir.) C.B. Clarke	40	-
Schoenoplectus juncoides (Roxb.) Palla	6	183
Scleria lithosperma (L.) Sw.	-	226
Euphorbiaceae		
Chamaesyce hirta (L.) Millsp.	16	6
Fabaceae		
Calopogonium mucunoides Desv.	1	-
Desmodium adscendens (Sw.) DC.	5	-
Lamiaceae		
Hyptis suaveolens (L.) Poit.	1	2
Ocimum campechianum Mill.	-	2
Malvaceae		
Urena lobata L.	36	1
Nyctaginaceae		
Boerhavia erecta L.	-	14
Onagraceae		
Ludwigia octovalvis (Jacq.) P. H. Raven	5	5
Phyllanthaceae		
Phyllanthus niruri L.	3	1
Phyllanthus orbicularis Kunth	5	-
Phyllanthus tenellus Roxb.	3	-
Phyllanthus urinaria L.	-	5
Plantaginaceae		
Lindernia crustacea (L.) F. Muell	104	147
Poaceae		
Digitaria ciliaris (Retz.) Koeler	-	12
Digitaria horizontalis Willd.	21	-
Eleusine indica (L.) Gaertn.	6	2
Eragrostis ciliaris (Retz.) Koeler	8	4
Panicum maximum Jacq.	2	47
Panicum trichoides Sw.	-	3
Portulacaceae		
Talinum paniculatum (Jacq.) Willd.	-	69
Rubiaceae		
Oldenlandia corymbosa L.	16	96
Spermacoce verticilata L.	4	3
Solanaceae		
Physalis angulata L.	19	-
Turneraceae		
Turnera subulata Sm.	33	5
Total	659	1,339

The families with the highest species richness were Cyperaceae with nine, Poaceae with six and Asteraceae with five species. These families contributed 50% of the total species. In contrast, ten families had only one species each, which corresponds to 62.5% of the total of all recorded families (Figure 1).

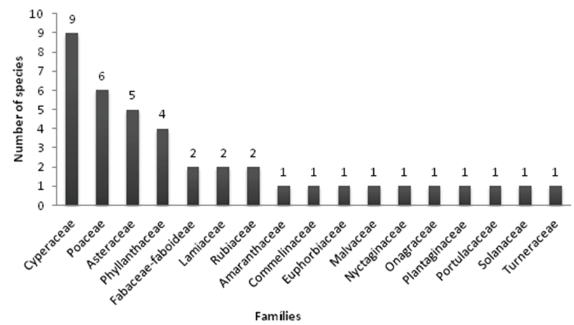

Figure 1. Total floristic composition in the weed seed bank assessed in the field and in the greenhouse from a smallholder corn field in Lago Verde County, Maranhão State, northeastern Brazil.

The genera with the highest floristic richness were the following: *Cyperus* with five and *Phyllanthus* with four species. These genera contributed 22.5% of the floristic composition of the weed community in the soil weed seed bank.

Eleven species were found only in the field: *C. diffusa, C. compressus, C. distans, F. dichotoma, P. lanceolatus, C. mucunoides, D. adscedens, P. orbicularis, P. tenellus, D. horizontalis* and *P. angulata.*

However, 11 species were found only in the greenhouse: *A. tenella*, *E. hieracifolius, C. diffusus, C. sphacelatus, S. lithosperma, O. campechianum, B. erecta, P. urinaria, D. ciliaris, P. trichoides* and *T. paniculatum.*

Eighteen species were common both in the field and in the greenhouse: *A. conyzoides, E. mollis, E. coccinea, P. ruderale, C. iria, S. juncoides, C. hirta, H. suaveolens, U. lobata, L. octovalvis, P. niruri, L. crustacea, E. indica, E. ciliaris, P. maximum, O. corymbosa, S. verticilata* and *T. subulata.*

The greatest density was observed when the weed seed bank was assessed in the greenhouse, with 372 plants m^{-2}. This exceeded by more than two times the density observed when it was assessed in the field, which was 183 plants m^{-2}.

A germination curve showed that approximately 80% of seeds germinated in the first 70 days of the study in the greenhouse. The peak in germination was observed during the first assessment 25 days after the beginning of the study. This period coincided with the start of the rainy season in the region, leading to an increase in weed germination and the emergence of the weed seed bank in the soil. Germination stabilization occurred after the fifth assessment, 115 days after the start of the study (Figure 2).

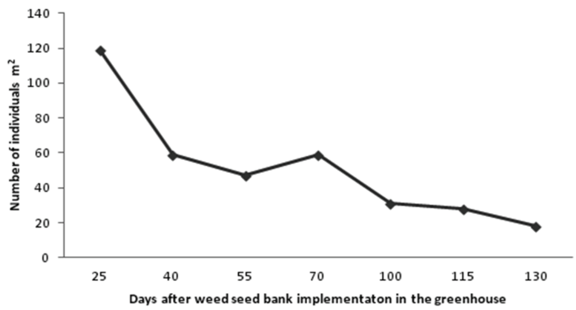

Figure 2. Germination curve in the weed seed bank in the soil assessed in the greenhouse from a smallholder corn field in Lago Verde County, Maranhão State, northeastern Brazil.

The most important species, based on the Importance Value Index (IVI), were *L. crustacea* (IVI 27.7%) in the field and *S. lithosperma* (IVI 37.0%) in the greenhouse, with the highest contributions from the relative density (RD) (Table 2).

Table 2. Phytosociologial parameters of the predominant species in the soil weed seed bank, in the field and in the greenhouse, from a smallholder corn field in Lago Verde County, Maranhão State, northeastern Brazil. RF, RD and RA = Relative Frequency, Relative Density and Relative Abundance. IVI = Importance Value Index.

Phytosociologial parameters in soil weed seed bank									
Field					Greenhouse				
Species	RF	RD	RA	IVI%	Species	RF	RD	RA	IVI%
L. crustacea	8.7	13.6	5.4	27.7	*S. lithosperma*	11.6	17.8	7.6	37.0
E. coccinea	11.4	9.0	2.7	23.1	*C. sphacelatus*	14.0	16.6	5.9	36.5
C. compresssus	4.4	10.3	8.2	22.9	*C. diffusus*	11.0	14.6	6.5	32.1
F. miliacea	3.3	7.3	7.7	18.3	*S. juncoides*	6.3	14.4	11.4	32.1
P. ruderale	7.1	6.5	3.2	16.8	*L. crustacea*	15.2	11.6	3.8	30.6
C. iria	6.0	5.0	2.9	13.9	*P. maximum*	0.9	3.7	20.5	25.1
P. lanceolatus	4.9	5.2	3.7	13.8	*O. corymbosa*	7.7	7.6	4.8	20.1
U. lobata	2.7	4.7	6.0	13.4	*E. coccinea*	6.9	3.3	2.4	12.6
T. subulata	4.9	4,.	3.0	12.2	*C. iria*	5.4	3.2	2.9	11.5
D. horizontalis	4.4	3.5	2.8	10.7	*A. conyzoides*	0.3	0.4	6.5	7.2

Floristic diversity was greater in the weed seed bank that was assessed in the greenhouse, with H' = 2.89 nats ind.$^{-1}$, versus H' = 2.34 nats ind.$^{-1}$ when it was assessed in the field. The highest number of individuals found in the greenhouse contributed to the greatest floristic diversity in this area.

Discussion

Species from the Cyperaceae family largely dominated the weed seed bank in the soil. The formation of a seed bank represents an important regeneration strategy for many weed species from this family (LECK; SCHÜTZ, 2005). This result corroborates similar studies conducted in other tropical regions, such as those from Kamoshita et al. (2010), who observed that 86% of the species present in the seed banks of 22 rice fields from smallholders in Cambodia were from the Cyperaceae family.

As demonstrated by the data, ten families (50%) had only one species (Table 1). It is generally accepted that in floristic surveys with a large number of families with only one species, this indicates a pattern characteristic of high-diversity sites (RATTER et al., 2003).

Species that were common both in the field and in the greenhouse demonstrated greater plasticity, that is, the capacity to adapt to different sites in addition to a tolerance of anthropic activities and the stresses imposed by environmental factors.

Differences observed between the number of seeds germinated in the field and in the greenhouse might be explained by various factors including seed and seedling losses in the field due to predators, including microorganisms, insects, rodents, lizards, birds and other animals. According to Ghersa and Martinez-Ghersa (2000), weed seed losses from predators can reach 5 to 15%, but in post-dispersal weed seed studies conducted in smallholder rice fields in the Philippines, Chauhan et al. (2010) observed that over a period of only 14 days, fire ants (*Solenopsis geminata*) were the main predators and were responsible for the removal of 98, 88 and 75% of *D. ciliaris*, *E. indica* and *E. colona* seeds, respectively, that had previously been placed on the soil surface.

In addition to losses from predation, germination failure might have occurred due to periods of soil water stress or to intra- and interspecific competition, as observed by Herault and Hiernaux (2004) in weed seed and population dynamics studies conducted in Africa and also by Isaac and Guimarães (2008) in research conducted on the weed seed bank and emergent flora in agricultural fields in Mato Grosso State, in western Brazil.

In the greenhouse, however, seeds were protected from predators and were systematically irrigated, unlike in the field. Maia et al. (2004), on studying weed seed banks in natural fields, also observed that soil moisture content was one of the most important abiotic factors affecting patterns of variation in vegetation. Other authors have also considered soil water content as a determining factor affecting weed seed bank germination (MUNHOZ; FELFILI, 2006; VIVIAN et al., 2008).

Moreover, the withdrawal of weed seedlings from the greenhouse trays after the assessments eliminated competition and control of abiotic factors such as relative humidity, light and temperature was continually performed.

The higher germination rates observed during the first 70 days in the greenhouse were probably due to the high seedling recruitment rates from weather conditions favorable for seed germination that occur for longer periods in tropical regions and due to the abiotic factors control such as light, humidity and temperature in the greenhouse (GARCIA, 1995). Similar results were reported by Zimdahl et al. (1988) in the Philippines, where 50% of the weed seed bank in the soil in the rice fields germinated during the first six weeks. Begum et al. (2006) also observed the highest peak in germination in the weed seed bank at 30 days in rice fields in Malaysia.

These results suggest that the weed seed bank reservoir at the study site might be drastically decreased if management practices that prevent germination or make it difficult or that prevent the deposition of new seeds into this bank, that is, that allow no further seed rains in the area, were to be adopted.

In agricultural fields where the soil is not turned over for planting as it was in this study, as well as where the input of new weed seeds is minimized, the weed seed bank rates of decline might still vary depending on the weather and the climate (GARCIA, 1995).

According to Roberts and Feast (1973), in temperate climate regions, the weed seed bank rate of decline is 32% a year. In contrast, in tropical regions, the weed seed bank is generally smaller and the decline tends to be faster because there is a high seedling recruitment rate due to the favorable climatic conditions for germination that are also observed for longer periods than in temperate regions; high seed mortality due to stress from pathogens and predators due to high relative humidity and higher temperatures that favor these biotic agents; seedling mortality due to germination during short, hot, dry periods that can occur during the rainy season and the shorter duration of weed seed dormancy in tropical rather than in temperate regions (GARCIA, 1995).

The density of 372 viable seeds m^{-2} found in the weed seed bank assessed in the greenhouse is lower compared to the 22,313 seeds m^{-2} in lowland areas and 6,768 seeds m^{-2} in a crop rotation (soybean, fallow, bean) reported by Carmona (1995) in the savannah of central Brazil, as well as the 6,188 seeds m^{-2} recorded by Lacerda et al. (2005) under conventional tillage in São Paulo State in southeastern Brazil.

Similarly, the greenhouse density in this study is lower than the 48,821 seeds m^{-2} in África (BUAH et al., 1996) and the 5,313 seeds m^{-2} in cassava fields in Amazonas State, northern Brazil (COSTA et al., 2009), the 451 seeds m^{-2} found by Gasparino et al. (2006) in agricultural fields in Paraná State, southern Brazil, and the 2,028 seeds m^{-2} recorded in a direct seeding in Mato Grosso State, western Brazil, by Isaac and Guimarães (2008).

This is probably due to management practices that the smallholder farmers from Lago Verde County have been using in the past ten years. In contrast to the majority of other smallholders in Maranhão State, they eliminated the practice of slash and burn planting and sow without disturbing the soil. The remains of the previous crops are left on the ground as a straw mulch.

They also practice crop succession by planting cowpeas after rice and pigeonpeas [*Cajanus cajan* (L.) Millsp.] (Fabaceae) at the beginning of the dry season, so that the soil remains covered during over half of the year, resulting in a reasonable level of weed suppression and promoting other benefits in the soil's chemical and physical properties.

The species dominance in the weed seed bank might be related not only to cultural practices and cropping history but also to breeding capacity. All of the seeds cited in this paper propagate by seeds. In contrast, *F. dichotoma* and *S. lithosperma* (Cyperaceae) also propagate asexually by rhizomes as well as sexually by using seeds (LORENZI, 2008).

According to the IRRI (2010), one plant from the species *L. octovalvis* (Onagraceae) is capable of producing 250,000 seeds. Among the Cyperaceae, the species *S. juncoides* is capable of producing, on average, 82,098 seeds m^{-2} (LECK; SCHÜTZ, 2005), while *F. miliaceae*, *F. dichotoma* and *C. iria* can produce 10,000, 6,500 and 5,000 seeds per plant, respectively (GALINATO et al., 1999; LORENZI, 2008).

Conclusion

The floristic diversity of the soil seed bank from the corn field was higher when it was assessed in the greenhouse than when it was assessed in the field.

The density of the soil seed bank was higher when it was assessed in the greenhouse than when it was assessed in the field

The dominant species in the soil weed seed bank based on the Importance Value Index were *Scleria lihosperma* in the greenhouse and *Lindernia crustacea* in the field.

The current results could help predict infestation potential and could lead to improved weed management strategies in corn-growing areas for smallholdings in the state of Maranhão, in northeastern Brazil.

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