Use of topsoil for restoration of a degraded pasture area

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Abstract – The objective of this work was to evaluate the influence of topsoil thickness, shading and origin when performing environmental restoration in a degraded pasture area. The experiment was conducted in a randomized block design with a factorial (3 x 2 x 2) + 2 layout. Treatments consisted of combinations of topsoil origins (forest at early or middle regeneration stages), topsoil thicknesses (10, 20, or 30-cm superficial soil layer), and presence or absence of 70% shading; with two additional control treatments. Surveys on topsoil physical-chemical attributes and flora and soil coverage were conducted. Good correlation was observed between bulk density and total porosity. Vegetation comprised a total of 2,932 individuals of herbaceous, shrub and subshrub plants; 33 species in 11 families and 1 morphospecies were identified. A floristic survey of the tree stratum revealed 235 individuals belonging to 21 species and 14 families, as well as 2 unidentified species. The best natural regeneration index is observed in the 20-cm topsoil layer, where shading exerts a positive influence on the humidity and natural regeneration of the seed bank. Topsoil from middle-stage forest is the most suitable for restoration of degraded pasture areas.

Index terms: ecosystem restoration, fertility, natural regeneration, topsoil application.

Uso de topsoil na restauração de uma área de pastagem degradada

Resumo – O objetivo deste trabalho foi avaliar a influência da espessura, sombreamento e origem do topsoil na restauração ambiental de uma área de pastagem degradada. O experimento foi realizado em delineamento em blocos casualizados, em esquema fatorial (3 x 2 x 2) + 2. Os tratamentos foram compostos pela combinação das origens do topsoil (estágio inicial ou médio de regeneração), espessuras do topsoil (10, 20 ou 30 cm de camada superficial de solo) e ausência ou presença de sombrite de 70%; com duas testemunhas adicionais (T1 e T2). Foi realizada a caracterização físico-química do topsoil, assim como o levantamento florístico e a cobertura do solo. Houve boa correlação entre a densidade do solo e a porosidade total. A cobertura vegetal desenvolvida apresentou um total de 2.932 indivíduos de hábitos herbáceo, arbustivos e subarbustivos, identificadas 33 espécies em 11 famílias e 1 morfoespécie. Já o levantamento florístico do estrato arbóreo registrou 235 indivíduos pertencentes a 21 espécies e 14 famílias e 2 espécies sem identificação. O topsoil de 20 cm de espessura é o que apresenta melhor índice de regeneração natural, onde o sombreamento exerceu uma influência positiva sobre a umidade e a regeneração natural do banco de sementes. O topsoil proveniente de floresta de estágio médio é o mais adequado para restauração de áreas de pastagem degradadas.

Termos para indexação: restauração de ecossistemas, fertilidade, regeneração natural, transposição de solo.

Introduction

In reclaiming soil and vegetation and recovering integrated biological processes, components of the soil-plant-atmosphere system must be considered. Thus, revegetation should be dealt with by multidisciplinary teams, which identify problems and seek solutions based on the diverse aspects of scientific knowledge on soil (fertility, physical-chemical, biota, nutrient cycling); plants (botany, physiology, interactions with animals); atmosphere (weather); and their ecological interactions (Leal Filho et al., 2013).

The technique of topsoil application, which is both inexpensive and simple to perform, restores degraded land acting as a source of propagules for a great diversity of organisms, which allows a quick succession. Adding concentrated organic topsoil and nutrients to a degraded area under natural regeneration can contribute significantly to its resilience (Bechara et al., 2007).

Thus, topsoil use can be a crucial tool for successful revegetation of degraded areas (Zhang et al., 2001). The high density and diversity values of the soil seed bank in most surveys in Brazilian forests reveal the potential of using the seed bank in restoring degraded areas, thereby increasing diversity and contributing to the maintenance of restoration projects.

Pasture areas in Brazil occupy approximately 172 million hectares, of which approximately 80% are degraded at some degree. These pastures are mainly composed of grasses of the *Urochloa* (Syn. *Brachiaria*) genus (Reaser et al., 2005), whose species tend to be invasive. For this reason, they are identified as an important obstacle to natural regeneration, forest succession, and development of native species (Pilon & Duringan, 2013). Thus, topsoil application as a forest restoration technique in abandoned pasture has been widely used in recent years, as it is a low-cost and efficient technique in restoring structure, function, diversity and dynamics of degraded areas as compared to the reference ecosystem. Furthermore, topsoil is a nutrient-rich material for plant propagules and soil microorganisms in restoration projects (Golos & Dixon, 2014).

However, an important feature of topsoil that must be better defined is its thickness, because the plant community depends largely on topsoil to develop properly in the environment. Ideally, topsoil is applied keeping its original thickness; but, in case of insufficient topsoil available, local losses may occur during operations.

The objective of this work was to evaluate the influence of topsoil thickness, shading and origin when performing environmental restoration in a degraded pasture area.

Materials and Methods

The experimental area, located in the Passa Sete farm, which belongs to a mining company (Anglo American Brazil) headquartered in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, Brazil (18°51'47.34"S, 43°24'2.71"W), occupies an area of 1,260 m² of degraded pasture, formed predominantly by *Urochloa* sp. and occasionally by *Sida* sp.

Vegetation found in this environment is characterized by fragments of semideciduous forest in the early and middle stages of forest regeneration (Machado et al., 2010). The dominant climate in the region is Cwa (according to the Köppen classification), with a dry season lasting 4-5 months that coincides with the coldest months. The annual average temperature is 20.6°C and relative humidity ranges between 75 and 80%. Average annual rainfall ranges between 1,400 and 1,500 mm, with rainfall concentrated from November to March. Predominant soils in the region are Haplic Rhodic Ferralsols, Haplic Cambisols, and Dark Red Argisols, and occur in areas with a predominantly slightly hilly relief (FAO, 2006).

Topsoil used in this study was taken from two distinct areas of seasonal semideciduous montane forest, located within the limits of the tailings dam established by Anglo American Brazil. In the first area, the forest was in the middle regeneration stage, and the topsoil had been removed and stacked 6 months before the experiment began. In the second area, the forest was in the early regeneration stage, and topsoil was removed by the time the experiment started, in February 2012.

Fourteen treatments and three replicates were established and implemented in 42 plots of 5x5 m (25 m²). The experiment was conducted in a randomized complete block design with a factorial (3x2x2) 2 layout. Treatments combined three aspects: topsoil thicknesses (10, 20, or 30 cm superficial soil layer), topsoil origins (forest at early or middle regeneration stage) and presence or absence of 70% shading. Two additional control treatments marked only by the presence or absence of shading were also performed. Treatments were identified by the following codes: 0-C and 0-S (control treatments, with and without shading, respectively); 10M-C and 10M-S (10-cm-thick topsoil from middle-stage forest, with and without shading; 10I-C and 10I-S (10-cm-thick topsoil from early-stage forest, with and without shading; 20M-C and 20M-S (20-cm-thick topsoil from middle-stage forest, with and without shading; 20I-C and 20I-S (20-cm-thick topsoil from early-stage forest, with and without shading; 30M-C and 30M-S (30-cm-thick topsoil from middle-stage forest, with and without shading; 30I-C and 30I-S (30-cm-thick topsoil from early-stage forest, with and without shading. The plots were assembled and separated from each other by wooden rods to contain the movement of topsoil between plots. Each block was divided into two rows of seven plots; between

the rows, 1-m-wide access roads were established and between blocks of 1.5 m.

Topsoil was trucked to the experimental area and deposited in the plots with the help of backhoes and/or wheelbarrows, and it was then spread with hoes according to the randomly selected treatment for each plot. In total, 180 m^3 of topsoil was used.

Samples were collected in June, 2012 for the soil physical-chemical characterization. From each plot, five single 0–10-cm-thick samples were combined to form a composite sample, totaling 42 samples. Each sample was air-dried, passed through a 2-mm-mesh sieve, wrapped in plastic, labelled and sent to Soil Fertility Laboratory, at Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM).

Chemical analyses of soil samples followed the protocol of Claessen (1997) and were used to determine water pH level; P available, K; Ca^{2+}, Mg^{2+}, Al^{3+}; potential acidity (H+Al); sum of bases (Ca^{2+} + Mg^{2+} + K^{+}), cation exchange capacity at pH 7.0 (CEC), effective cation exchange capacity, base saturation [(Ca^{2+} + Mg^{2+} + K^{+})/CEC at pH 7], Al saturation and soil organic matter content.

In November 2012, for the analyses of bulk density, particle density, and total porosity of topsoil using the volumetric ring method, 42 samples were collected from the center of each plot, with the help of volumetric rings. Each sample was also wrapped in plastic wrap, labelled and sent to Laboratório de Fertilidade do Solo at UFVJM for analysis.

To verify the structure of herbaceous components and estimate the percentage of live coverage on topsoil, the Braun-Blanquet scale (Braun-Blanquet, 1979) was used. In November 2012, five subplots of 1x1 m (1 m²) were randomly selected from each 25-m² plot, and all individuals present within each subplot were drawn, numbered, and identified. Soil coverage was visually estimated in each subplot selected, such that soil coverage in the subplots amounted to 20% of the total coverage of the plot.

Species identification was performed immediately in the field when possible. When it was not possible,

Table 1. Physical and chemical attributes of 0–10-cm-thick topsoil applied in a degraded pasture area of Passa Sete farm, in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, Brazil[(1)].

Physical attributes	Treatment													
	0-C	0-S	10M-C	10M-S	10I-C	10I-S	20M-C	20M-S	20I-C	20I-S	30M-C	30M-S	30I-C	30I-S
Sand (g kg^{-1})	550	520	560	570	460	480	580	570	440	450	570	590	450	440
Silt (g kg^{-1})	150	170	50	100	210	200	40	100	190	230	110	70	220	200
Clay (g kg^{-1})	300	310	390	330	330	320	380	330	370	320	320	340	330	360
Chemical attributes														
pH H_2O	4.7b	5.2a	4.7b	4.7b	4.7b	4.9b	4.6b	4.6b	4.6c	4.8b	4.6b	4.7b	4.6b	4.7b
P (mg dm^{-3})	0.5c	0.6b	0.8b	1.0a	0.9b	0.9b	0.8b	0.9b	0.9b	0.9b	0.8b	1.0a	0.9b	0.8b
K^{+} (mg dm^{-3})	61.6d	74.4c	106.4c	139.0 a	109.1c	126.5a	132.0a	140.5a	107.3c	117.5b	138.9a	139.4a	109.0c	112.8b
Ca^{2+} ($cmol_c$ dm^{-3})	0.3c	0.3c	0.7b	1.0a	0.5c	0.5c	1.0a	1.0a	0.5c	0.4c	0.8b	1.0a	0.6b	0.4c
Mg^{2+} ($cmol_c$ dm^{-3})	0.3a	0.4a	0.4a	0.4a	0.3a	0.3a	0.4a	0.3a	0.5a	0.2a	0.3a	0.5a	0.3a	0.9a
Al^{3+} ($cmol_c$ dm^{-3})	1.2d	1.1d	1.2d	1.2d	1.7c	1.6c	1.4c	1.2c	1.8b	1.7b	1.3c	1.4c	1.8a	1.6c
H+Al ($cmol_c$ dm^{-3})	5.2c	4.7c	8.0b	9.1a	8.5b	8.8a	10.3a	9.5a	8.2b	8.2b	10.0a	8.8a	8.4b	8.3b
SB ($cmol_c$ dm^{-3})	0.6d	0.9d	1.4c	1.8a	1.0c	1.2c	1.7b	1.6b	1.3c	0.9d	1.5b	1.8a	1.2c	1.0c
t ($cmol_c$ dm^{-3})	1.8c	1.9c	2.6b	3.0a	2.7b	2.8b	3.1a	2.9a	3.0a	2.6b	2.8b	3.2a	3.1a	2.5b
CEC ($cmol_c$ dm^{-3})	5.9c	5.6c	9.4b	10.9a	9.5a	9.9a	12.0a	11.1a	9.4a	9.1b	11.5a	10.6a	9.7a	9.2b
SOM (dag kg^{-1})	0.5d	1.0d	2.1b	2.0b	1.4c	2.4a	2.5a	2.0b	1.6c	2.2b	2.4a	2.4a	2.1b	1.3c
Al saturation (%)	65.3a	57.0b	46.0b	41.0c	61.3a	58.3b	45.0b	43.3c	58.3b	64.3a	47.0b	42.3c	60.0a	62.0a
Base saturation (%)	10.7a	15.0a	15.3a	16.0a	11.3a	11.7a	15.0a	14.7a	13.7a	10.3a	13.3a	17.3a	13.0a	10.7a

[(1)]Means followed by equal letters, in the row, do not differ significantly by Tukey's test, at 5% probability. pH (H_2O) ratio 1:2.5 (soil:water); P and K: Mehlich-1; Ca, Mg and Al: KCl 1 mol L^{-1}; H + Al: calcium acetate 0.5 mol L^{-1} at pH 7.0; SB: sum of bases; t: effective cation exchange capacity; T: CEC pH 7.0; SOM: soil organic matter content; M: Al saturation; BS: base saturation. Treatments – 0-C and 0-S: control treatments, with and without shading, respectively; 10M-C and 10M-S: 10-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 10I-C and 10I-S:10-cm-thick topsoil from early-stage forest, with and without shading, respectively; 20M-C and 20M-S: 20-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 20I-C and 20I-S: 20-cm-thick topsoil from early-stage forest, with and without shading, respectively; 30M-C and 30M-S: 30-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 30I-C and 30I-S: 30-cm-thick topsoil from early-stage forest, with and without shading, respectively.

species were identified with the help of literature and photographic records. Species and families were classified according to Angiosperm Phylogeny Group (APG III) (Bremer et al., 2009), and their spellings and nomenclatural synonyms were verified at Tropicos (2014) and The International Plant Names Index (IPNI, 2012).

Survey of tree species was conducted throughout the area of the 25-m² plots, and all individuals existing within each plot were counted and identified. Identification, classification and verification of spellings and nomenclatural synonyms were performed using the same methods described for herbaceous plants.

Phytosociological parameters considered in the analysis of community organization were as follows: frequency, density, absolute and relative abundance and Shannon diversity index (Mueller-Dombois & Ellenberg, 1974). To confirm the regeneration rate of species, the formula proposed by Finol (1971) was used: NR = [(RD + RF) / 2], where NR is the percentage of natural regeneration, RD is the relative density of the species, and RF is the relative frequency.

The data were evaluated using analysis of variance; for results significant at 5% by F-test, and Dunnett's test at 5% probability was used to compare the means of all treatments with each control treatment. Factorial analysis of variance without control treatments was performed only when the result was significant in the previous analysis and was followed by Tukey's test at a 5% probability. All statistical analyses were performed using the software Statistica, version 10.0 (Statsoft, Inc., Tulsa, Oklahoma, USA).

Results and Discussion

In particle size analysis, percentages of sand, silt and clay were identified, according to Santos et al. (2006). Topsoil was observed to have a medium texture, with clay content below 35% (Table 1). Particle density results did not differ according to treatments (p=0.289); however, bulk density and total porosity revealed overall significant differences depending on the evaluated thicknesses (p=0.001, p=0.000, respectively).

When comparing bulk density in all treatments with bulk density in each control treatment (0-C and 0-S), the only treatment that showed no difference was 10M-C (Table 2). Even with significant differences among treatments, the highest values for bulk density are are not limiting for root growth. Soil water infiltration was between 1.27 and 1.57 g cm^{-3} (Corsini & Ferraudo, 1999).

For total porosity, different results were observed. Compared to 0-C, treatments that showed significant differences were 10M-S, 20M-C, 20I-C, and 20I- S. Compared to 0-S, 10M-C, and 30I-S treatments were the only ones that did not differ significantly. It was also observed that treatments with higher total porosity values presented lower bulk density values. This was also found by Beutler et al. (2004).

The highest values for bulk density were observed in 10M-C and 10I-C treatments. For total porosity, the highest values were observed for 20M-C and 20I-C treatments, with good correlation with bulk density values, because the thickness with higher thickness value showed the lowest bulk density.

In terms of soil density, value for 10-cm-thick topsoil (0.9743 g cm^{-3}) was higher than those for 20-cm-thick

Table 2. Bulk density and total porosity of topsoil in a degraded pasture area of Passa Sete farm, in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, Brazil, for each treatment compared to control treatments.

Treatment[(1)]	Bulk density (g cm^{-3})		Total porosity (cm^3 cm^{-3})	
	0-C	0-S	0-C	0-S
0-C	-	1.157[ns]	-	0.505[ns]
0-S	1.151[ns]	-	0.448[ns]	-
10M-C	1.014[ns]	1.014[ns]	0.519[ns]	0.519[ns]
10M-S	0.874*	0.874*	0.623*	0.623*
10I-C	0.934*	0.934*	0.586[ns]	0.586*
10I-S	0.910*	0.910*	0.574[ns]	0.574*
20M-C	0.844*	0.844*	0.632*	0.632*
20M-S	0.919*	0.919*	0.594[ns]	0.594*
20I-C	0.808*	0.808*	0.643*	0.643*
20I-S	0.882*	0.882*	0.618*	0.618*
30M-C	0.902*	0.902*	0.608[ns]	0.608*
30M-S	0.882*	0.882*	0.617[ns]	0.617*
30I-C	0.883*	0.883*	0.597[ns]	0.597*
30I-S	0.914*	0.914*	0.524[ns]	0.524[ns]

[(1)]Treatments: 0-C and 0-S, control treatments, with and without shading, respectively; 10M-C and 10M-S, 10-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 10I-C and 10I-S, 10-cm-thick topsoil from early-stage forest, with and without shading, respectively; 20M-C and 20M-S, 20-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 20I-C and 20I-S, 20-cm-thick topsoil from early-stage forest, with and without shading, respectively; 30M-C and 30M-S, 30-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 30I-C and 30I-S, 30-cm-thick topsoil from early-stage forest, with and without shading, respectively. [ns]Not significant. *Significant at 5% probability by Dunnett's test.

and 30-cm-thick topsoil (0.8258 and 0.8920 g cm^{-3}, respectively). In terms of total porosity, the value for 20-cm-thick topsoil was 0.6372 cm^3, which was statistically higher than values for 10-cm-thick and 30-cm-thick topsoil.

Soil coverage values ranged from 3 to 19% (for 20I-C and 10I-S treatments, respectively). Although 10I-S treatment showed the highest percentage of soil coverage in relation to species richess, only 11 species (the third smallest number of species) were observed in soils under this treatment. Nevertheless, 10I-S comprised 440 individuals, the second largest number among total individuals in this study (Table 3).

The values observed are considered low compared to those found by Silva et al. (2012) in the evaluation of a gravel soil coverage after using topsoil in the dry and the rainy seasons, with 66 and 82% coverage, respectively. In the present study, however, it is noteworthy that topsoil was applied in February, when there was a strong summer in the region, which led to low regeneration and high mortality. As the survey was conducted in the second week of November (beginning of the rainy season), most of the individuals were in initial development and therefore generated a minimum soil coverage in the plots. Thus, expectations were that, with consecutive rains, there would be an increase in soil coverage, since herbaceous and subshrub species play an important role in soil protection against erosive processes and in incorporating organic matter into the soil, thus contributing to nutrient cycling (Martins et al., 2002).

In addition to low vegetation, soil coverage was characterized by the dominance of *Sida glaziovii* K. Schum, considered a ruderal species that colonizes mainly pasture areas, propagates by seeds (Constantin et al., 2007) and inhabits places of low environmental stress and high disturbance intensity. It is usually herbaceous, with a rapid development cycle, high aggressiveness and low competitive capacity (Chaves & Silva, 2012).

Vegetation developed on topsoil with or without shading comprised a total of 2,932 herbaceous, shrub, and subshrub individuals (Table 3). They were identified as belonging to 33 species in 11 families and 1 morphospecies. Asteraceae was the family with the largest number of species (9), followed by Fabaceae (6), Convolvulaceae and Malvaceae (4), Solanaceae (3) and Poaceae (2); the other families were represented by only 1 species each. Regarding the numbers of individuals, the most common families were the Malvaceae (1,956), Poaceae (159) and Cyperaceae (149). Anemochoric species were more frequent (50%) than autochoric (25%) and zoochoric species (23%). However, in terms of number of individuals, autochoric species (70%) were more abundant than anemochoric (20%) and zoochoric species (12%). The distribution of herbaceous, shrub and subshrub individuals in the different dispersal syndromes varied depending on topsoil origin, either with or without shading. A significant difference was observed among dispersal guilds and topsoil origins (Table 4).

Topsoil from early-stage forest was observed to alter the proportions of autochoric and anemochoric individuals, and topsoil from middle-stage forest changed the proportions of zoochoric individuals. However, the presence of shading favored anemochoric individuals, thus increasing their numbers in comparison with the number of individuals in the absence of shading. These anemochoric species produce seeds and vegetative propagules with great potential for colonization and reproduction (Moravcová et al., 2015).

Floristic survey of the tree stratum revealed 235 individuals of 21 species and 14 families, as well as two unidentified species classified as morphospecies (Table 5). The family with the highest species diversity was Fabaceae (4), followed by Rutaceae, Solanaceae, Myrtaceae and Asteraceae (2 each). However, the family with the highest number of individuals was Siparunaceae, with 133 individuals of *Siparuna guianensis* Aubl., which is known in Brazil as holy sheet, is an understory and late succession species and is widely distributed; it had been found in high densities in several previous surveys in the region (Prado Júnior et al., 2010; Lopes et al., 2011). These are not long-lived trees, but their substantial ecological plasticity leads to a high colonization capacity and makes them important in the tree community (Prado Júnior et al., 2012). The abundance of *S. guianensis* was associated with topsoil origin, which carried local vegetal memory and was, therefore, a determining factor for regeneration. However, these results were also influenced by the presence of shading on the plots, which facilitated germination of secondary species (to the detriment of pioneer ones), because it recreates an

Table 3. List of herbaceous, shrub, and subshrub species observed in treatments in the experimental area of Passa Sete farm, in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, Brazil[1].

Family/species		With shading											Without shading									
		C	Middle stage				Early stage						C	Middle stage				Early stage					
	DS[2]	0-C	10 M-C	20 M-C	30 M-C	Total 1	10 I-C	20 I-C	30 I-C	Total 2	Total A		0-S	10 M-S	20 M-S	30 M-S	Total 1	10 I-S	20 I-S	30 I-S	Total 2	Total B	Total (A+B)
Amaranthaceae																						
Amaranthus viridis	Ane	0	0	0	0	0	1	0	2	3	3		1	0	2	0	2	0	0	2	2	5	8
Asteraceae																						
Ageratum conyzoides	Ane	0	4	0	1	5	14	5	7	26	31		2	1	0	0	1	3	26	2	31	34	65
Acanthospermum hispidum DC.	Ane	0	0	2	0	2	1	4	4	9	11		0	1	1	0	2	3	0	0	3	5	16
Melampodium paniculatum	Ane	0	0	0	0	0	0	15	0	15	15		0	0	0	0	0	0	0	0	0	0	15
Tagetes minuta	Ane	0	1	0	1	2	5	0	0	5	7		0	0	0	0	0	0	2	0	2	2	9
Conyza bonariensis	Ane	0	0	0	0	0	0	1	0	1	1		0	3	0	0	3	0	0	0	0	3	4
Ageratum fastigiatum	Ane	0	0	0	0	0	0	0	0	0	0		0	3	0	0	3	0	0	0	0	3	3
Emilia fosbergii	Ane	0	0	0	0	0	0	1	0	1	1		0	1	0	0	1	0	0	0	0	1	2
Gnaphalium coarctatum	Ane	0	0	1	0	1	0	0	0	0	1		0	1	0	0	1	0	0	0	0	1	2
Siegesbeckia orientalis L.	Auto	0	0	0	0	0	0	0	1	1	1		0	0	0	1	1	0	0	0	0	1	2
Commelinaceae																						
Commelina benghalensis	Auto	0	2	4	0	6	42	23	36	101	107		5	0	0	1	1	16	3	8	27	33	140
Convolvulaceae																						
Merremia cissoides (Lam.) Hallier f.	Ane	0	0	0	0	0	0	0	0	0	0		0	2	0	3	5	0	0	0	0	5	5
Dichondra microcalyx	Ane	0	0	0	0	0	0	0	0	0	0		0	0	1	0	1	0	0	0	0	1	1
Ipomoea purpurea	Ane	0	0	0	0	0	0	0	0	0	0		0	0	1	0	1	0	0	0	0	1	1
Ipomoea triloba	Ane	0	0	0	0	0	0	0	0	0	0		0	1	0	0	1	0	0	0	0	1	1
Cyperaceae																						
Cyperus esculentus L.	Ane	0	0	2	0	2	13	35	65	113	115		0	1	2	2	5	3	8	18	29	34	149
Fabaceae																						
Zornia reticulata	Zoo	0	1	3	0	4	9	11	27	47	51		1	11	0	22	33	4	5	2	11	45	96
Desmodium barbatum	Zoo	0	3	0	4	7	2	1	5	8	15		0	2	3	0	5	0	2	0	2	7	22
Aeschynomene denticulata	Auto	0	0	2	0	2	1	3	0	4	6		0	0	0	0	0	0	0	0	0	0	6
Chamaecrista rotundifolia	Auto	0	0	0	0	0	0	0	3	3	3		0	0	1	0	1	1	0	0	1	2	5
Crotalaria incana L.	Auto	0	0	0	1	1	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	1
Stylosanthes viscosa	Auto	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	1	0	1	1	1
Lamiaceae																						
Marsypianthes chamaedrys (Vahl) Kuntze	Auto	0	0	0	0	0	14	3	15	32	32		2	0	0	0	0	0	0	0	0	2	34
Malvaceae																						
Sida glasiovii	Auto	150	6	17	6	29	138	151	100	389	568		258	53	16	4	73	368	553	25	946	1,277	1,845
Sida rhombifolia	Zoo	0	1	2	0	3	1	3	11	15	18		3	4	10	2	16	2	0	25	27	46	64
Sidastrum micranthum	Auto	0	7	7	0	14	3	2	1	6	20		1	3	3	2	8	0	0	1	1	10	30
Sida cordifolia	Zoo	0	1	0	1	2	1	2	0	3	5		3	1	0	5	6	1	2	0	3	12	17
Unidentified																						
Morphospecies 1	Ane	0	9	20	6	35	6	9	7	22	57		0	20	7	6	33	21	12	12	45	78	135
Poaceae																						
Brachiaria decumbens (Stapf) R.D. Webster	Ane	0	1	0	0	1	12	16	30	58	59		11	7	4	2	13	4	11	10	25	49	108
Melinis minutiflora P. Beauv.	Ane	0	0	0	0	0	6	0	17	23	23		0	0	1	0	1	17	10	0	27	28	51
Rubiaceae																						
Diodia teres Walt.	Zoo	0	0	0	0	0	0	12	0	12	12		0	0	2	44	46	0	0	3	3	49	61
Solanaceae																						
Physalis angulata	Zoo	0	0	1	0	1	0	3	1	4	5		0	1	0	0	1	3	9	0	12	13	18
Datura stramonium L.	Zoo	0	2	2	0	4	0	0	1	1	5		0	1	1	2	4	0	3	2	5	9	14
Solanum viarum	Zoo	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	1	1	1	1
Total individuals		150	33	61	18	121	248	274	320	902	1,173		284	108	52	96	268	440	619	107	1,166	1,718	2,932
Total species		1	10	11	5	18	13	14	15	25	27		8	14	13	13	27	11	12	11	21	31	37

[1]Treatments – 0-C and 0-S: control treatments, with and without shading, respectively; 10M-C and 10M-S: 10-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 10I-C and 10I-S: 10-cm-thick topsoil from early-stage forest, with and without shading, respectively; 20M-C and 20M-S: 20-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 20I-C and 20I-S: 20-cm-thick topsoil from early-stage forest, with and without shading, respectively; 30M-C and 30M-S: 30-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 30I-C and 30I-S: 30-cm-thick topsoil from early-stage forest, with and without shading, respectively. [2]DS, dispersal syndrome; Ane, anemochoric; Auto, autochoric; and Zoo, zoochoric.

shade-tolerant understory microclimate to which these species are adapted (Valentini et al., 2010).

Regarding species diversity, 20M-C contained the largest number of species (14), followed by 30M-C (11) and 10M-C (7) (Table 6). The Shannon index was 1.91, a considerable value in terms of diversity. Comparing the rates of species and individuals belonging to the three ecological groups (pioneers, initial secondary, late secondary and without characterization), it was observed that 53% of species were pioneers. However, 69% of individuals were late secondary species. Differences among guilds and topsoil origins were found only for initial secondary, autochoric dispersion and middle-stage topsoil. Animals as dispersal agents

Table 4. Contingency table with observed and expected (in parentheses) frequencies of herbaceous, shrub, and subshrub individuals.

Dispersal syndrome	Topsoil origin (%)[1]				Chi-Square test	
	FEI-SS	FEI-CS	FEM-SS	FEM-CS	χ^2	p
Anemochoric	164 (270.7)	276 (202.8)	73 (60.3)	48 (27.2)	82.862	0.000*
Autochoric	976 (795.3)	536 (595.8)	84 (177.0)	52 (79.9)	56.156	0.000*
Zoochoric	64 (138.0)	90 (103.4)	111 (30.7)	21 (13.9)	43.935	0.000*
χ^2	263.87	1,607.23	748.76	2,257.48	-	-
p	0.000*	0.000*	0.000*	0.000*	-	-

[1]FEI-SS: forest in early stage, without shading; FEI-CS: forest in early stage, with shading; FEM-SS: forest in middle stage, without shading; FEM-CS: forest in middle stage, with shading. *Significant at 5% probability by Dunnett's test.

Table 5. Phytosociological data for tree species observed in topsoil treatments in the experimental area of Passa Sete farm, in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, Brazil.[1]

Species	NI	NP	AF (%)	AD	RF (%)	RD (%)	NR (%)
Siparuna guianensis	133	18	42.86	1,266.67	20.00	56.6	38.3
Zanthoxylum rhoifolium	15	10	23.81	142.86	11.11	6.38	8.75
Solanum mauritianum	12	9	21.43	114.29	10.00	5.11	7.55
Campomanesia xanthocarpa	8	5	11.90	76.19	5.56	3.4	4.48
Myrcia splendens	5	5	11.90	47.62	5.56	2.13	3.84
Cecropia hololeuca	7	4	9.52	66.67	4.44	2.98	3.71
Solanum lycocarpum	9	3	7.14	85.71	3.33	3.83	3.58
Xylopia sericea	5	4	9.52	47.62	4.44	2.13	3.29
Casearia arborea	5	4	9.52	47.62	4.44	2.13	3.29
Dictyoloma vandellianum	5	4	9.52	47.62	4.44	2.13	3.29
Aegiphila sellowiana	4	4	9.52	38.1	4.44	1.7	3.07
Plathymenia foliolosa	3	3	7.14	28.57	3.33	1.28	2.3
Enterolobium contortisiliquum	4	2	4.76	38.1	2.22	1.7	1.96
Eremanthus crotonoides	3	2	4.76	28.57	2.22	1.28	1.75
Apuleia leiocarpa	3	2	4.76	28.57	2.22	1.28	1.75
Piptadenia gonoacantha	3	2	4.76	28.57	2.22	1.28	1.75
Matayba elaeagnoides	2	2	4.76	19.05	2.22	0.85	1.54
Morphospecies 2	2	2	4.76	19.05	2.22	0.85	1.54
Morphospecies 1	3	1	2.38	28.57	1.11	1.28	1.19
Vernonia densiflora	1	1	2.38	9.52	1.11	0.43	0.77
Sparattosperma leucanthum	1	1	2.38	9.52	1.11	0.43	0.77
Trema micrantha	1	1	2.38	9.52	1.11	0.43	0.77
Luehea grandiflora	1	1	2.38	9.52	1.11	0.43	0.77
Total	235	90	214.29	2,238.1	100	100	100

[1]NI, number of individuals; NP, number of plots; AF, absolute frequency; AD, absolute density (individuals per hectare); RF, relative frequency; RD, relative density; and RN, regeneration index.

Table 6. List of tree species observed in treatments in the experimental area of Passa Sete farm, in the municipality of Conceição do Mato Dentro, in the state of Minas Gerais, Brazil[(1)].

Family/Species			With shading											Without shading										
			C	Middle stage				Early stage						C	Middle stage				Early stage					
	EG	DS	0-C	10 M-C	20 M-C	30 M-C	Total 1	10 I-C	20 I-C	30 I-C	Total 2	Total A		0-S	10 M-S	20 M-S	30 M-S	Total 1	10 I-S	20 I-S	30 I-S	Total 2	Total B	Total (A+B)
Annonaceae																								
Xylopia sericea A. St.-Hil.	P	Zoo	0	1	2	1	4	0	0	0	0	4		0	0	0	0	0	0	0	1	1	1	5
Asteraceae																								
Eremanthus crotonoides (DC.) Sch. Bip.	P	Ane	0	2	0	0	2	0	0	0	0	2		0	0	1	0	1	0	0	0	0	1	3
Vernonia densiflora Gardner	P	Ane	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	1	1	1	1
Bignoniaceae																								
Sparattosperma leucanthum (Vell.) K. Schum.	IS	Ane	0	0	1	0	1	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	1
Cannabaceae																								
Trema micrantha (L.) Blume	P	Zoo	0	0	0	1	1	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	1
Fabaceae																								
Enterolobium contortisiliquum (Vell.) Morong	IS	Auto	0	0	3	0	3	0	0	0	0	3		0	0	1	0	1	0	0	0	0	1	4
Apuleia leiocarpa (Vogel) J.F. Macbr.	IS	Ane	0	1	2	0	3	0	0	0	0	3		0	0	0	0	0	0	0	0	0	0	3
Piptadenia gonoacantha (Mart.) J.F. Macbr.	P	Auto	0	0	1	0	1	0	0	0	0	1		0	0	0	2	2	0	0	0	0	2	3
Plathymenia foliolosa Benth.	IS	Ane	0	0	1	1	2	0	0	0	0	2		0	0	1	0	1	0	0	0	0	1	3
Morphospecies 2	WC	Auto	0	0	0	1	1	0	0	0	0	1		0	0	1	0	1	0	0	0	0	1	2
Lamiaceae																								
Aegiphila sellowiana Cham.	P	Zoo	0	0	1	0	1	0	2	0	2	3		0	0	0	0	0	0	0	1	1	1	4
Malvaceae																								
Luehea grandiflora Mart.	P	Ane	0	0	1	0	1	0	0	0	0	1		0	0	0	0	0	0	0	0	0	0	1
Myrtaceae																								
Campomanesia xanthocarpa Mart. ex O. Berg	LS	Zoo	0	1	0	0	1	3	0	1	4	5		0	1	0	0	1	0	0	2	2	3	8
Myrcia splendens (Sw.) DC.	LS	Zoo	0	1	0	0	1	0	2	1	3	4		0	0	0	0	0	0	0	1	1	1	5
Rubiaceae																								
Morphospecies 1	WC	Zoo	0	0	0	3	3	0	0	0	0	3		0	0	0	0	0	0	0	0	0	0	3
Rutaceae																								
Zanthoxylum rhoifolium Lam.	LS	Zoo	0	0	2	4	6	1	0	1	2	8		0	0	1	2	3	1	0	3	4	7	15
Dictyoloma vandellianum A.H.L. Juss	P	Ane	0	0	1	3	4	0	1	0	1	5		0	0	0	0	0	0	0	0	0	0	5
Salicaceae																								
Casearia arborea (Rich.) Urb.	IS	Zoo	0	0	2	1	3	0	0	0	0	3		0	0	1	1	2	0	0	0	0	2	5
Sapindaceae																								
Matayba elaeagnoides Radlk.	IS	Zoo	0	0	0	0	0	0	0	0	0	0		0	0	1	1	2	0	0	0	0	2	2
Siparunaceae																								
Siparuna guianensis Aubl.	LS	Zoo	0	44	44	33	121	6	1	1	8	129		0	1	2	1	4	0	0	0	0	4	133
Solanaceae																								
Solanum mauritianum Scop.	P	Zoo	0	2	4	1	7	0	0	0	0	7		0	2	0	1	3	0	2	0	2	5	12
Solanum lycocarpum A. St.-Hil.	P	Zoo	1	0	0	0	0	0	1	0	1	2		7	0	0	0	0	0	0	0	0	7	9
Urticaceae																								
Cecropia hololeuca Miq.	P	Zoo	0	0	1	5	6	0	0	0	0	6		0	0	1	0	1	0	0	0	0	1	7
Total individuals	-	-	1	52	66	54	172	10	7	4	21	194		7	4	10	8	22	1	2	9	12	41	235
Total species			1	7	14	11	20	3	5	4	7	21		1	3	9	6	12	1	1	6	7	17	23

[(1)]Treatments – 0-C and 0-S: control treatments, with and without shading, respectively; 10M-C and 10M-S: 10-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 10I-C and 10I-S: 10-cm-thick topsoil from early-stage forest, with and without shading, respectively; 20M-C and 20M-S: 20-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 20I-C and 20I-S: 20-cm-thick topsoil from early-stage forest, with and without shading, respectively; 30M-C and 30M-S: 30-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 30I-C and 30I-S: 30-cm-thick topsoil from early-stage forest, with and without shading, respectively. EG, ecological group; P, pioneers; IS, initial secondary; WC, without characterization; LS, late secondary; DS, dispersal syndrome; Zoo, zoochoric; Ane, anemochoric; and Auto, autochoric.

offer a great advantage: they not only ensure the species' dissemination in the area, but also add other important species whose seeds are present in their faeces (Silva et al., 2012). Therefore, the rates found in this study for the number of species (57%) and individuals (88%) with zoochoric dispersion corroborate those reported by Silva et al. (2012), who observed zoochoric as the predominant dispersal syndrome among species (87.5%).

Numbers of species and individuals observed in each treatment were different (Table 7). 20M-C and 30M-C treatments were the only ones to differ from both control treatments. Regarding the number of individuals, 10M-C, 20M-C and 30M-C were the treatments that differed from both control treatments. Of the five species with the highest number of individuals and the best regeneration rates, four (*Siparuna guianensis, Zanthoxylum rhoifolium, Campomanesia xanthocarpa* and *Myrcia splendens*) were late shade-tolerant secondary species with occurrence in understory. This shows the positive effect of shading: an area that has been recovering for only 9 months already presents a large number of species and individuals typical of advanced successional stages.

Table 7. Number of species and individual trees for each treatment in comparison with control treatments.

Treatment(1)	Number of species		Number of individuals	
	0-C	0-S	0-C	0-S
0-C	-	0.333^{ns}	-	0.333^{ns}
0-S	0.333^{ns}	-	2.333^{ns}	-
10M-C	3.000^{ns}	3.000^{ns}	17.333*	17.333*
10M-S	1.333^{ns}	1.333^{ns}	1.333^{ns}	1.333^{ns}
10I-C	1.667^{ns}	1.667^{ns}	3.333^{ns}	3.333^{ns}
10I-S	0.333^{ns}	0.333^{ns}	0.333^{ns}	0.333^{ns}
20M-C	6.333*	6.333*	22.000*	22.000*
20M-S	3.333^{ns}	3.333^{ns}	3.333^{ns}	3.333^{ns}
20I-C	2.333^{ns}	2.333^{ns}	2.333^{ns}	2.333^{ns}
20I-S	0.000^{ns}	0.000^{ns}	0.667^{ns}	0.667^{ns}
30M-C	5.333*	5.333*	18.000*	18.000*
30M-S	2.000^{ns}	2.000^{ns}	2.667^{ns}	2.667^{ns}
30I-C	1.333^{ns}	1.333^{ns}	1.333^{ns}	1.333^{ns}
30I-S	2.000^{ns}	2.000^{ns}	3.000^{ns}	3.000^{ns}

(1)Treatments – 0-C and 0-S: control treatments, with and without shading, respectively; 10M-C and 10M-S: 10-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 10I-C and 10I-S: 10-cm-thick topsoil from early-stage forest, with and without shading, respectively; 20M-C and 20M-S: 20-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 20I-C and 20I-S: 20-cm-thick topsoil from early-stage forest, with and without shading, respectively; 30M-C and 30M-I: 30-cm-thick topsoil from middle-stage forest, with and without shading, respectively; 30I-C and 30I-S: 30-cm-thick topsoil from early-stage forest, with and without shading, respectively. ^{ns}Nonsignificant. *Significant at 5% probability by Dunnett's test.

Approximately 91% of the identified species occurred in treatments with shading, and, of these, 95% were observed in treatments with topsoil taken from middle-stage forest. Similarly, 86% of individuals occurred in treatments with shading, and 90% of which were observed in treatments with topsoil taken from middle-stage forest. This results confirm that, although shade-tolerant secondary species can develop and establish both in shaded areas (sub-forest) and clearings (Queiroz & Firmino, 2014), their best performances are observed in shaded environments. This evidences the importance of creating small shading areas to enable the establishment of non-pioneer species in areas under restoration with the use of topsoil (Queiroz & Firmino, 2014).

Comparisons with control treatments (0-C and 0-S, with and without shading respectively) showed that the determining factors for the success of treatments were topsoil origin and shading. Among the five species with the greatest number of individuals and better regeneration rates, only four (*Siparuna guianensis*, *Zanthoxylum rhoifolium*, *Campomanesia xanthocarpa* and *Myrcia splendens*) were late shade-tolerant secondary species occurring in the understory. This showed the positive effect of shading. Once an area is in recovery, after only nine months, it has a large number of species and individuals of advanced successional stages. Prado Júnior et al. (2010) observed that, out of the 20 species with higher importance value, 1 was classified as a pioneer species, 12 as early secondary species, and 7 as late secondary species. In the present study, analysis of the relative density per group showed the highest value for early successional species. However, analysis of the relative dominance showed higher values for late secondary species than for the others because generally such species are very long-lived and become large in forest formations.

Conclusions

1. The physical-chemical attributes of topsoil reach the best indices in the 0–10-cm layer in degraded pastures.

2. The best index of natural regeneration is presented in the thickness of 20 cm, both in terms of species diversity and number of individuals.

3. Shading exerts a positive influence on the natural regeneration of the seed bank.

4. Topsoil origin is a factor that exerts a positive influence on physical-chemical attributes and floristic composition; topsoil from middle-stage forest is the most suitable for restoration of degraded pasture areas.

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