Original Article

Soil Influences on Tree Species Distribution in a Rupestrian Cerrado Area

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ABSTRACT

This study aimed to analyze relations between the distribution of tree species and variations in soil texture, fertility and organic matter levels in a rupestrian cerrado area located in Diamantina-MG. Individual trees with circumference at soil level (PC) ≥ 3 cm were sampled in 10 plots of 20x50m. Samples of surface soil (0.00-0.20 m of depth) were collected from each plot and analyzed for their chemical and physical properties. Through canonical correspondence analysis, *Eremanthus incanus, Kielmeyera lathrophyton, Terminalia sp* and *Vochysia discolor* show a stronger relation to higher potassium and remaining phosphorus levels; the species *Xylopia sericea, Protium spruceanum* and *Protium heptaphyllum* show a stronger relation to higher levels of organic matter and total cation exchange capacity; the species *Roupala montana, Qualea grandiflora,* and *Erythroxylum suberosum* grew uniformly in all plots. There is relation between species distribution and chemical and physical soil variables in the area.

Keywords: chemical and physical soil characteristics, organic matter, canonical correspondence analysis, Serra do Espinhaço.

1. INTRODUCTION

The Cerrado has one of the greatest biological diversities on the planet. According to Deus (2011), this biome has an endemic flora of 40%, meaning this percentage of species is unique to Brazilian savannas. Its phytophysiognomy shows several endangered species as well as some of potential medicinal use. Its estimated richness includes over 6,000 tree species and 800 bird species, in addition to a wide variety of fish and other life forms. Therefore, the Cerrado, in addition to the Atlantic Forest, is considered one of the world's hotspots, being one of the planet's richest but also, most threatened biomes (Mittermeier et al., 2011).

With a tropical savanna type formation, the Cerrado covers about 2 million km² in Central Brazil, approximately 24% of the national territory (MMA, 2015). The most common physiognomy is an open formation of low trees and shrubs coexisting with a grassy ground layer. There are, however, several other physiognomies, ranging from clean fields to tree formations. In the Espinhaço Chain, formations of rupestrian cerrado are the dominant vegetation cover, growing on boulders or rocks, in shallow or stony soils of recent origin, or in sandy deposits (Kamino et al., 2008). The Diamantina municipality is located in the region of Espinhaço Meridional with predominance of rocky and sandy soils (Abreu et al., 2005). Some authors (Giulietti et al., 2009; Carmo & Jacobi, 2013) cite rare species distributed in these environments. Thus, it is expected that the edaphic and climatic characteristics in these areas of the Cerrado biome influence tree distribution and consequently, the floristic pattern.

A series of studies has already been carried out to explain the relationships between environmental factors and vegetation, and the results have been diverse and sometimes divergent. Goodland & Pollard (1973) emphasized that soil fertility may not necessarily be the cause of the physiognomic gradient in a closed environment. Silva et al. (2015), when studying the relationship between soil and vegetation in an area of the Cerrado biome located in the triple border between Minas Gerais, Goiás and Bahia, concluded that fine sand, clay and aluminum are responsible for 93.7% of variability in the relationship between soils and phytophysiognomies. Terra et al. (2015) assessed the correlations of vegetation aspects with top-soil-climatic variables in a forest remnant in Bocaina de Minas, Serra da Mantiqueira, MG, and concluded that soil fertility was the variable that most explained species distribution variability.

Knowing how vegetation variables behave throughout a biome has direct implications for conservation initiatives and recovery of degraded areas. Anthropic pressures in the Cerrado have been increasing, which makes understanding environmental relationships and plant population distribution even more important to develop conservation methods.

The goal of the present study was to investigate the physical and chemical soil characteristics that most influence the population distribution of species with greater relative density in a vegetation section of cerrado rupestre in the Diamantina municipality – MG. A canonical correspondence analysis (CCA) was performed to identify species that may be used in environments presenting restrictive conditions. Studies of this nature may assist in developing forestry and environmental activities, as well as in recovering degraded areas.

2. MATERIAL AND METHODS

The sampled area is located at Sítio Santa Helena, 5 km from Diamantina, a municipality located in the Southern Espinhaço region. Its altitude is 1,149 m, latitude 18° 17'S, and longitude 43° 34'W. The climate of the region, according to the Köppen classification, is Cwb: its temperate is humid, with dry winter and summer rains. The predominant formations are rupestrian and cerrado rock, the latter of which corresponds to the environment studied. Soils are classified as *neossolo quartzarênico órtico típico* according to the Brazilian Soil Classification System - SiBCS (EMBRAPA, 2013). The vegetation of the area is in a healthy state in terms of conservation and natural regeneration.

Soil sampling and floristic structure analysis was performed using the plots method (Mueller-Dombois & Ellenberg, 1974). A sampling block of 1.0 ha was allocated, divided into 10 subplots of 1,000 m2 (20 x 50 m), denominated P1 through P10. The fact that the cerrado trees have tortuous trunks and bifurcations just above the ground often makes it impossible to measure them at a height of 1.30 m. The measurement of tree circumference at soil height (CAS) was adopted, but

always intentionally measuring above any morphological adaptation that the plant presented at this point. As an inclusion criteria, individuals with stem circumference equal to or greater than 3.0 cm were sampled. Species and family name were recorded for each individual sampled. Individual identification was carried out in the field. Unidentified individuals had their botanical material collected to identify them later on using specialized literature (Silva et al., 2005) and by comparison with known species, studied and registered in the samples of the Dendrological Herbarium Jeanini Felfili (HDJF) of the Federal University of the Jequitinhonha and Mucuri Valleys. Species of the Velloziaceae family were excluded for the standardization of the analysis, since only woody species were considered.

Six simple soil samples were collected, from a depth of 0 to 20 cm, forming a composite sample for each plot (Ribeiro et al., 1999). The physicochemical analysis was performed after the samples were air dried, homogenized and sieved in a 2 mm mesh.

The phytosociologic parameters assessed in structure analysis were: number of individuals (NI), absolute density (DA), relative density (DR), absolute frequency (FA), relative frequency (FR), and plot unit in which a species was verified (UP). Martins (1993) cited the formulas used for the calculation.

For the granulometric analysis of the soils (coarse sand, fine sand, silt and clay fractions), the EMBRAPA methodology was used (EMBRAPA, 2011). Water pH was measured using 1: 2.5 (v/v) soil proportions: solution. The total organic carbon content was determined by the Walkley-Black method (Walkley & Black, 1934) and, subsequently, the organic matter content was determined by multiplying the values of total organic carbon by the conversion factor of 1.724 (Walkley & Black, 1934). The exchangeable Ca^{2+}, Mg^{2+} and Al^{3+} cations were extracted by KCl 1.0 mol L^{-1} solution and the Ca^{2+} and Mg^{2+} contents were determined by titration with EDTA 0.01 mol$_c$ L^{-1} and the Al^{3+} contents by titration with NaOH 0.025 mol L^{-1} (Silva et al., 2009). The P, K, Zn, Fe, Cu were extracted by solution Mehlich-1 and B extracted in hot water, the contents determined by spectrophotometry (Silva et al., 2009). The potential acidity (H+Al) was extracted by 0.5 mol L^{-1} in a calcium acetate solution at pH 7.0, and determined by titration (Silva et al., 2009). The sum of bases (SB), the effective cation exchange capacity (t) - CTC, aluminum saturation (m), and base saturation (V) were calculated (Alvarez et al., 1999).

Initially, the environmental matrix included 20 variables. This data set was reduced with the *principal* component analysis (MCA) (Regazzi, 2001), because fewer variables could explain the variability of species occurrence better. Transforming the original variable set into a new one that maintains maximum variability, achieves the reduction. Thus, quantitative data obtained from soil analysis, which best explained set variability according to the MCA, was related to the 10 plots by means of an order generated by the canonical correspondence analysis (CCA). This analysis detects the measured environmental variable that can supposedly better explain variation patterns found in each plot's data (Cruz Ruggiero et al., 2002; Cruz et al., 2012). All processing was performed with R software (R Core Team, 2014), Vegan package (Oksanen et al., 2013).

Pearson correlation coefficients were calculated for the main variables identified by principal component analysis, and the three axes of ordering the canonical correspondence analysis to verify the relationships between them.

3. RESULTS AND DISCUSSION

A total of 1417 individuals were recorded and distributed in ninety species and thirty families, representing a density of 1417 ind/ha. The number of individuals in each plot ranged from 74 to 243 in the P3 and P9 plots, respectively (Figure 1).
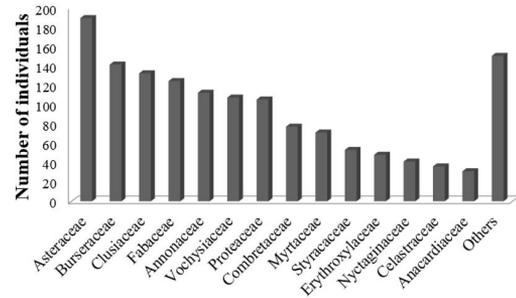
Families with the greatest diversity (number of species/family/ha) were Fabaceae (9), Myrtaceae (8), Asteraceae (7), Melastomataceae (7), Lauraceae (6) and Rubiaceae representing 46.7% of local richness, similar to results from other studies (Oliveira et al., 2015;
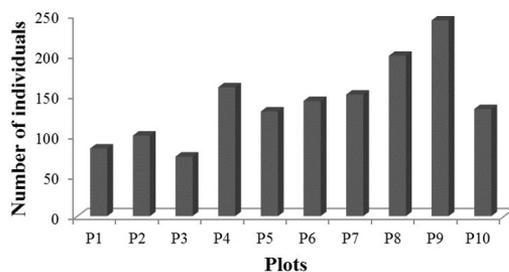
Figure 1. Number of individuals sampled per plot, in 10 plots (P1 to P10), in a rupestrian cerrado area in Diamantina, MG.

Torres et al., 2017). Therefore, most of the local diversity is concentrated in a few families.

The richness and abundance of the Fabaceae family in the cerrado has been verified in other studies (Carvalho & Marques-Alves, 2008; Lima et al., 2015). These studies consider this family to be a predominant

one in the savanna flora, given its high density in all cerrado phytophysiognomies. Cordeiro (2000) attributed this behavior to the nodulation capacity of its species, which promotes greater adaptability in regions with low nitrogen content. This is an advantage over other species, mainly in the Cerrado, where the soil is poor in nutrients.

The greatest abundance was concentrated in the Asteraceae (189), Burseraceae (141), Clusiaceae (132), Fabaceae (124), Vochysiaceae (107) and Protoaceae (105) families (Figure 2). These seven families together held 64.22% of registered individuals, while the other 23 families accounted for the remaining 35.78%, evidencing a lower abundance of individuals of these families.

The Asteraceae family was mainly characterized by the high number of individuals sampled from *Eremanthus incanus* (147) species (Table 1). Popularly known as candeia. *Eremanthus incanus*, together with

Figure 2. Number of individuals per family in a rupestrian cerrado area in Diamantina, MG.

Table 1. Species of higher occurrence in a rupestrian cerrado area in Diamantina, MG.

Species	Families	NI	DA	DR%	UP	FA%	FR%
Eremanthus incanus	Asteraceae	147	1470	10.37	10	100	3.58
Kielmeyera lathrophyton	Clusiaceae	96	960	6.77	10	100	3.58
Xylopia sericea	Annonaceae	80	800	5.65	4	40	1.43
Terminalia sp	Combretaceae	76	760	5.36	9	90	3.23
Protium spruceanum	Burseraceae	75	750	5.29	3	30	1.08
Protium heptaphyllum	Burseraceae	70	700	4.94	4	40	2.15
Roupala montana	Proteaceae	69	690	4.87	9	90	3.23
Qualea grandiflora	Vochysiaceae	56	560	3.95	9	90	3.23
Erythroxylum suberosum	Erythroxylaceae	48	480	3.39	9	90	3.23
Vochysia discolor	Vochysiaceae	45	450	3.18	7	70	2.51
Myrcia guianensis	Myrtaceae	38	380	2.68	8	80	2.87
Roupala sp.	Proteaceae	36	360	2.54	4	40	1.43
Plenckia populnea	Celastraceae	32	320	2.26	8	80	2.87
Bowdichia virgilioides	Fabaceae Faboideae	31	310	2.19	7	70	2.51
Tapirira guianensis	Anacardiaceae	31	310	2.19	4	40	1.43
Guapira noxia	Nyctaginaceae	30	300	2.12	7	70	2.51
Styrax oblongus	Styracaceae	30	300	2.12	2	20	0.72
Dalbergia miscolobium	Fabaceae Faboideae	28	280	1.98	8	80	2.87
Platymiscium sp.	Fabaceae Faboideae	28	280	1.98	6	60	2.15
Piptocarpha rotundifolia	Asteraceae	27	270	1.91	3	30	1.08
Xylopia aromatica	Annonaceae	23	230	1.62	2	20	0.72
Clusia criuva	Clusiaceae	21	210	1.48	5	50	1.79
Copaifera langsdorffii	Fabaceae Caesalpinioideae	21	210	1.48	5	50	1.79
Pera sp.	Peraceae	18	180	1.27	4	40	1.43
Styrax camporum	Styracaceae	15	150	1.06	5	50	1.79
Calophyllum brasiliense	Clusiaceae	15	150	1.06	3	30	1.08
Other species	-	231	2310	16.30	-	-	43.73
Total	**-**	**1417**	**14170**	**100**	**-**	**-**	**100.00**

NI = number of individuals; DA = absolute density; DR% = relative density; UP = parcel unit; FA = absolute frequency; FR = relative frequency.

Eremanthus erythropappus, it is the most important candeia species in Minas Gerais (Scolforo et al., 2008). Candeia is a native species and belongs to the ecological group of pioneers, being considered a precursor in field invasion (Longhi et al., 2009). It can easily and quickly develop in inhospitable environments, with shallow and sandy soils, resulting in the formation of stands and occupation of the area. The species is an important option for the recovery of degraded areas, frequent in the Southern Espinhaço region (Scolforo et al., 2008).

The pedological variables, through main component analysis, were reduced from twenty to eight. The variables

Table 2. Pearson correlation coefficients between the pedological variables and the three ordering axes of canonical correspondence analysis in a rupestrian cerrado gradient in Diamantina-MG.

Pedological Variables pedológicas	Axis 1	Axis 2	Axis 3
P-rem	-0.8373	-0.029	-0.2697
MO	0.8081	0.0622	0.2146
T	0.7627	-0.0676	0.4216
V	-0.6734	0.4365	0.1327
m	0.433	-0.5947	-0.1254
k	-0.3692	0.3836	0.5814
Mg	0.3494	0.7263	0.4099
SB	-0.1546	0.5292	0.4841

that best explain the variation of the distribution in the plots were P-rem, organic matter, T, V, Mg, m, SB and K.

The canonical correspondence order analysis (COA) explained a large part of the total variation in the first three axes, 42.48; 16.11 and 13.93%, presenting a total of 72.52%. This value can be considered high and suggests a causal relationship between the vegetation and chemical and physical soil attributes in the area. Several factors can influence species distribution, such as microclimate, relief, water availability, etc. However, this study only assessed the influence of edaphic factors.
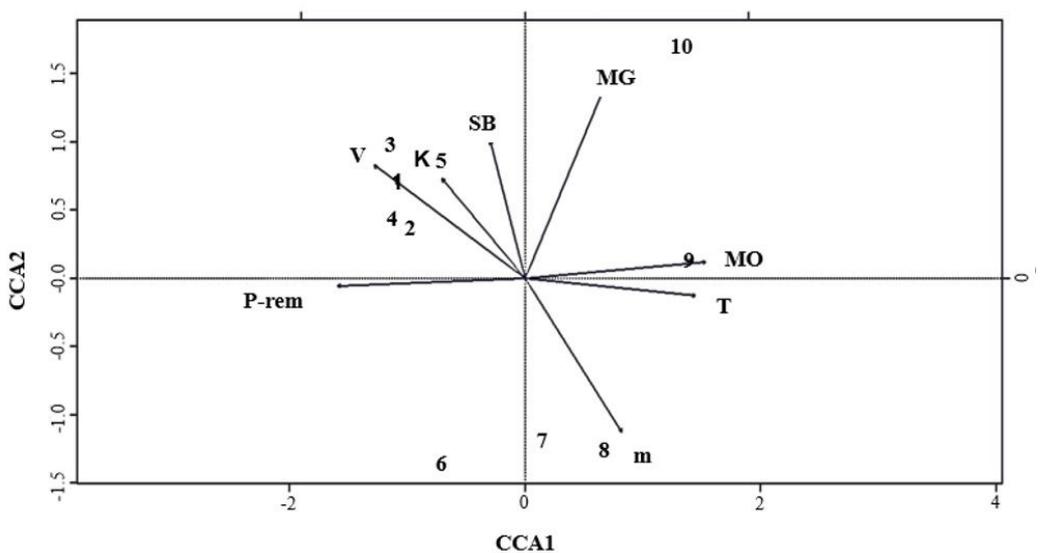
The variables had stronger correlations ($r > 0.6$) in the CCA, at a significance level of 5% with axis 1 (Table 2); in a descending order, P-rem ($r = 0.837$), organic matter ($r = 0.808$), T ($r = 0.763$), and V ($r = 0.673$). With the second axis, the strongest correlations ($r > 0.3$) in a descending order were Mg ($r = 0.726$), m ($r = 0.595$), SB ($r = 0.529$), V ($r = 0.436$), and k ($r = 0.384$).

In the ordering diagram produced by the CCA (Figure 3), numbers represent the plots, and vectors represent the environmental variables showing changing direction for these variables in the ordering space (Ter Braak, 1987).

Parcels 1, 2, 3, 4 and 5, grouped in the northeastern quadrant of the diagram (Figure 3), are positively

Figure 3. The ordering axis produced by the canonical correspondence analysis of the 10 plots sampled in rupestrian cerrado vegetation; interrelations between the distribution of study environments and the environmental variables of soil.

related to base saturation (V), potassium (K), sum of bases (SB) and remaining phosphorus (P-rem), which were the variables with the highest values. According to the Fifth Approach (Ribeiro et al., 1999), there was no difference between these plots in the classification of V and SB contents. The values considered to be low for V (less than 5%) and SB (lower than 0.33 cmolc/dm³) were verified, corroborating the soil dystrophy described for cerrado soils (Haridasan, 2008) and low natural fertility.

Regarding potassium, there was a variation from 26 to 93 mg/dm³. Plots 1 to 5 had medium (41 to 70 mg/dm³) to good (71 to 120 mg/dm³) levels, whereas in plots 6 to 10, low K levels were observed (16 to 40 mg/dm³). There is an expressive relationship between lowest K levels and highest T levels. As already pointed out by Camargos et al. (2008), K, T and soil texture are directly related. The level of exchangeable potassium suitable for plants is higher in clayey soils with higher T than in sandy soils with low T, as in the case of plots 1 to 5.

The remaining phosphorus values obtained in this study presented a wide range, varying from 15.5 to 40.2 mg/L. This shows that, even at small distances, soils have different potentials for phosphorus fixation. A negative relationship between aluminum saturation and P-rem and K levels was observed. Goodland & Pollard (1973) and Gianotti et al. (2013) also observed this in their studies: they suggested that aluminum's main effect on soil would be competing with exchangeable bases via the same exchange sites in the soil colloidal complex, further impoverishing it. The organic matter and the cation exchange capacity at pH 7.0 (T) presented a great variation between plots (Table 3) and a positive relation, which can be attributed to the fact that organic matter is most responsible for cation retention in Brazilian soils, especially in sandier soils (Ribeiro et al., 1999).

The significant variation in organic matter content (from 2.43 to 8.96) may be associated with the vegetation cover. In the plots with higher individual densities and, consequently, greater litter deposition, there is a tendency to increase the organic matter content and, therefore, favor the development of existing species or the emergence of new ones. According to Silva et al. (2015), the accumulation capacity of organic matter is

one of the main processes of differentiation between the studied environments, which, together with the texture, directly influence the pattern of vegetation cover present in the area.

In plots 1 to 5, there was a great predominance of *Eremanthus incanus, Kielmeyera latrofhyton, Terminalia sp.* and *Vochysia discolor*. These correlated to the highest K and P-rem levels, and to the lowest organic matter and CTC contents. In a study carried out in Mogi-Guaçu, Batista & Couto (1990), a correlation between potassium content and vegetation variables was also observed, where K was the most influential edaphic variable in the development of fifteen of the most important native species in the area. The species *Xylopia sericea, Protium spruceanum* and *Protium heptaphyllum* were exclusively predominant in the plots located on the right side of axis 1, thus demonstrating tolerance to higher aluminum saturation levels and a preference for sites with higher organic matter and T levels.

However, the *Roupala montana*, *Qualea grandiflora* and *Erythroxylum suberosum* species did not show any distribution related to soil conditions. Instead, they varied uniformly in all plots. Ratter et al. (1996, 2003) highlighted *Q. grandiflora* as an important species with wide distribution in the cerrado, present in 85% of the studies evaluated by these authors. This can be attributed to the fact that the species is an aluminum accumulator, which gives it a competitive advantage in the acidic soils of this biome (Felfili et al., 1993).

This group of species with good adaptability to environments with more restrictive soil conditions, such as low fertility, high aluminum levels and high acidity, are presented as important alternatives, for example in reforestation projects and recovery of degraded areas. However, further evaluations are needed. According to Souza et al. (2003) and Carvalho et al. (2005), caution is required in the interpretation of species distribution, in line with environmental variables, since fundamental variables, such as light conditions and species dispersion factors, are not always easily perceptible or measurable. Some species are sensitive to these variables interactively and not in isolation.

Table 3. Chemical and physical characteristics of the superficial layer (0.00-0.20 m) of the 10 plots (6 samples per plot) of the rupestrian cerrado area in Diamantina, MG, Brazil.

Plot	pH H$_2$O	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	(t)	(T)	V	M	MO	P-rem	Zn	Fe	Cu	SandG.	SandF.	Silt	Clay
		mg dm^{-3}		cmol$_c$ dm^{-3}							%		dagkg^{-1}	mgL^{-1}	mg dm^{-3}			g kg^{-1}			
1	4.5	1.6	30	0.0	0.05	1.10	6.1	0.13	1.23	1.23	2.1	89.4	2.56	40.2	3.17	116	0.09	330	530	40	100
2	4.3	1.6	41	0.0	0.06	1.30	4.9	0.16	1.46	1.46	3.2	89.0	2.56	38.2	2.08	88.9	0.12	240	600	30	130
3	4.6	1.6	93	0.0	0.09	1.40	6.6	0.33	1.73	1.73	4.8	80.9	2.81	38.9	3.42	74.2	0.01	270	560	40	130
4	4.5	1.7	41	0.0	0.06	1.40	5.9	0.16	1.56	6.06	2.6	89.7	2.43	38.2	1.38	102.7	0.00	260	610	00	130
v	4.3	2.3	44	0.0	0.08	1.60	7.1	0.19	1.79	7.29	2.6	89.4	3.20	32.3	1.07	87.4	0.02	310	520	70	100
6	4.5	2.5	48	0.0	0.06	2.40	12.2	0.18	2.58	12.4	1.5	93.0	6.08	25.4	1.13	81.7	0.24	270	540	20	170
7	4.5	1.8	37.5	0.0	0.06	1.95	8.9	0.16	2.11	9.06	1.7	92.5	4.42	30.5	1.29	104.5	0.05	230	600	45	120
8	4.8	2.3	29	0.0	0.06	1.35	7.85	0.13	1.48	7.98	1.65	91.4	4.67	29.3	1.60	116.2	0.00	260	570	55	110
9	4.6	2.5	26	0.0	0.07	2.15	12.6	0.14	2.29	12.7	1.15	93.5	6.31	23.3	1.52	96.4	0.00	220	510	155	110
10	4.6	1.8	56.5	0.0	0.11	2.25	15.2	0.26	2.51	15.5	1.9	88.3	8.96	15.5	1.44	329.6	0.05	200	550	70	180

Water pH, KCl and CaCl$_2$ - Ratio 1:2.5; P - Na - K - Fe - Zn -Mn - Cu – Mehlich Extractor-1; Ca -Mg - Al - Extractor: KCl - 1mol L^{-1}; H + Al – Extractor Calcium Acetate 0.5mol L^{-1} – pH 7.0; S - Extractor – monocalcium phosphate in acetic acid; Mat. Org. (MO) = C.Org x 1.724 - Walkley & Black (1934); SB = Sum of exchangeable bases; CTC (t) – Effective Cation Exchange Capacity; CTC (T) – Cation Exchange capacity at pH 7.0 ; V= Basal saturation index; M= Aluminum saturation index; P-rem= Phosphorus remnan.

4. CONCLUSION

The differences in the distribution and abundance of the species throughout the studied section are related to variations in chemical fertility and soil acidity.

The species observed showed good adaptation to environments with restrictive conditions, such as high acidity and low fertility, and were found to be important alternatives for use in areas with conditions similar to those studied in this research.

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REFERENCES

Abreu PAA, Silva AC, Pedreira LCVSF. *Serra do Espinhaço Meridional, paisagens e ambientes*. Belo Horizonte: O Lutador; 2005.

Alvarez VVH, Novais RF, Barros NF, Cantarutti RB, Lopes AS. Interpretação dos resultados das análises de solos. In: Ribeiro AC, Guimarães PTG, Alvarez VAV, editor. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais*. Viçosa: CFSEMG; 1999. p.25-32

Batista EA, Couto HTZ. Influência de fatores químicos e físicos do solo sobre o desenvolvimento da vegetação de Cerrado na Reserva Biológica de Moji-Guaçu, SP. *Revista do Instituto Florestal* 1990; 2: 69-86.

Camargos VL, Silva AF, Meira JAA No, Martins SV. Influência de fatores edáficos sobre variações florísticas na Floresta Estacional Semidecídua no entorno da Lagoa Carioca, Parque Estadual do Rio Doce, MG, Brasil. *Acta Botanica Brasílica* 2008; 22(1): 75-84. http://dx.doi.org/10.1590/S0102-33062008000100010.

Carmo FF, Jacobi CM. A vegetação de canga no Quadrilátero Ferrífero, Minas Gerais: caracterização e contexto fitogeográfico. *Rodriguésia* 2013; 64(3): 527-541. http://dx.doi.org/10.1590/S2175-78602013000300005.

Carvalho AR, Marques-Alves S. Diversidade e índice sucessional de uma vegetação de cerrado *sensu stricto* na Universidade Estadual de Goiás-UEG, campus de Anápolis. *Revista Árvore* 2008; 32(1): 81-90. http://dx.doi.org/10.1590/S0100-67622008000100010.

Carvalho DA, Oliveira AT Fo, Vilela EA, Curi N, Van Den Berg E, Fontes MAL et al. Distribuição de espécies arbóreo-arbustivas ao longo de um gradiente de solos e topografia em um trecho de floresta ripária do rio São Francisco em Três Marias, MG, Brasil. *Brazilian Journal of Botany* 2005; 28(2): 329-345. http://dx.doi.org/10.1590/S0100-84042005000200013.

Cordeiro L. Fixação de nitrogênio em leguminosas ocorrentes no cerrado. In: Klein AL, editor. *Eugen Warming e o Cerrado brasileiro: um século depois*. São Paulo: Universidade Estadual de São Paulo; 2000.

Cruz CD, Regazzi AJ, Carneiro PCS. *Modelos biométricos aplicados ao melhoramento genético*. 2. ed. Viçosa: UFV; 2012.

Cruz Ruggiero PG, Batalha MA, Pivello VR, Meirelles ST. Soil-vegetation relationships in cerrado (Brazilian savanna) and semideciduous forest, Southeastern Brazil. *Plant Ecology* 2002; 160(1): 1-16. http://dx.doi.org/10.1023/A:1015819219386.

Deus MJ. *Guia de campo: vegetação do Cerrado 500 espécies*. Brasília: MMA/SBF; 2011.

Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA. *Manual de métodos de análise de solo*. 2. ed. Rio de Janeiro: EMBRAPA; 2011.

Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA. *Sistema brasileiro de classificação de solos*. 3. ed. Brasília: EMBRAPA; 2013.

Felfili JM, Silva MC Jr, Rezende AV, Machado JWB, Walter BMT, Silva PEN et al. Análise comparativa da florística e fitossociologia da vegetação arbórea do cerrado *sensu stricto* na Chapada Pratinha, DF-Brasil. *Acta Botanica Brasílica* 1993; 6(2): 27-46. http://dx.doi.org/10.1590/S0102-33061992000200003.

Gianotti ARC, Souza MJH, Pereira IM, Machado ELM, Vieira AD, Magalhães RM. Soil and phytosociological characterization of an area with predominance of arnica (*Lychnophora pohlii* Sch. Bip.). *Revista Brasileira de Ciência do Solo* 2013; 37(3): 565-571. http://dx.doi.org/10.1590/S0100-06832013000300002.

Giulietti AM, Rapini A, Andrade MJG, Queiroz LP, Silva JMC. *Plantas raras do Brasil*. Belo Horizonte: Conservation International; 2009.

Goodland R, Pollard R. The Brazilian cerrado vegetation: a fertility gradient. *Journal of Ecology* 1973; 61(1): 219-224. http://dx.doi.org/10.2307/2258929.

Haridasan M. Nutritional adaptations of native plants of the cerrado biome in acid soils. *Brazilian Journal of Plant Physiology* 2008; 20(3): 183-195. http://dx.doi.org/10.1590/S1677-04202008000300003.

Kamino LHY, Oliveira-Filho AT, Stehmann JR. Relações florísticas entre as fitofisionomias florestais da Cadeia do Espinhaço, Brasil. *Megadiversidade* 2008; 4: 39-49.

Lima RAF, Rando JG, Barreto KD. Composição e diversidade no cerrado do leste de Mato Grosso do Sul, Brasil. *Revista Árvore* 2015; 39(1): 9-24. http://dx.doi.org/10.1590/0100-67622015000100002.

Longhi P, Souza A, Garcia R, Pioveza V. Estudo de caso do processo de extração do óleo essencial da madeira de Candeia no sul de Minas Gerais. *Floresta* 2009; 39(3): 555-570. http://dx.doi.org/10.5380/rf.v39i3.15355.

Martins FR. *Estrutura de uma floresta mesófila*. 2. ed. Campinas: UNICAMP; 1993.

Ministério do Meio Ambiente – MMA. *Mapeamento do uso e cobertura do cerrado: Projeto TerraClass Cerrado 2013*. Brasília: MMA; 2015.

Mittermeier RA, Turner WR, Larsen FW, Brooks TM, Gascon C. Global biodiversity conservation: the critical role of hotspots. In: Zachos FE, Habel JC, editors. *Biodiversity hotspots*. Berlin: Springer; 2011. http://dx.doi.org/10.1007/978-3-642-20992-5_1.

Mueller-Dombois D, Ellenberg H. *Aims and methods of vegetation ecology*. New York: Wiley; 1974.

Oksanen J, Blanchet FG, Kindt R, Legendre P, Minchin PR, O'Hara RB et al. *Vegan: Community Ecology Package. R package version 2.0-10* [online]. Vienna: CRAN; 2013 [cited 2015 Apr 02]. Available from: http://CRAN.R-project.org/package=vegan

Oliveira CP, Francelino MR, Cysneiros VC, Andrade FC, Booth MC. Composição florística e estrutura de um cerrado sensu stricto no oeste da Bahia. *Cerne* 2015; 21(4): 545-552. http://dx.doi.org/10.1590/01047760201521041722.

R Core Team. *R: A language and environment for statistical computing* [online]. Vienna: R Foundation for Statistical Computing; 2014 [cited 2015 Apr 02]. Available from: http://www.R-project.org/

Ratter JA, Bridgewater S, Atkinson R, Ribeiro JF. Analysis of the floristic composition of the brasilian cerrado vegetation II: comparison of the woody vegetation of 98 areas. *Edinburgh Journal of Botany* 1996; 53(02): 153-180. http://dx.doi.org/10.1017/S0960428600002821.

Ratter JA, Bridgewater S, Ribeiro JF. Analysis of the floristic composition of the Brazilian cerrado vegetation iii: comparision of the woody vegetation of 376 areas. *Edinburgh Journal of Botany* 2003; 60(1): 57-109.

Regazzi AJ. *INF 766 - Análise multivariada*. Viçosa: Universidade Federal de Viçosa; 2001.

Ribeiro AC, Guimaraes PTG, Alvarez V VH. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais – 5ª Aproximação*. Viçosa: CFSEMG; 1999.

Scolforo JR, Oliveira AD, Silva CPC, Andrade IS, Camolesi JF, Borges LFR et al. *O manejo da candeia nativa*. Lavras: UFLA; 2008.

Silva FC, Eira PA, Raij B van, Silva CA, Abreu CA, Gianello C et al. Métodos de análises químicas para avaliação da fertilidade do solo. In: Silva FC, editor. *Manual de análises químicas de solos, plantas e fertilizantes*. Brasília: EMBRAPA; 2009. p. 107-189.

Silva MC Jr. *100 árvores do cerrado: manual de campo*. Brasília: Rede de Sementes do Cerrado; 2005.

Silva RBM, Francelino MR, Moura PA, Moura TA, Pereira MG, Oliveira CP. Relação solo/vegetação em ambiente de cerrado sobre influência do grupo Urucuia. *Ciência Florestal* 2015; 25(2): 363-373. http://dx.doi.org/10.5902/1980509818455.

Souza JS, Espírito-Santo FDB, Fontes MAL, Oliveira-Filho AT, Botezelli L. Análise das variações florísticas e estruturais da comunidade arbórea de um fragmento de floresta semidecídua às margens do rio Capivari, Lavras-MG. *Revista Árvore* 2003; 27(2): 185-206. http://dx.doi.org/10.1590/S0100-67622003000200009.

Ter Braak CJF. The analysis of vegetation environment relationships by canonical correspondence analysis. *Vegetatio* 1987; 69(1-3): 69-77. http://dx.doi.org/10.1007/BF00038688.

Terra MCNS, Mello JM, Mello CRM, Santos RM, Nunes ACR, Raimundo MR. Influência topo-edafo-climática na vegetação de um fragmento de Mata Atlântica na Serra da Mantiqueira, MG. *Ambiente & Água* 2015; 10: 928-942. http://dx.doi.org/10.4136/1980-993X.

Torres DM, Fontes MAL, Samsonas HP. Relações solo-vegetação na estruturação de comunidades de cerrado sensu stricto no sul de Minas Gerais, Brasil. *Rodriguésia* 2017; 68(1): 115-128. http://dx.doi.org/10.1590/2175-7860201768121.

Walkley A, Black IA. An examination of the different method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 1934; 37(1): 29-38. http://dx.doi.org/10.1097/00010694-193401000-00003.