Revista Brasil. Bot., V.31, n.3, p.377-388, jul.-set. 2008

Influence of soil properties on the abundance of plant species in ferruginous rocky soils vegetation, southeastern Brazil[1]

REGINA DE CASTRO VINCENT[2,4] and MARICO MEGURO[3]

(received: November 03, 2005; accepted: May 29, 2008)

ABSTRACT – (Influence of soil properties on the abundance of plant species in ferruginous rocky soils vegetation, southeastern Brazil). Ferruginous "campos rupestres" are a particular type of vegetation growing on iron-rich primary soils. We investigated the influence of soil properties on plant species abundance at two sites of ferruginous "campos rupestres" and one site of quartzitic "campo rupestre", all of them in "Quadrilátero Ferrífero", in Minas Gerais State, southeastern Brazil. In each site, 30 quadrats were sampled to assess plant species composition and abundance, and soil samples were taken to perform chemical and physical analyses. The analyzed soils are strongly acidic and presented low fertility and high levels of metallic cations; a principal component analysis of soil data showed a clear segregation among sites due mainly to fertility and heavy metals content, especially Cu, Zn, and Pb. The canonical correspondence analysis indicated a strong correlation between plant species abundance and soil properties, also segregating the sites.

Key words - ferruginous "campo rupestre", metalliferous soil, plant-soil relationships, "Quadrilátero Ferrífero"

RESUMO – (Influência das propriedades do solo sobre a abundância das espécies vegetais em campos ferruginosos no sudeste do Brasil). Os campos ferruginosos são um tipo particular de vegetação que cresce sobre solos primários ricos em ferro. Estudou-se a influência do solo sobre a abundância em espécies vegetais em duas áreas de campos ferruginosos e uma área de campo rupestre quartzítico, todos no Quadrilátero Ferrífero, em Minas Gerais, sudeste do Brasil. Em cada área foram amostradas 30 parcelas para avaliar a composição florística e a abundância, e analisar o solo. Os solos das áreas estudadas são fortemente ácidos, com baixa fertilidade e altos níveis de cátions metálicos, e mostraram clara separação na análise de componentes principais, devido principalmente à fertilidade e ao teor de metais pesados, especialmente Cu, Zn e Pb. A análise de correspondência canônica indicou uma forte correlação entre a abundância e as propriedades do solo, também separando as áreas.

Palavras-chave - campos rupestres ferruginosos, Quadrilátero Ferrífero, relações planta-solo, solo metalífero

Introduction

Ferruginous "campos rupestres" grow on "canga", a rock consisting of fragments of iron-formation and hard hematite cemented by limonite, an hydrated iron oxide (Simmons 1960, 1968, Pomerene 1964, Rizzini 1997). In Brazil, they are found mainly in a region known as "Quadrilátero Ferrífero", in Minas Gerais State (southeastern Brazil), and in "Serra dos Carajás", in Pará State (northern Brazil), sites that hold the main Brazilian iron ores. In literature, this vegetation was also called "canga vegetation" (Secco & Mesquita 1983, Morellato & Rosa 1991, Silva 1991, 1992), "campos rupestres" or rocky fields (Silva & Rosa 1990, Silva *et al.* 1996) or ferruginous fields (Rizzini 1997, Vincent *et al.* 2002). Since the term "campo rupestre" historically defines fields growing on quartzitic substrates (Magalhães 1966, Giulietti *et al.* 1987, 1997), we recommend the specification of the geological substrate for other "campos rupestres". In Minas Gerais, ferruginous "campos rupestres" occur mainly in the "cerrado" Province, a phytogeographical region characterized by a savannic vegetation with a physiognomic-floristic gradient varying from "campo sujo", a grassland with scattered shrubs, to a forest with more or less closed canopy, the "cerradão" (Coutinho 1978). Ferruginous "campos rupestres" of Minas Gerais hold many elements of "cerrado" and quartzitic "campo rupestre" flora and the families with more species are characteristic of the Espinhaço Range (Jacobi *et al.* 2007, Viana & Lombardi 2007).

Rocky substrates and their derived primary soils may impose particular constraints to plant establishment, including soil scarcity, low water content, and low levels of nutrient. Additionally, high levels of heavy metals in metalliferous soils promote selection of resistant plant species that may show physiological and/or morphological adaptations (Porto & Silva 1989, Silva & Rosa 1990).

1. This work is part of a PhD thesis developed at the University of São Paulo, Departamento de Ecologia, São Paulo, SP, Brazil.
2. Secretaria Estadual do Meio Ambiente, DAIA, Av. Prof. Frederico Hermann Jr., 345, 05489-900 São Paulo, SP, Brazil.
3. Universidade de São Paulo, Instituto de Biociências, Departamento de Ecologia, Caixa Postal 11461, 05422-970 São Paulo, SP, Brazil.
4. Corresponding author: regina_c_vincent@yahoo.com.br

In this type of substrate there are ecotypes adapted to high metal concentration in soil (Duvigneaud & Denaeyer-De Smet 1960, Antonovics *et al.* 1971, Porto 1989, Köhl 1997), a low number of plant species and the presence of endemic species (Porto & Silva 1989, Silva & Rosa 1990). The metallophile vegetation is characterized by individuals with high concentrations of heavy metals in their tissues and occasionally by dwarf or giant ecotypes (Porto & Silva 1989). The presence of high content of metal cations on soils is expected to influence phytosociological parameters of some populations (Howard-Williams 1970, Antonovics *et al.* 1971).

There are few studies concerning vegetation-soil heavy metal relationships in Brazilian metalliferous "campos rupestres". Heavy metal accumulation in plant tissues was studied in "Serra dos Carajás", Pará State (Porto & Silva 1989, Silva 1992), "Quadrilátero Ferrífero", Minas Gerais State (Porto & Silva 1989, Teixeira & Lemos-Filho 1998), on ferruginous soils, and in ultramafic soils in Niquelândia, Goiás State (central Brazil, Reeves *et al.* 2007). Mining activities promote the destruction of this still poorly known ecosystem, suppressing plant species or populations that evolved in such a particular environment. The aims of present study were to investigate the influence of chemical and physical soil properties on plant species abundance in ferruginous "campos rupestres" and to compare them to a quartzitic "campo rupestre" in "Quadrilátero Ferrífero".

Material and methods

Study sites – The "Quadrilátero Ferrífero" is located in the southern portion of the "Cadeia do Espinhaço", in Minas Gerais State, southeastern Brazil (19°45'-20°30' S, 44°30'-43°07' W; figure 1). The climate is Cwb of Köppen, with a dry season from April to September (Herz 1978). In the region, there are four types of physiognomies, depending on the geological nature of substrate: "campos cerrados" and quartzitic, granitic, and ferruginous "campos rupestres" (Giulietti *et al.* 1997, Rizzini 1997, Drummond *et al.* 2005). Ferruginous "campos rupestres" may develop on iron-rich rocky outcrops (locally known as "canga couraçada") and iron-rich stony soils ("canga nodular"), and the variation of their physiognomies depends on the degree of weathering of the same type of rock (Rizzini 1997, Vincent *et al.* 2002).

This study was carried out in the "Parque Estadual da Serra do Rola-Moça" (PESRM) and in its vicinity, in northwestern portion of "Quadrilátero Ferrífero" (figure 1), in the municipalities of Belo Horizonte, Brumadinho, Ibirité, and Nova Lima, in Minas Gerais State, Brazil. This park and vicinities include "cerrado" physiognomies (Brazilian savanna) in altitudes below 1,000 m, riparian forests along valleys, and ferruginous and quartzitic "campos rupestres" above 1,000 m. In order to understand the relationship between vegetation and soil properties in ferruginous "campos rupestres", we studied two areas of canga substrate and one of quartzitic "campo rupestre" as a control study site: a. "Canga couraçada" (CCo): this is a "campo sujo" growing on ferruginous rocky outcrop and situated on Serra da Mutuca (20°01' S and 43°59' W; 1,350 m) in PESRM. Shrubs grow on crevices and herbs grow on soil islands or directly on the rocks (epilithic plants). b. "Canga nodular" (CNo): this is a "campo sujo" growing on ferruginous stony (nodular) soil and situated on "Serra do Rola-Moça" (20°03' S and 44°01' W; 1,350 m) in PESRM. This field is composed mainly by grasses and sedges mixed with shrubs and subshrubs and with a sparse population of a shrubby Velloziaceae (*Vellozia compacta* Mart. ex Schult. f.). c. Quartzitic "campo rupestre" (QCR): this is a grassland growing on nodular quartzitic soils intermixed by sparse quartzitic outcrops and situated on "Serra da Calçada" (20°06' S and 43°59' W; 1,300 m), Retiro das Pedras, near PESRM. It shows a "campo limpo" physiognomy, *i.e.*, a grassland composed mainly by grasses and sedges. Ferruginous "campos rupestres" surround this area.

Figure 1. Distribution of "campos rupestres" above 1,000 m (■) and "cerrado" vegetation (□) in Minas Gerais State (MG), southeastern Brazil. The three study sites (○) are located inside "Quadrilátero Ferrífero" (▤). Modified from PRODEMGE (1996).

Sampling – Fieldwork was conducted between December 2000 and June 2002. At each study site one area of 50 × 50 m was delimited, where 30 quadrats (2 × 1 m) were randomly established. In QCR we used quadrats of 1.0 × 0.5 m due to the very high number of individuals found in a preliminary sampling when no strong difference on the number of recorded species was verified. All plants in the quadrats were recorded and determined to the species level when possible; individuals were defined as a unit emerging from soil. The voucher specimens were deposited in the herbaria of the "Universidade Federal de Minas Gerais" (BHCB) and "Escola Superior de Agricultura Luiz de Queiroz" (ESA). We used absolute density as measure of abundance (Mueller-Dombois & Ellenberg 1974) due to the difference in quadrat size among sites.

Three soil samples (0-10 cm deep) were collected within each quadrat and then mixed, totalling 30 samples by site. The soil samples were air-dried, sieved in 2 mm sieve, and the fine and coarse fractions were weighted to calculate the proportion of "fine soil" (FS) in the substrate. Chemical and physical analyses – pH, organic matter (OM), P, exchangeable K^+, Ca^{2+} and Mg^{2+}, H^++Al^{3+} (H+Al), sum of bases (SB), cation exchange capacity (CEC), base saturation (V), B, sand, silt and clay proportions, and the levels of metallic cations Cu, Fe, Mn, and Zn – were made at soil laboratories of "Escola Superior de Agricultura Luiz de Queiroz" (ESALQ-USP), while the determinations of metallic cations Cd, Cr, Ni, and Pb were made at "Instituto Agronômico de Campinas" (IAC).

Data analysis – Soil variables were tested for normality by Shapiro-Wilk test ($P < 0.05$) and for homogeneity of variances by Levene test ($P < 0.05$). Since soil variables didn't have fulfilled parametric assumptions, multiple comparison tests were performed among the three study sites with Kruskal-Wallis one-way ANOVA to detect significant differences ($P < 0.05$) (Siegel 1956, Zar 1996).

A principal component analysis (PCA) was performed with soil variables in the 90 quadrats to verify the segregation among study sites and to identify the variables most strongly correlated to groups (ter Braak 1995). Sum of bases and base saturation were not included due to their strong correlation with the other variables.

A canonical correspondence analysis (CCA) was performed to investigate the relationships between species abundance and soil variables in the 90 quadrats. Absolute density values were log-transformed after to add the value 1 to the original values to avoid problems with zero values (ter Braak 1995, ter Braak & Looman 1995, Oliveira-Filho *et al.* 2001). Only species with $n \geq 10$ individuals and with occurrence in more than three of the 90 quadrats were included in the analysis. After a preliminary analysis, six variables were excluded due to high collinearity with other variables – pH and base saturation – or low correlation with the ordination axes ($-0.4 < r < 0.4$) – sum of bases, Cr and Ni levels, and fine soil proportion. The programs used were PCOrd (McCune & Mefford 1999) for ordination analyses and Statistica 6 (StatSoft, Inc. 2001) for tests of homogeneity of variances, normality and multiple comparisons.

Results

Soil properties – The soils of study sites are strongly acidic, and present low levels of P, low base saturation, high levels of Ca, Fe, Zn and Pb, and the substrate has a high proportion of coarse soil (≥ 2 mm) (table 1).

The sites were clearly discriminated in the PCA diagram (figure 2), where the two first axes explained 65.3% of total variance (Axis 1 = 39.0%, Axis 2 = 26.3%). The first axis was strongly positively correlated to CEC, OM, Fe and P levels, and negatively correlated to Mg, pH, Mn, and Pb; this axis separates CCo from CNo and QCR, reflecting differences between rocky outcrop and

Table 1. Physical and chemical soil properties of "canga couraçada" (CCo) and "canga nodular" (CNo) in "Parque Estadual da Serra do Rola-Moça" and of quartzitic "campo rupestre" (QCR) in "Retiro das Pedras", southeastern Brazil. OM = organic matter; H+Al = potential acidity; SB = sum of bases; CEC = cation exchange capacity; V = base saturation; FS = fine soil. Different letters after mean ($\overline{x}$) and standard deviation (s) indicate significant differences in Kruskal-Wallis test ($P < 0.05$).

	CCo (n = 30)		CNo (n = 30)		QCR (n = 30)	
	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s
pH (in $CaCl_2$)	3.43	± 0.12 c	4.38	± 0.22 a	4.01	± 0.10 b
OM (g dm^{-3})	136.07	± 18.97 a	83.17	± 9.98 b	39.83	± 4.58 c
P (mg dm^{-3})	14.83	± 2.51 a	10.23	± 1.17 b	5.20	± 1.03 c
K ($mmol_c$ dm^{-3})	1.93	± 0.30 b	1.80	± 0.30 b	3.98	± 1.29 a
Ca ($mmol_c$ dm^{-3})	14.80	± 5.03 b	26.07	± 6.31 a	18.23	± 4.61 b
Mg ($mmol_c$ dm^{-3})	2.80	± 0.81 b	5.30	± 1.24 a	5.48	± 1.19 a
H+Al ($mmol_c$ dm^{-3})	247.07	± 30.29 a	86.83	± 17.46 b	72.53	± 9.58 c
SB ($mmol_c$ dm^{-3})	19.53	± 5.82 c	33.17	± 7.56 a	27.43	± 6.55 b
CEC ($mmol_c$ dm^{-3})	266.60	± 31.35 a	120.00	± 14.64 b	102.28	± 18.40 c
V (%)	7.33	± 2.09 b	28.03	± 6.98 a	28.37	± 7.28 a

continue

continuation

	CCo (n = 30)			CNo (n = 30)			QCR (n = 30)		
	$\bar{x}$		s	$\bar{x}$		s	$\bar{x}$		s
B (mg dm^{-3})	0.90	±	0.46 a	1.06	±	0.71 a	0.25	±	0.15 b
Cu (mg dm^{-3})	0.94	±	0.72 c	9.67	±	3.43 a	2.16	±	0.43 b
Fe (mg dm^{-3})	508.00	±	27.41 a	182.40	±	43.66 c	251.00	±	32.80 b
Mn (mg dm^{-3})	5.10	±	2.39 c	31.81	±	5.85 a	21.47	±	7.02 b
Zn (mg dm^{-3})	2.80	±	2.83 b	7.47	±	1.50 a	0.93	±	0.23 b
Cd (mg dm^{-3})	0.07	±	0.05 b	0.16	±	0.04 a	0.09	±	0.04 b
Cr (mg dm^{-3})	0.04	±	0.03 b	0.05	±	0.04 ab	0.07	±	0.03 a
Ni (mg dm^{-3})	0.18	±	0.09 a	0.22	±	0.15 a	0.16	±	0.09 a
Pb (mg dm^{-3})	0.66	±	0.26 c	1.27	±	0.73 b	1.74	±	0.60 a
Sand (% of FS)	56.90	±	5.74 b	63.37	±	6.01 a	49.30	±	7.63 c
Silt (% of FS)	18.63	±	3.22 a	17.47	±	3.73 a	10.07	±	2.10 b
Clay (% of FS)	24.47	±	4.70 b	19.17	±	3.13 c	40.70	±	6.79 a
FS (% of substrate)	35.39	±	9.31 b	34.20	±	9.65 b	55.88	±	22.1 a

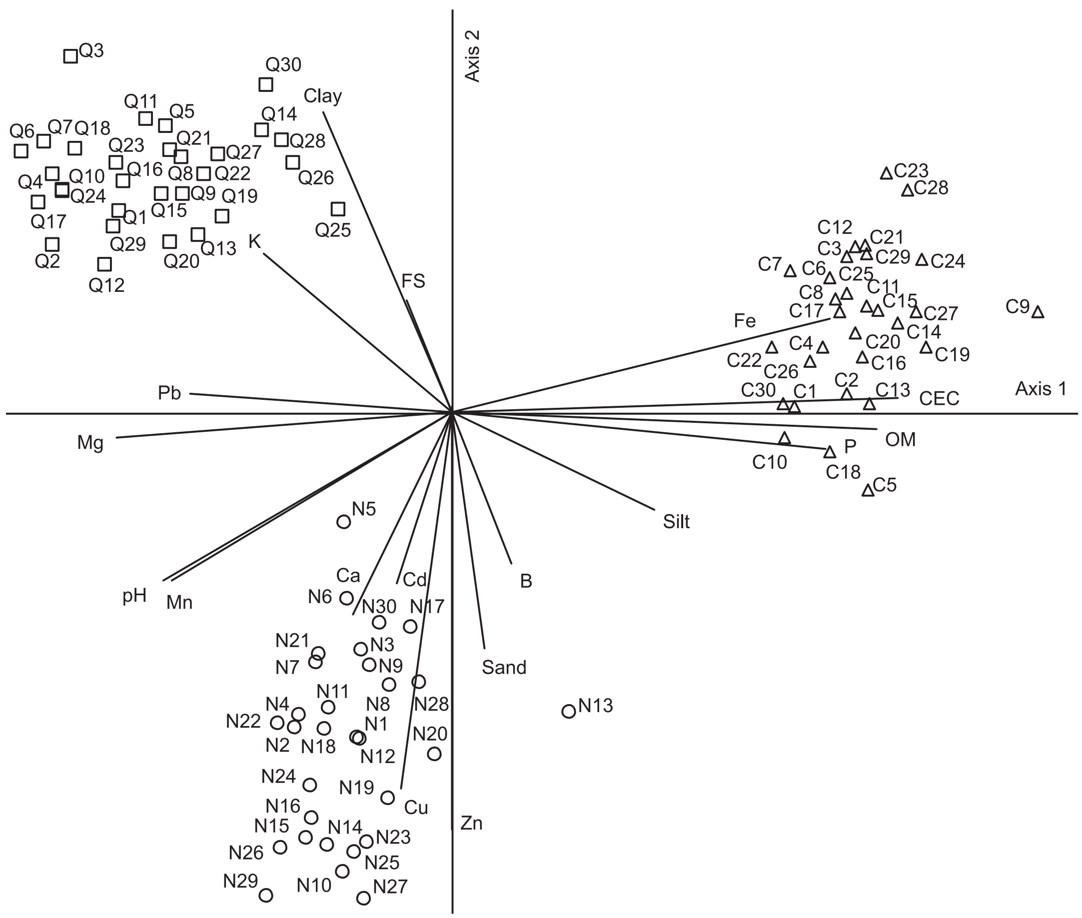

Figure 2. Diagram of ordination in the two first axes yielded by principal component analysis (PCA) of soil properties in the study areas: "canga couraçada" (C), "canga nodular" (N), and quartzitic "campo rupestre" (Q). Soil properties are given as vectors.

nodular soils. The second axis was negatively correlated mainly to Zn, Cu and sand proportion, and positively correlated to clay proportion; this axis separates CNo from QCR. The "canga couraçada" quadrats have presented the highest levels of Fe, OM, and P and the highest values of H + Al and CEC; the "canga nodular" quadrats showed the highest levels of Zn, Cu, Ca, and Cd, while the quartzitic "campo rupestre" quadrats showed the highest levels of K, Pb, clay and fine soil proportion (FS) (table 1). Except for Fe and Pb, CNo showed the highest levels of available metallic cations in soil.

Soil-plant species relationships – We found 40 species in "canga couraçada" (CCo), 131 in "canga nodular" (CNo), and 104 in quartzitic "campo rupestre" (QCR), totalling 228 species and 49 families. (R.C. Vincent *et al.*, unpublished data).

116 species were selected for canonical correspondence analysis, belonging mainly to Asteraceae (24.1%), Poaceae (17.2%) and Cyperaceae (9.5%) (table 2). The sites were clearly segregated in CCA (figure 3) as also observed in PCA (figure 2). The eigenvalues of two first axis of CCA diagram were high (Axis 1 = 0.801;

Table 2. Species selected for canonical correspondence analysis (CCA). Abbrev. = abbreviations used on figure 3 to species names. (AD = absolute density (ind m^{-2}); CCo = "canga couraçada"; CNo = "canga nodular"; QCR = "campo rupestre"; UN = undetermined species). Collector's number of R. C. Vincent; voucher material deposited in BHCB* and ESA herbaria.

Abbrev.	Species	Family	Voucher	AD		
				CCo	CNo	QCR
Aam	*Ayapana amygdalina* (Lam.) R. M. King & H. Rob.	Asteraceae	581*	–	–	1.80
Ac1	Acanthaceae 1	Acanthaceae	666	–	–	1.00
Ach	*Axonopus chrysoblepharis* (Lag.) Chase	Poaceae	363	–	–	31.53
Afa	*Ageratum fastigiatum* (Gardner) R. M. King & H. Rob.	Asteraceae	465*	–	1.32	0.07
Agl	*Arthrocereus glaziovii* (K. Schum.) N. P. Taylor & Zappi	Cactaceae	21*	0.23	–	–
Ain	*Andropogon ingratus* Hack.	Poaceae	729*	1.77	11.07	32.53
Amy	*Ageratum myriadenium* (Sch. Bip. ex Baker) R. M. King & H. Rob.	Asteraceae	8*	0.53	–	–
Apl	*Alstroemeria plantaginea* Mart.	Alstroemeriaceae	329	0.17	–	–
Apr	*Axonopus* cf. *pressus* (Nees ex Steud.) Parodi	Poaceae	131*	–	13.70	–
Are	*Aristida recurvata* Kunth	Poaceae	550*	–	0.48	2.73
As2	*Aspilia* sp.	Asteraceae	188	–	0.15	6.60
Asi	*Axonopus siccus* (Nees) Kuhlm.	Poaceae	543*	0.42	18.08	126.40
Asp	*Achyrocline* sp.	Asteraceae	162	–	0.37	–
Ate	*Acianthera teres* (Lindl.) Borba	Orchidaceae	125	6.65	–	–
Bca	*Borreria* cf. *capitata* DC.	Rubiaceae	392	–	–	5.13
Bju	*Bulbostylis junciformis* C. B. Clarke	Cyperaceae	705	–	2.30	1.80
Bpa	*Bulbostylis paradoxa* Nees	Cyperaceae	712	0.05	0.10	3.47
Bri	*Baccharis riedelii* Sch. Bip. ex Baker	Asteraceae	627	–	–	13.00
Bs1	*Barbacenia* sp.	Velloziaceae	5	3.07	–	–
Bse	*Baccharis serrulata* Pers.	Asteraceae	17	0.25	–	–
Bsp	*Bulbostylis* sp.	Cyperaceae	552	–	0.20	16.40
Bsu	*Baccharis subdentata* DC.	Asteraceae	166*	0.02	0.43	0.27
Bva	*Byrsonima* cf. *variabilis* A. Juss.	Malpighiaceae	93	–	0.25	–
Cam	*Calea* cf. *multiplinervia* Less.	Asteraceae	639	–	0.37	1.00
Can	*Croton antisyphiliticus* Mart.	Euphorbiaceae	669	–	–	7.20
Cca	*Croton campestris* A. St.-Hil.	Euphorbiaceae	230*	–	0.57	–
Cde	*Chamaecrista desvauxii* (Collad.) Killip	Fabaceae	674*	–	0.17	–
Chc	*Chromolaena campestris* (DC.) R. M. King & H. Rob.	Asteraceae	641	–	–	8.53
Che	*Chrysolaena herbacea* (Vell.) H. Rob.	Asteraceae	610	–	0.17	–

continue

continuation

Abbrev.	Species	Family	Voucher	AD		
				CCo	CNo	QCR
Chm	*Chamaecrista mucronata* (Spreng.) H. S. Irwin & Barneby	Fabaceae	78	–	0.90	–
Cin	*Chaptalia integerrima* (Vell.) Burkart	Asteraceae	111	–	0.63	1.40
Cmu	*Chromolaena multiflosculosa* (DC.) R. M. King & H. Rob.	Asteraceae	609*	0.67	1.58	–
Cpi	*Chaptalia piloselloides* (Vahl) Baker	Asteraceae	623	–	0.50	3.07
Cpo	*Chamaesyce potentilloides* (Boiss.) Croizat	Euphorbiaceae	670	–	0.25	0.53
Cst	*Chromolaena* cf. *stachyophylla* (Spreng.) R. M. King & H. Rob.	Asteraceae	638*	–	0.58	0.07
Cth	*Cuphea thymoides* Cham. & Schltdl.	Lythraceae	74	–	2.58	4.60
Cy1	Cyperaceae 1	Cyperaceae	107	–	9.30	–
Cy2	Cyperaceae 2	Cyperaceae	724	0.13	0.62	–
Cy3	Cyperaceae 3	Cyperaceae	725	–	–	1.67
Cy4	Cyperaceae 4	Cyperaceae	726	–	–	8.13
Dco	*Declieuxia* cf. *cordigera* Mart. & Zucc.	Rubiaceae	690	–	–	4.47
Doe	*Declieuxia oenanthioides* Mart. & Zucc.	Rubiaceae	474*	–	0.40	–
Ds2	*Ditassa* sp. 2	Apocynaceae	657	–	–	1.73
Ds3	*Ditassa* sp. 3	Apocynaceae	658	–	–	1.73
Dsa	*Dyckia* cf. *saxatilis* Mez	Bromeliaceae	20	0.05	0.40	–
Ein	*Echinolaena inflexa* (Poir.) Chase	Poaceae	138*	–	7.57	39.07
Epo	*Eragrostis polytricha* Nees	Poaceae	135	–	0.60	–
Ese	*Epidendrum secundum* Jacq.	Orchidaceae	28*	0.20	–	–
Esp	*Erythroxylum* sp.	Erythroxylaceae	769	–	0.52	–
Fa1	Fabaceae 1	Fabaceae	770	–	–	0.93
Gan	*Galianthe* cf. *angustifolia* (Cham. & Schltdl.) Cabral	Rubiaceae	423	0.83	–	–
Gma	*Galactia martii* DC.	Fabaceae	224*	–	4.17	–
Gre	*Gaylussacia reticulata* Mart. ex Meisn.	Ericaceae	177	–	3.65	–
Gsp	*Gomphrena* sp.	Amaranthaceae	662	–	0.23	–
Hli	*Hyptis lippioides* Pohl ex Benth.	Lamiaceae	155	–	0.23	0.07
Hlu	*Hyptis* cf. *lucida* Pohl ex Benth.	Lamiaceae	681	–	0.23	–
Hsp	*Hippeastrum* sp.	Amaryllidaceae	254	0.33	–	–
Jca	*Jacaranda caroba* (Vell.) DC.	Bignoniaceae	91	–	1.30	0.07
Kpu	*Kielmeyera* cf. *pumila* Pohl.	Clusiaceae	471	–	0.20	0.07
Kva	*Kielmeyera variabilis* Mart.	Clusiaceae	130	–	0.58	–
Lde	*Lessingianthus desertorum* (Mart. ex DC.) H. Rob.	Asteraceae	223	–	0.20	–
Ler	*Lychnophora ericoides* Mart.	Asteraceae	11*	0.93	–	–
Lgr	*Lippia gracilis* Phil.	Verbenaceae	16	0.20	–	–
Lla	*Leptocoryphium lanatum* (Kunth.) Nees	Poaceae	745	–	–	28.27
Lly	*Lucilia lycopodioides* (Less.) S. E. Freire	Asteraceae	447*	–	0.67	–
Lps	*Lessingianthus psilophyllus* (DC.) H. Rob.	Asteraceae	612*	–	0.50	1.53
Ls1	*Lessingianthus* sp. 1	Asteraceae	89	–	1.55	0.53
Ls2	*Lessingianthus* sp. 2	Asteraceae	633	–	–	15.60
Lsi	*Lessingianthus simplex* (Less.) H. Rob.	Asteraceae	615*	–	6.25	–
Lsp	*Lagenocarpus* sp.	Cyperaceae	714	–	–	5.67
Lxa	*Leandra* cf. *xanthostachys* Cogn.	Melastomataceae	247*	–	0.17	–
Mas	*Mandevilla* sp.	Apocynaceae	655	–	–	5.20
Mca	*Mimosa calodendron* Mart. ex Benth.	Fabaceae	325*	0.30	–	–

continue

continuation

Abbrev.	Species	Family	Voucher	AD		
				CCo	CNo	QCR
Mis	*Mikania* sp.	Asteraceae	771	–	0.18	–
Mmi	*Melinis minutiflora* P. Beauv.	Poaceae	102	0.45	10.27	–
Mne	*Mimosa* cf. *neuroloma* Benth.	Fabaceae	221*	–	0.22	–
Nru	*Neomarica rupestris* (Ravenna) Chukr	Iridaceae	79	–	0.18	–
Pap	*Paspalum polyphyllum* Nees ex Trin.	Poaceae	752*	–	1.90	2.40
Pch	*Phyllanthus choretroides* Müll. Arg.	Euphorbiaceae	503	–	–	2.80
Pde	*Peperomia decora* Dahlst.	Piperaceae	9	2.05	–	–
Pep	*Peltaea* cf. *polymorpha* (A. St.-Hil.) Krapov. & Cristóbal	Malvaceae	357	–	0.15	1.47
Pfs	*Pfaffia* sp.	Amaranthaceae	664	–	0.40	–
Pgn	*Pfaffia gnaphaloides* (L. f.) Mart.	Amaranthaceae	123	–	2.88	–
Pme	*Periandra mediterranea* (Vell.) Taub.	Fabaceae	68	–	0.25	–
Pni	*Phyllanthus niruri* L.	Euphorbiaceae	668*	–	3.53	–
Po1	Poaceae 1	Poaceae	766	–	–	30.93
Po2	Poaceae 2	Poaceae	765	–	–	1.73
Po3	Poaceae 3	Poaceae	767	–	–	2.53
Po4	Poaceae 4	Poaceae	768	–	–	4.80
Po5	Poaceae 5	Poaceae	772	–	0.32	–
Ppo	*Pseudogynoxys pohlii* (Sch. Bip. ex Baker) Leitão Filho	Asteraceae	168	–	2.18	–
Psc	*Paspalum scalare* Trin.	Poaceae	753	1.97	2.48	–
Psp	*Paspalum* sp.	Poaceae	746	–	0.32	1.00
Pto	*Peixotoa tomentosa* A. Juss.	Malpighiaceae	66	–	0.32	0.13
Pur	*Polygala* cf. *urbanii* Chodat	Polygalaceae	683	–	0.50	0.07
Ran	*Rhynchospora andina* Kük.	Cyperaceae	717	–	–	33.27
Rco	*Rhynchospora consanguinea* (Kunth.) Boeck.	Cyperaceae	229*	–	0.38	0.60
Rs1	*Rhynchospora* sp.	Cyperaceae	553*	–	0.17	–
Rsp	*Ruellia* sp.	Acanthaceae	121	–	0.38	–
Sbr	*Symphyopappus brasiliensis* (Gardner) R. M. King & H. Rob.	Asteraceae	18	0.43	–	–
Sca	*Sophronitis caulescens* (Lindl.) Van den Berg & M. W. Chase	Orchidaceae	1	9.42	–	–
Sgl	*Stachytarpheta glabra* Cham.	Verbenaceae	12	0.52	–	–
Sma	*Sisyrinchium marchio* Steud.	Iridaceae	699	–	–	2.07
Ssa	*Schizachyrium sanguineum* (Retz.) Alston	Poaceae	758*	–	0.32	40.47
Ssp	*Symphyopappus* sp.	Asteraceae	640	–	–	4.93
Sur	*Stevia urticifolia* Thunb.	Asteraceae	475*	–	0.25	0.20
Tmu	*Tibouchina multiflora* Cogn.	Melastomataceae	19*	0.20	–	–
Tob	*Turnera oblongifolia* Cambess.	Turneraceae	434	–	0.63	2.40
Tre	*Thrasyopsis repanda* (Nees) Parodi	Poaceae	764	–	–	14.20
Tsp	*Trachypogon spicatus* Kuntze	Poaceae	105	–	57.33	0.07
Un2	UN sp. 2	UN	773	–	0.22	–
Un4	UN sp. 4	UN	774	–	–	3.73
Un7	UN sp. 7	UN	704	–	–	2.13
Vku	*Viguiera kunthiana* Gardner	Asteraceae	622	–	–	3.00
Vre	*Vellozia* cf. *resinosa* Mart. ex Schult. f.	Velloziaceae	4*	3.38	–	–
Zdi	*Zornia* cf. *diphylla* (L.) Pers.	Fabaceae	676	–	0.02	2.33

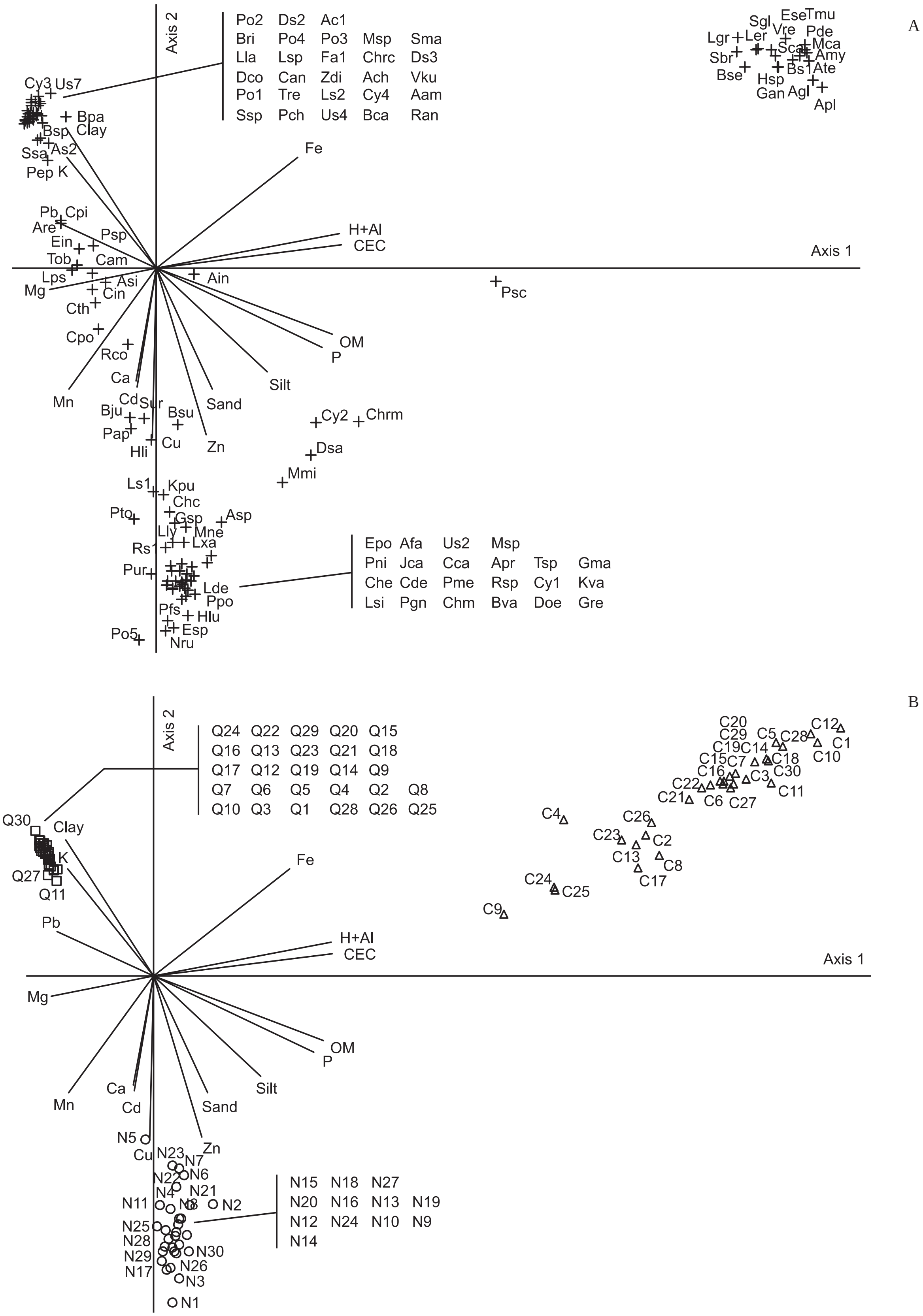

Figure 3. Diagram of ordination in the two first axes yielded by canonical correspondence analysis (CCA) of soil properties and plant species densities in "canga couraçada" (C), "canga nodular" (N) and quartzitic "campo rupestre" (Q). A. Species; B. Quadrats. Soil properties are given as vectors. Full names of species are given in the table 2.

Axis 2 = 0.628), the first one explaining 18.8% of total variance and the second 14.7% (table 3). The Pearson's correlation index obtained from Monte Carlo permutation test showed that plant abundance was significantly correlated with soil properties ($r = 0.983$, $P < 0.01$ in the first axis; $r = 0.970$, $P < 0.01$ in the second one). The first axis was positively correlated to CEC, H+Al, OM, P and Fe, and negatively correlated with Mg and Pb levels; this axis separates CCo from QCR and CNo. The second axis showed strong negative correlation with Cu, Zn, besides Mn, Cd, Ca and sand, and positive correlation with clay and K, and has separated CNo from CCo and QCR (figure 3b).

The dispersion of quadrats in CCA diagram reveals a gradient in CCo (figure 3b). A group of quadrats showed high abundance of individuals of species found only in this area (upper right of the figure 3a), mainly *Barbacenia* sp.1 and *Vellozia* cf. *resinosa* (Velloziaceae), and *Acianthera teres* and *Sophronitis caulescens* (Orchidaceae), while the remnant quadrats showed lower densities of the exclusive species and more individuals of species common to the "canga nodular", such as *Paspalum scalare* and *Melinis minutiflora* (Poaceae), *Chromolaena multiflosculosa* (Asteraceae), Cyperaceae 2, and *Dyckia* cf. *saxatilis* (Bromeliaceae) (figure 3a). In CNo, we also observed such a gradient but not so intense, while the QCR quadrats were strongly aggregated in the CCA diagram (figure 3b). A gradient between QCR and CNo was observed in figure 3a, where exclusive species have occupied the ends of gradient and the common ones have occupied intermediary positions in the diagram according to their abundances, mainly *Chaptalia piloselloides*, *C. integerrima* and *Lessingianthus psilophyllus* (Asteraceae), *Aristida recurvata* and *Echinolaena inflexa* (Poaceae), *Turnera oblongifolia* (Turneraceae), and *Cuphea thymoides* (Lythraceae). Among the species common to the three sites, *Andropogon ingratus* and *Axonopus siccus* (Poaceae) have showed higher densities in CNo and QCR (table 2) occupying the centre of CCA diagram, while *Baccharis subdentata* (Asteraceae) and *Bulbostylis paradoxa* have showed higher affinity to CNo and QCR soils respectively (figure 3a, table 2).

Table 3. Summary of canonical correspondence analysis (CCA) and Monte Carlo permutation test of plant species densities and soil properties for "canga couraçada", "canga nodular" and quartzitic "campo rupestre".

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.801	0.628	0.086
Percentage of variance explained	18.8	14.7	2.0
Cumulative percentage of variance	18.8	33.5	35.5
Pearson's correlation for species-soil	0.983	0.970	0.896
Significance of correlation (Monte Carlo test)	0.01	0.01	0.01

Discussion

Soils from the ferruginous "campos rupestres" and the quartzitic "campo rupestre" studied here are similar to those of other quartzitic "campos rupestres" concerning to low pH, P levels and base saturation (Vitta 1995, Conceição & Giulietti 2002, Teixeira & Lemos-Filho 2002). The highest levels of most of metallic cations in CNo was expected since intemperization releases elements from rock. The high acidity of soil may enhance availability of metal cations toxic to plants, except for copper, because H^+ and Cu antagonism may reduce copper toxicity (Malavolta *et al.* 1967, Levitt 1980, Bornemisza 1982). Thus, except for this cation, the high concentration of heavy metals in the acidic soils of the study sites probably acts as an additional stress factor to their plants. The quartzitic fields where QCR is situated are embedded among ferruginous formations, probably explaining the high Pb, Mn, Cu, and Fe concentrations found, as recorded by Teixeira & Lemos-Filho (1998) in soils of a quartzitic rocky outcrop in Serra de Itabirito, a range also situated in "Quadrilátero Ferrífero".

The high OM content found in CCo soil (table 1), although partially explained by the high proportion of not decomposed plant debris, may reduce both the availability and the toxicity of Zn to plants (Malavolta *et al.* 1967, Levitt 1980, Bornemisza 1982).

The Fe content found in CCo is similar to that found at "Serra dos Carajás" (northern Brazil), where the values are 435.3 and 589.6 mg dm^{-3} (Silva 1992). At "Serra do Itabirito", in "Quadrilátero Ferrífero", Teixeira & Lemos-Filho (2002) found Fe amounts similar to CNo values, both in ferruginous and quartzitic outcrops, respectively 151.5 and 171.0 mg dm^{-3}, while the value found in southeastern "Quadrilátero Ferrífero" (Gonçalves-Alvim & Fernandes 2001) was lower than any other ferruginous outcrop (74.0 mg dm^{-3}). The comparison of other metal levels among ferruginous outcrops from "Cadeia do Espinhaço" and "Serra dos Carajás" reveals that CCo have the highest amounts of Cu and Zn, but less Mn, Cr and Cd (Silva 1992, Gonçalves-Alvim & Fernandes 2001, Teixeira & Lemos-Filho 2002). In ultramafic soils at Niquelândia (central Brazil) the total amounts of Cr, Cu, Mn and Ni were very high (Reeves *et al.* 2007), but it is not possible to compare them to those found here due to the employed method, since they determined total amounts, while the present study deals only with available content.

The study sites were different edaphically, floristically and phytosociologically, as evidenced by ordination analyses (figures 2 and 3). The main edaphic variables influencing site segregation are related to soil fertility, such as CEC, P and Mg levels, H+Al, OM content, clay, and to the amounts of metallic cations, mainly Fe, Pb, Zn, and Cu (figure 2).

Some authors have related the physiognomical gradient of "cerrado" to soil fertility (Alvim & Araújo 1952, Goodland 1979), while others did not find such relationship (Gibbs *et al.* 1983, Ruggiero *et al.* 2002). This absence of relationship, however, could be explained by the choice of the *stratum* analyzed; the superficial root systems of many "cerrado" herbs and subshrubs allow higher exploration of superficial soil horizon by these plants than by the woody component (Walker 1984). Thus, spatial edaphic and microtopographic variability of superficial soil produce more edaphic microsites for herbaceous and subshrub species than for woody species, which may respond to a combination of those microsites (Sagers & Lyon 1997, Vieira 1997). Additionally, herbaceous and subshrub flora of "cerrado" have two or three times the number of species of the woody flora (Mantovani & Martins 1993, Castro *et al.* 1999); a relation of 1.7:1 was observed in a phytosociological survey performed in both strata of an 1 ha area of "campo cerrado" in São Paulo State (Vincent *et al.* 1992). In same way "campos rupestres" present such spatial heterogeneity since there are areas with exposed rock (outcrops), stony or nodular soils or primary soils, besides edaphic and microtopographic variability characteristic of the superficial soil. Although "cerrado" soils are deeper than "campo rupestre" ones, their higher variability occurs in superficial soil, then it is reasonable to expect high correlation between soil properties and the lower layer of vegetation. The spatial edaphic heterogeneity together with the high species diversity of herbaceous-subshrub layer make this *stratum* more useful to verify factors affecting physiognomical gradient in "cerrado" or in "campos rupestres" as suggested by data obtained here (figure 3).

The CCo quadrat gradient observed in CCA diagram (figure 3) must not be attributed to the soil variables analyzed here, since this pattern was not observed in PCA diagram (figure 2). Probably, this is a result of a gradient of exposed rock proportion, since the quadrats with higher density of epilithic species clumped together. On the other hand, the gradient in CNo quadrats reflects the gradient of heavy metal levels, especially Cu, Zn, and Cd (figures 2, 3). High levels of Cu, Ni, and Co on metalliferous soils in Rhodesia were correlated with floristic composition and with the density of populations of *Becium hombley* and *B. obovatum* (Lamiaceae) (Howard-Williams 1970). The distribution of QCR quadrats and species reveals a correlation between the group of species exclusive to QCR and soil, while the species shared by QCR and CNo grow on soils with intermediate properties.

Although sharing a common geological origin, the "canga couraçada" and the "canga nodular" showed quite different soil properties probably due to the effect of rock degradation on release of mineral particles and chemical elements, besides the differences in exposed rock proportion. On the other hand, although CNo and QCR have nodular substrates the different geological origins play an important role in soil differences. The data presented here have showed the influence of some soil properties on the abundance and distribution of species within and among areas.

Acknowledgements – We thank Jaime Bertoluci for comments on the manuscript and for helping in the fieldwork, Andrea de Souza and Jane M.Q. Alves for helping in the fieldwork, João Renato Stehmann, Marcos Sobral, Jimi Nakagima, Pedro L. Viana, Rubens Mota and Lindolpho Capellari Junior for species identification, and Instituto Estadual de Florestas (IEF/MG) and Copasa for permit access to the areas. We also thank the anonymous referees for suggestions to manuscript. R.C. Vincent have received a grant from Capes.

References

ALVIM, P.T. & ARAÚJO, W.A. 1952. El suelo como factor ecológico en el desarrollo de la vegetación en el centro-oeste del Brasil. Turrialba 2:153-160.

ANTONOVICS, J., BRADSHAW, A.D. & TURNER, R.G. 1971. Heavy metal tolerance in plants. Advances in Ecological Research 7:1-85.

BORNEMISZA, E. 1982. Introducción a la química de suelos. (Monografias Científicas, Série de Química, 25). OEA, Washington, DC.

CASTRO, A.A.J.F., MARTINS, F.R., TAMASHIRO, J.Y. & SHEPHERD, G.J. 1999. How rich is the flora of Brazilian cerrados? Annals of the Missouri Botanical Garden 86: 192-224.

CONCEIÇÃO, A.A. & GIULIETTI, A.M. 2002. Composição florística e aspectos estruturais de campo rupestre em dois platôs no Morro do Pai Inácio, Chapada Diamantina, Bahia, Brasil. Hoehnea 29:37-48.

COUTINHO, L.M. 1978. O conceito de cerrado. Revista Brasileira de Botânica 1:17-23.

DRUMMOND, G.M., MARTINS, C.S., MACHADO, A.B.M., SEBAIO, F.A. & ANTONINI, Y. (orgs.) 2005. Biodiversidade em Minas Gerais – Um atlas para sua conservação. 2nd ed. Fundação Biodiversitas, Belo Horizonte.

DUVIGNEAUD, P. & DENAEYER-DE SMET, S. 1960. Action de certains métaux lourds du sol (cuivre, cobalt, manganèse, uranium) sur la végétation du Haut-Katanga. *In* Rapports du sol et de la végétation (G. Viennot-Bourgin, ed.). Masson et Cie., Paris, p.121-139.

GIBBS, P., LEITÃO-FILHO, H.F. & SHEPHERD, G.J. 1983. Floristic composition and community structure in an area of cerrado in SE Brazil. Flora 173:433-449.

GIULIETTI, A.M., MENEZES, N.L., PIRANI, J.R., MEGURO, M. & WANDERLEY, M.G.L. 1987. Flora da Serra do Cipó, Minas Gerais: caracterização e lista das espécies. Boletim de Botânica da Universidade de São Paulo 9:1-151.

GIULIETTI, A.M., PIRANI, J.R. & HARLEY, R.M. 1997. Espinhaço range region – eastern Brazil. *In* Centres of plant diversity – a guide and strategy for their conservation, The Americas (S.D. Davis, V.H. Heywood, O. Herrera-MacBryde, J. Villa-Lobos & A.C. Hamilton, eds.). WWF/IUCN. IUCN Publications Unit, Cambridge, v.3, p.397-404.

GOODLAND, R. 1979. Análise ecológica da vegetação do cerrado. *In* Ecologia do cerrado (R. Goodland & M.G. Ferri, eds.). Itatiaia/EDUSP, Belo Horizonte/São Paulo, p.61-186.

GONÇALVES-ALVIM, S.J. & FERNANDES, G.W. 2001. Biodiversity of galling insects: historical, community and habitat effects in four neotropical savannas. Biodiversity and Conservation 10:79-98.

HERZ, N. 1978. Metamorphic rocks of the Quadrilátero Ferrífero, Minas Gerais, Brazil. Geological Survey Professional Paper 641:1-81.

HOWARD-WILLIAMS, C. 1970. The ecology of *Becium hombley* in Central Africa with special reference to metalliferous soils. Journal of Ecology 58:745-763.

JACOBI, C.M., CARMO, F.F., VINCENT, R.C. & STEHMANN, J.R. 2007. Plant communities on ironstone outcrops: a diverse and endangered Brazilian ecosystem. Biodiversity and Conservation 16:2185-2200.

KÖHL, K.I. 1997. Do *Armeria maritima* (Mill.) Willd. ecotypes from metalliferous soils and non-metalliferous soils differ in growth response under Zn stress? A comparison by a new artificial soil method. Journal of Experimental Botany 48:1959-1967.

LEVITT, J. 1980. Responses of plants to environmental stresses. v.II. Water, radiation, salt, and other stresses. Academic Press, New York.

MAGALHÃES, G.M. 1966. Sobre os cerrados de Minas Gerais. Anais da Academia Brasileira de Ciências 38:59-70.

MALAVOLTA, E., HAAG, H.P., MELLO, F.A.F. & BRASIL-SOBRINHO, M.O.C. 1967. Nutrição mineral de algumas culturas tropicais. Pioneira/EDUSP, São Paulo.

MANTOVANI, W. & MARTINS, F.R. 1993. Florística do cerrado na Reserva Biológica de Moji Guaçu, SP. Acta Botanica Brasilica 7:33-60.

McCUNE, B. & MEFFORD, M.J. 1999. Multivariate analysis of ecological data. Version 4.14. (PCOrd). MjM Software, Oregon.

MORELLATO, P.C. & ROSA, N.A. 1991. Caracterização de alguns tipos de vegetação na região amazônica, Serra dos Carajás, Pará, Brasil. Revista Brasileira de Botânica 14:1-14.

MUELLER-DOMBOIS, D. & ELLENBERG, H. 1974. Aims and methods of vegetation ecology. Willey and Sons, New York.

OLIVEIRA-FILHO, A.T., CURI, N., VILELA, E.A. & CARVALHO, D.A. 2001. Variation in tree community composition and structure with changes in soil properties within a fragment of semideciduous forest in South-Eastern Brazil. Edinburgh Journal of Botany 58:139-158.

POMERENE, J.B. 1964. Geology and ore deposits of the Belo Horizonte, Ibirité, and Macacos quadrangles, Minas Gerais, Brazil. Geological Survey Professional Paper 341:1-84.

PORTO, M.L. 1989. Tolerância ao cobre em ecótipos de *Schinus lentiscifolius* (Anacardiaceae) de áreas de mineração no Rio Grande do Sul, Brasil. Acta Botanica Brasilica 3:23-31.

PORTO, M.L. & SILVA, M.F.F. 1989. Tipos de vegetação metalófila em áreas da Serra de Carajás e de Minas Gerais. Acta Botanica Brasilica 3:13-21.

PRODEMGE, Minas Gerais. 1996. Atlas de zoneamento agroclimático do estado de Minas Gerais. *In* www.geominas.mg.gov.br (acessed 2005 February 20).

REEVES, R.D., BAKER, A.J.M., BECQUER, T., ECHEVARRIA, G. & MIRANDA, Z.J.G. 2007. The flora and biogeochemistry of the ultramafic soils of Goiás state, Brazil. Plant Soil 293:107-119.

RIZZINI, C.T. 1997. Tratado de fitogeografia do Brasil. Âmbito Cultural, Rio de Janeiro.

RUGGIERO, P.G.C., BATALHA, M.A., PIVELLO, V.R. & MEIRELLES, S.T. 2002. Soil-vegetation relationships in cerrado (Brazilian savanna) and semideciduous forest, southeastern Brazil. Plant Ecology 160:1-16.

SAGERS, C.L. & LYON, J. 1997. Gradient analysis in a riparian landscape: contrasts among forest layers. Forest Ecology and Management 96:13-26.

SECCO, R.S. & MESQUITA, A.I. 1983. Notas sobre a vegetação de canga da Serra Norte – I. Boletim do Museu Paraense Emílio Goeldi, nova série Botânica 59:1-13.

SIEGEL, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York.

SILVA, M.F.F. 1991. Análise florística da vegetação que cresce sobre canga hematítica em Carajás – Pará (Brasil). Boletim do Museu Paraense Emílio Goeldi, série Botânica 7:79-105.

SILVA, M.F.F. 1992. Distribuição de metais pesados na vegetação metalófila de Carajás. Acta Botanica Brasilica 6:107-22.

SILVA, M.F.F. & ROSA, N.A. 1990. Estudos botânicos na área do Projeto Ferro Carajás – Serra Norte. I. Aspectos fito-ecológicos dos campos rupestres. *In* Anais do XXXV Congresso Nacional de Botânica (1984). SBB, Manaus, p.367-379.

SILVA, M.F.F., SECCO, R.S. & LOBO, M.G.A. 1996. Aspectos ecológicos da vegetação rupestre da Serra dos Carajás, estado do Pará, Brasil. Acta Amazonica 26:17-44.

SIMMONS, G.C. 1960. Origin of certain cangas of the "Quadrilátero Ferrífero" of Minas Gerais, Brazil. Boletim da Sociedade Brasileira de Geologia 9:37-59.

SIMMONS, G.C. 1968. Geology and iron deposits of the Western Serra do Curral, Minas Gerais, Brazil. Geological Survey Professional Paper 341:1-57.

STATSOFT, Inc. 2001. Statistica (Data analysis software system), version 6.

TEIXEIRA, W.A. & LEMOS-FILHO, J.P. 1998. Metais pesados em folhas de espécies lenhosas colonizadoras de uma área de mineração de ferro em Itabirito, Minas Gerais. Revista Árvore 22:381-388.

TEIXEIRA, W.A. & LEMOS-FILHO, J.P. 2002. Fatores edáficos e a colonização de espécies lenhosas em uma cava de mineração de ferro em Itabirito, Minas Gerais. Revista Árvore 26:25-33.

TER BRAAK, C.J.F. 1995. Ordination. *In* Data analysis in community and landscape ecology (R.H.G. Jongman, C.J.F. ter Braak & O.F.R. Van Tongeren, eds.). Cambridge Univ. Press, Cambridge, p.91-173.

TER BRAAK, C.F.J. & LOOMAN, C.W.N. 1995. Regression. *In* Data analysis in community and landscape ecology (R.H.G. Jongman, C.J.F. ter Braak & O.F.R. Van Tongeren, eds.). Cambridge Univ. Press, Cambridge. p.29-77.

VIANA, P.L. & LOMBARDI, J.A. 2007. Florística e caracterização dos campos rupestres sobre canga na Serra da Calçada, Minas Gerais, Brasil. Rodriguésia 58:159-177.

VIEIRA, S.R. 1997. Variabilidade espacial de argila, silte e atributos químicos em uma parcela experimental de um latossolo roxo em Campinas (SP). Bragantia 56:181-190.

VINCENT, R.C., JACOBI, C.M. & ANTONINI, Y. 2002. Diversidade na adversidade. Ciência Hoje 31:64-67.

VINCENT, R.C., MIYAZAKI, S.L., GOMES, E.P.C. & MANTOVANI, W. 1992. Estrutura e composição florística do cerrado de Emas, Pirassununga, SP. *In* Anais do 8º Congresso da SBSP. SBSP, Campinas, p.139-151.

VITTA, F.A. 1995. Composição florística e ecologia de comunidades campestres na Serra do Cipó, Minas Gerais. Dissertação de Mestrado, Universidade de São Paulo, São Paulo.

WALKER, B.H. 1984. Structure and function of savannas: an overview. *In* Ecology and management of the world's savannas (J.C. Tohill & J.J. Mott, eds.). The Australian Academy of Science, Canberra, p.83-91.

ZAR, J.H. 1996. Biostatistical analysis. Prentice Hall, New Jersey.