EDINBURGH JOURNAL OF BOTANY 69 (1): 1–27 (2012) 1

doi:10.1017/S0960428611000382

THE INFLUENCE OF SOILS ON THE FLORISTIC COMPOSITION AND COMMUNITY STRUCTURE OF AN AREA OF BRAZILIAN CERRADO VEGETATION

A. V. Neri[1], C. E. G. R. Schaefer[2], A. F. Silva[1]†, A. L. Souza[3], W. G. Ferreira-Junior[1] & J. A. A. Meira-Neto[1]

This study investigated the influence of soil factors on the structure, richness and distribution of woody Cerrado species within the National Forest of Paraopeba, Minas Gerais State, Brazil. Individuals with basal stem circumference $\geq$ 10 cm were sampled in five plots of 20 $\times$ 100 m. The study was conducted in five environments with different physiognomies and types of soils. A total of 132 species were recorded. The species with the greatest importance values varied between different areas, as did structure. Canonical correspondence analysis ordination showed three different groups closely related to soil fertility and Al levels. These relations were also confirmed by Pearson's correlation where richness was positively related to pH, K, Ca, Mg and P and negatively to Al. The basal area was positively correlated with levels of P, Mg, Ca and T (base saturation) and negatively with Al, also using Pearson's correlation. Likewise, density was positively correlated with Mg and negatively with Al. The analysis shows that soil fertility and the concentration of Al are two of the most important factors responsible for structural and floristic variation and for differentiating dystrophic and mesotrophic Cerradão.

Keywords. Canonical correspondence analysis, Cerradão, Cerrado, soil–vegetation relationships, species diversity.

Introduction

The Cerrado* is part of the corridor of xeromorphic vegetation cutting across South America that includes the Caatinga in northeastern Brazil and the Chaco in

[1] Federal University of Viçosa, Plant Biology Department, P.H. Rolfs, s/n, 36570-000, Viçosa, MG, Brazil. E-mail for correspondence: andreza.neri@ufv.br
[2] Federal University of Viçosa, Department of Soil, P.H. Rolfs, s/n, 36570-000, Viçosa, MG, Brazil.
[3] Federal University of Viçosa, Forest Engineer Department, P.H. Rolfs, s/n, 36570-000, Viçosa, MG, Brazil.

† In memoriam.

* Cerrado is the generic name given to the savanna vegetation of Brazil and is the native vegetation of an area of approximately 2 million km^2. It ranges in structure from treeless campo to a quite dense forest of trees to c.15 m in height, and there is a range of nomenclature for its structural forms. Only two are mentioned in this paper: *Cerrado sensu stricto* (*s.s.*), probably the commonest form, consisting of a rather open dry woodland of trees and shrubs c.2–7 m in height, and *Cerradão*, a fairly closed woodland of trees c.6–15 m tall.

Paraguay, Bolivia and Argentina (Vanzolini, 1963). This corridor occupies an intermediate region between the two main humid tropical forests of South America: the Amazon Forest in the north-northwest, and the Atlantic Forest in the east and southeast (Oliveira-Filho & Ratter, 2002; Méio *et al.*, 2003).

The Cerrado vegetation is characterised by two layers: the woody layer, which includes trees and larger shrubs, and the herb–subshrub layer (Rizzini, 1992; Oliveira-Filho & Ratter, 2002). The difficulty of distinguishing tree from shrub species in the Cerrado is notorious: many species can flower and fruit both as small shrubs and as large trees (Rizzini, 1992). The flora of both layers exhibits typical characteristics of pyrophytic savanna vegetation: the trees are low with twisted trunks and thick cork providing resistance to fire (Ratter *et al.*, 1997), while both trees and shrubs have well-developed woody underground organs.

Studies that have tried to determine the main factors responsible for the distribution of this vegetation have to some extent varied in their conclusions, but in general the main factors are precipitation, soil fertility and drainage, fire regime, and the climatic fluctuations of the Quaternary (Eiten, 1972; Furley & Ratter, 1988; Ratter, 1992; Oliveira-Filho & Ratter, 1995, 2002; Furley, 1999). These are the same factors identified as important in the maintenance of savannas worldwide (Cole, 1986).

Today it is widely accepted that climate, soil and fire together have an important effect on the Cerrado vegetation. The dry season favours the occurrence of fire that hinders the establishment of forest species and also causes soil impoverishment. Of the chemical elements in the Cerrado soil, one of the most important is aluminium, as emphasised by Goodland (1969, 1971). This element occurs at high concentration in dystrophic soils and is extremely toxic for the majority of cultivated plants, but, as would be expected, the Cerrado native plants have a great tolerance to it. These tolerant plants are of diverse, unrelated families that accumulate aluminium in their tissues, particularly in leaves, but also in roots (Haridasan, 1982), such as Vochysiaceae, Rubiaceae, Myrtaceae, Melastomataceae, Symplocaceae, Loganiaceae and Myrsinaceae. Some families, including Vochysiaceae, accumulate aluminium and cannot survive in its absence (Haridasan, 1982; Oliveira-Filho & Ratter, 2002). On the other hand, species occurring only in areas with higher levels of calcium and magnesium, and lower aluminium levels, are characteristic of the mesotrophic Cerradão (or deciduous and semideciduous forests) and do not tolerate high aluminium concentrations (Ratter, 1971, 1992; Ratter *et al.*, 1973, 1978).

The correlation between the physiognomic variation of the Cerrado and soil fertility was first studied by Goodland & Pollard (1973) and Lopes & Cox (1977). They found a positive correlation between biomass of woody elements and fertility. However, data from other authors did not show the same correlation. Some works showed the occurrence of Cerradão instead of low density vegetation in areas of lower fertility (Ribeiro *et al.*, 1985; Ribeiro & Haridasan, 1990).

Early work carried out by the Anglo-Brazilian Xavantina–Cachimbo Expedition in 1967–69 in southeast Mato Grosso led to the identification of two types of Cerradão determined by the presence of different soil types (Ratter, 1971; Ratter *et al.*, 1973). In these publications the two types were named after their dominant characteristic species: *Hirtella glandulosa* Cerradão on dystrophic soils and *Magonia pubescens* Cerradão on mesotrophic soils. The work was continued in 1972 to cover an extensive area of central Brazil and these two types of Cerradão were shown to be widespread (Ratter *et al.*, 1977). The publication was in Portuguese and the two types were called Cerradão do tipo mesotrófico and Cerradão do tipo distrófico, which were later modified to Cerradão mesotrófico and Cerradão distrófico (or in English mesotrophic and dystrophic Cerradão).

The present work investigates the effect of soil factors on the diversity and structure of the Cerrado vegetation of the National Forest of Paraopeba, Minas Gerais State.

Material and Methods

Area of study

The present study was conducted in the National Forest of Paraopeba (in Portuguese Florestal Nacional de Paraopeba or FLONA de Paraopeba), Minas Gerais (19°20′S, 44°20′W), which covers an area of 200 ha (Fig. 1). The FLONA is a Sustainable Use Conservation Unit, according to the National System of Conservation Units (SNUC, 2000), a work that details the multiple uses of forest resources and scientific research, with emphasis on methods for sustainable exploitation of native forests.

The climate of the region is classified as Aw (tropical humid) by the Koeppen system (IBGE, 2007), with a rainy summer from October to March and a dry season from April to September. The annual mean temperature and the total annual rainfall are approximately 20.9°C and 1328 mm, respectively.

According to Silva-Júnior (1984) and personal statements from former employees, the FLONA vegetation regenerated after the area was clear-cut in 1952. There are records of fires in 1960 and 1963, but after that, the area has been protected from fire. For this reason we did not include the influence of fire as a factor in our analysis.

The selection of the studied areas was based primarily on classification of the soils (Neri, 2007) and not on vegetation types (physiognomies). The soil–vegetation gradient presents five classes with rather distinct characteristics, ranging from the upper landsurface closest to the calcareous Dry Forest outside the FLONA to the colluvial bottom, where the deepest Latosols occur (Fig. 2):

1 mesotrophic Cerradão on Red Latosol;
2 Cerrado *sensu stricto* on typical Yellow Latosol;
3 Cerrado *sensu stricto* on Haplic Cambisol Tb;
4 dense Cerrado *sensu stricto* on Yellow Red Latosol; and
5 dystrophic Cerradão on Red Latosol.

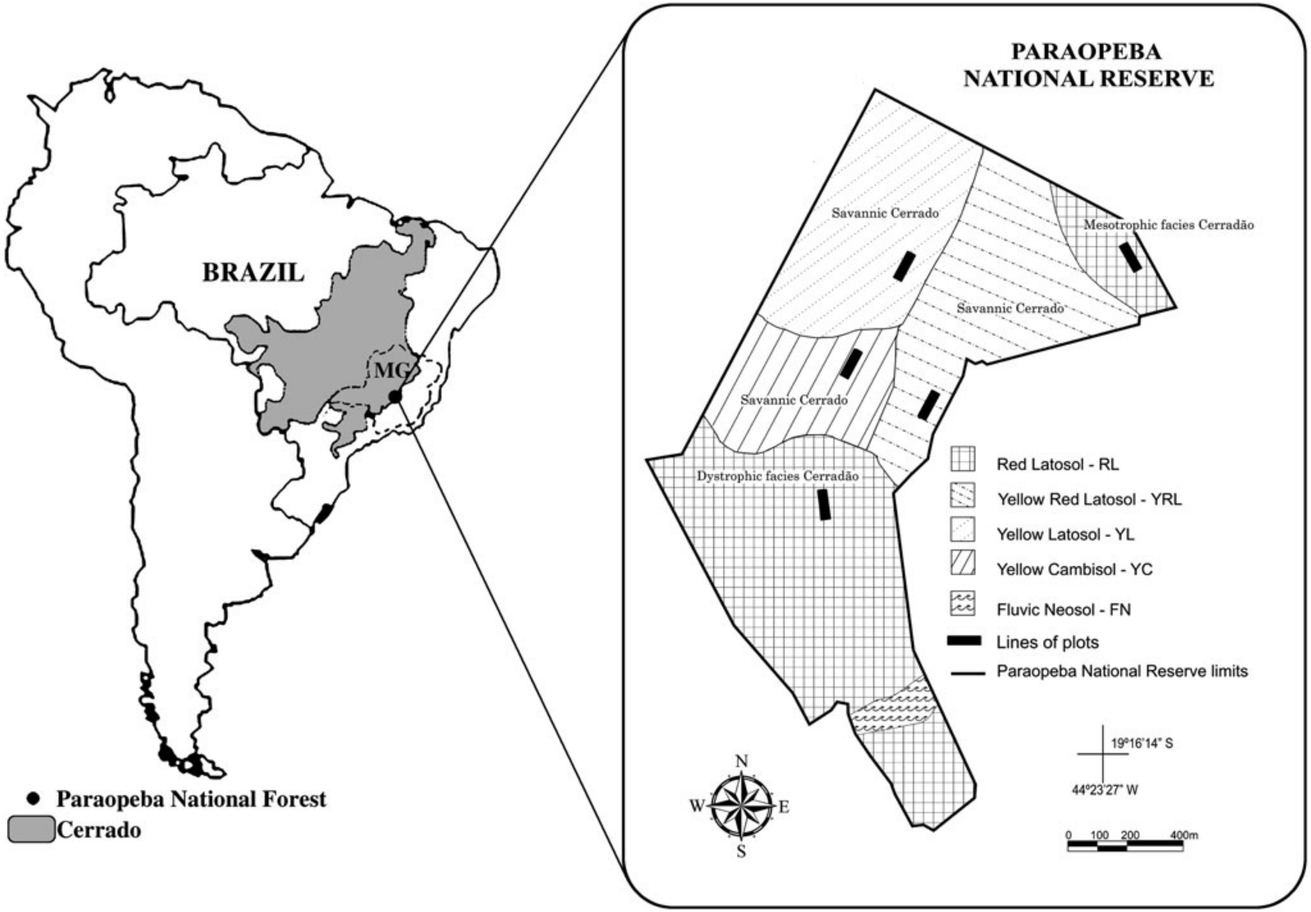

FIG. 1. Location of Paraopeba National Forest in Brazil and the areas studied.

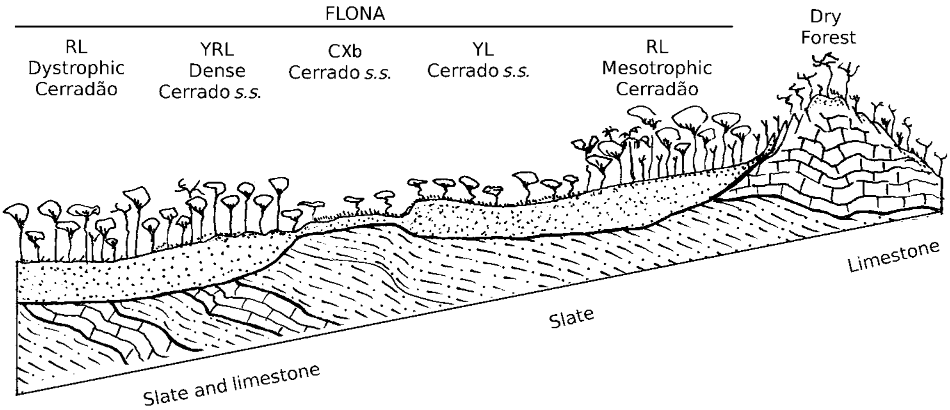

FIG. 2. Transect of soils, vegetation and lithology at the FLONA of Paraopeba, Brazil, illustrating the main soil–landform relationship.

The Red Latosol under mesotrophic Cerradão is located in a pediment approximately 500 m below a prominent crest of limestone outcrop where open, calcareous, Dry Forest occurs. Its colluvial nature suggests an influence of reworked materials eroded from the shallow limestone soils.

Structure and floristic analysis

The survey of the tree–shrub layer was carried out by placing quadrats of 20 × 100 m in each of the areas and then recording all woody individuals with a basal stem circumference ≥ 10 cm.

The classification of species into families followed APG II (APG II, 2003; Souza & Lorenzi, 2005). The nomenclature of the species and the abbreviations followed available information on the Missouri Botanical Garden website (www.mobot.org). Samples of fertile material were lodged in the herbarium of the Federal University of Viçosa (VIC).

Phytosociological parameters (Mueller-Dombois & Ellenberg, 1974; Rosot *et al.*, 1982) for describing the community structure were determined using the software 'Mata Nativa 2.0' (Cientec, 2002).

Soil and vegetation

Each of the vegetation quadrats of 20 × 100 m was divided into five subplots of 20 × 20 m and in each of these a soil sample was collected. These samples were composites of 10 subsamples and were from 0–10 cm depth. The subsamples were collected on the edge of a circle with a 5 m radius centred in the middle of the plot. Soil samples taken for chemical analysis were air-dried and sieved. Chemical soil properties were determined in the Soil Laboratory at the Federal University of Viçosa, following methods described by EMBRAPA (1997). The soil data were correlated with the richness, dominance and density of the vegetation calculated for each subplot (20 × 20 m).

We investigated the influence of edaphic variables on species abundance, using canonical correspondence analysis (CCA).

Statistical analysis

The correlation between the soil variables (pH, K, Ca, P-rem [remaining phosphorus], Al, Mg and P) and the species richness of each studied environment was calculated using Pearson's correlation coefficient (r_s) between the soil variables and absolute density, and absolute dominance was also calculated to study the influence of soil features on community structure (Table 1).

The 25 subplots were analysed by CCA using PCORD (McCune & Mefford, 1997). Soil attributes and abundance values for 44 species (those with 20 or more individuals sampled in the 1 ha area) were used for the calculations. Correlations between the species axes and soil variable axes were tested using Monte Carlo tests to estimate the significance of correlations among canonical axes.

Results

Floristics

A total of 4156 individuals were recorded in the five areas sampled; these included 132 species belonging to 47 families. The families with the greatest species richness were Fabaceae (18), Myrtaceae (9), Vochysiaceae (8), Bignoniaceae (7), Malpighiaceae and Rubiaceae (6 each), and Anacardiaceae, Annonaceae, Erythroxylaceae and Melastomataceae (4 each).

Of the 132 species, 14 were considered tolerant of variation in soil conditions, since they were observed in all studied areas: *Alibertia edulis* (Rich.) A.Rich. ex DC., *Bowdichia virgilioides* Kunth, *Erythroxylum* sp., *Erythroxylum suberosum* A.St.-Hil., *Eugenia dysenterica* DC., *Guapira noxia* (Netto) Lundell, *Leptolobium dasycarpum* Vogel, *Machaerium opacum* Vogel, *Myrcia guianensis* (Aubl.) DC., *Ouratea castaneifolia* (DC.) Engl., *Qualea grandiflora* Mart., *Qualea multiflora* Mart., *Roupala montana* Aubl. and *Zeyheria montana* Mart.

Apart from the species tolerant of variation in soil conditions, others restricted to specific environments were also observed. Eleven were restricted to the dystrophic Cerradão on Red Latosol: *Agonandra engleri* Hoehne, *Bauhinia rufa* (Bong.) Steud., *Bauhinia* sp., *Cabralea canjerana* (Vell.) Mart., *Cybianthus detergens* Mart., *Diospyros hispida* A.DC., *Enterolobium gummiferum* (Mart.) J.F.Macbr., *Guapira* sp., *Lacistema hasslerianum* Chodat, *Pouteria ramiflora* (Mart.) Radlk. and *Tontelea micrantha* (Mart. ex Schult.) A.C.Sm.

The mesotrophic Cerradão on Red Latosol is characterised by the low density or absence of herbaceous plants, probably because of the shade. In its understorey there

TABLE 1. Mean values and standard deviation of soil features of the National Forest of Paraopeba, Minas Gerais, Brazil

		P	P-rem	K	T	Ca^{2+}	Mg^{2+}	Al^{3+}
Physiognomy	pH	mg/kg			$cmol_c/dm^3$			
Dystrophic Cerradão RL	4.19 (±0.08)	1.24 (±0.22)	16.74 (±1.62)	44.00 (±7.94)	11.37 (±3.26)	0.20 (±0.07)	0.14 (±0.02)	2.54 (±0.13)
Mesotrophic Cerradão RL	6.43 (±0.19)	2.44 (±0.67)	34.74 (±1.36)	195.60 (±13.70)	15.86 (±1.34)	11.23 (±1.15)	1.47 (±0.19)	0.00 (±0.00)
Dense Cerrado *s.s.* YRL	4.91 (±0.10)	1.28 (±0.34)	20.54 (±1.79)	124.60 (±15.82)	9.85 (±0.48)	0.67 (±0.39)	0.82 (±0.29)	1.39 (±0.37)
Cerrado *s.s.* YL	5.19 (±0.05)	0.78 (±0.18)	21.40 (±1.51)	132.00 (±19.84)	8.15 (±0.46)	0.49 (±0.10)	0.52 (±0.05)	1.64 (±0.29)
Cerrado *s.s.* CXb	4.81 (±0.06)	0.72 (±0.19)	23.62 (±1.60)	97.00 (±14.35)	7.71 (±0.22)	0.37 (±0.23)	0.27 (±0.05)	1.94 (±0.13)

pH – active acidity; P – phosphorus; P-rem – remaining phosphorus; K – potassium; T – cation exchange capacity for pH 7; Ca^{2+} – exchangeable calcium; Mg^{2+} – exchangeable magnesium; Al^{3+} – aluminium.

RL – Red Latosol; YRL – Yellow Red Latosol; YL – Yellow Latosol; CXb – Haplic Cambisol.

is a prevalence of *Alibertia edulis*. Thirteen of the species found are exclusive to this environment: *Aspidosperma subincanum* Mart. ex A.DC., *Casearia rupestris* Eichler, *Dilodendron bipinnatum* Radlk., *Guazuma ulmifolia* Lam., *Guettarda viburnoides* Cham. & Schltdl., *Luehea divaricata* Mart., *Machaerium* sp., *Machaerium villosum* Vogel, *Magonia pubescens* A.St.-Hil., *Pseudobombax longiflorum* (Mart. & Zucc.) A.Robyns, *Pseudobombax tomentosum* (Mart. & Zucc.) A.Robyns, *Pouteria gardneri* (Mart. & Miq.) Baehni and *Trichilia claussenii* C.DC.

The dense Cerrado *sensu stricto* on Yellow Red Latosol also showed great richness, a total of 71 species, although only the following five were restricted to this area: *Handroanthus serratifolius* (Vahl) S.O.Grose, *Handroanthus* sp., *Rourea induta* Planch., *Vernonia* sp. and *Zanthoxylum* sp.

The Cerrado *sensu stricto* on typical Yellow Latosol is characterised by the presence of the species *Byrsonima cydoniifolia* A.Juss., *Eugenia dysenterica* DC., *Miconia albicans* (Sw.) Steud., *Pera glabrata* (Schott) Poepp. ex Baill., *Salvertia convallariodora* A.St.-Hil. and *Trichilia pallida* Sw.

The Cerrado *sensu stricto* on Haplic Cambisol Tb Dystrophic is characterised by well-defined herb–subshrub and shrub–tree layers, and is distinguished by the abundance of *Miconia albicans*.

Community structure

Mesotrophic Cerradão on Red Latosol

The mesotrophic Cerradão had a large number of individuals, in total 958 (4790 individuals/ha), with a high basal area value (40.18 m^2/ha). It was the most floristically rich area sampled, with 72 species from 36 families. The Shannon diversity index (H') was 3.26 and the equability (J') was 0.76 (Table 2). This vegetation has a great abundance of *Luehea divaricata*, *Alibertia edulis* and *Magonia pubescens* (Table 3).

The structure of the mesotrophic Cerradão was very different from the dystrophic Cerradão considering the phytosociological parameters and the species with the greatest importance values that characterise this vegetation: *Luehea divaricata*, *Alibertia edulis*, *Magonia pubescens*, *Myracrodruon urundeuva* Allemão, *Dilodendron bipinnatum* and *Terminalia argentea* Mart. & Zucc.

Cerrado sensu stricto *on typical Yellow Latosol*

The Cerrado *sensu stricto* on Yellow Latosol had 673 individuals (3365 individuals/ha). The basal area was small (19.27 m^2/ha), around half the basal area of the mesotrophic Cerradão and dense Cerrado *sensu stricto.* There were 61 species from 25 families. The Shannon diversity index was 3.35, and the equability was high, at 0.81.

Pera glabrata, *Trichilia pallida*, *Salvertia convallariodora*, *Miconia albicans*, *Eugenia dysenterica*, *Byrsonima cydoniifolia*, *Symplocos nitens* Benth., *Erythroxylum* sp.

TABLE 2. Data from the analysis of the structure of vegetation in the FLONA of the Paraopeba, Minas Gerais, Brazil

Area	*H′*	*J′*	*S′*	Fam.	NI	BA
D.C.	3.26	0.80	57	32	556	25.49 m^2/ha
M.C.	3.26	0.76	72	36	958	40.18 m^2/ha
C-YRL	3.54	0.83	71	38	1187	38.46 m^2/ha
C-YL	3.35	0.81	61	25	673	19.27 m^2/ha
C-HCD	2.28	0.72	53	24	782	19.32 m^2/ha

H′ – Shannon diversity; *J′* – equability; *S′* – number of species; Fam. – family; NI – number of individuals; BA – basal area.
D.C. – dystrophic Cerradão on Red Latosol; M.C. – mesotrophic Cerradão on Red Latosol; C-YRL – dense Cerrado *sensu stricto* on Yellow Red Latosol; C-YL – Cerrado *sensu stricto* on typical Yellow Latosol; C-HCD – Cerrado *sensu stricto* on Haplic Cambisol Tb Dystrophic.

and *Qualea parviflora* Mart. are the species with the highest importance values in this vegetation (Table 4). The species list is typical of dystrophic soils, with not a single mesotrophic species present.

Cerrado sensu stricto *on Haplic Cambisol Tb Dystrophic*

A total of 782 individuals were sampled in this area (3910 individuals/ha) with a small basal area of 19.32 m^2/ha, almost the same value as found in the Cerrado *sensu stricto* under typical Yellow Latosol. The number of species was low: 53 species, belonging to 24 families. The Shannon diversity index at 2.85 and the equability at 0.72 were the lowest recorded. The latter can be explained by the high abundance of *Miconia albicans*, representing 31% of the total individuals (Table 5). The other species that had high importance values were *Eugenia dysenterica*, *Pera glabrata*, *Erythroxylum* sp., *Byrsonima cydoniifolia*, *Qualea grandiflora* and *Q. parviflora*.

Dense Cerrado sensu stricto *on Red Yellow Latosol*

This environment had the highest density, 1187 individuals (5935 individuals/ha). Nevertheless, the basal area (38.46 m^2/ha) was smaller than the basal area found in the mesotrophic Cerradão. The species richness was high: 71 species from 38 families (Table 6). The Shannon diversity index at 3.54 and the equability at 0.83 were the highest of the FLONA. The diversity was one of the highest recorded in the Cerrado in general (see Felfili & Silva-Júnior, 2001).

This area did not have any dominant species, but the following had high importance values: *Platypodium elegans* Vogel, *Vochysia tucanorum* Mart., *Alibertia edulis*, *Xylopia aromatica* (Lam.) Mart., *Roupala montana*, *Qualea grandiflora*, *Q. parviflora* and *Styrax camporum* Pohl. *Platypodium elegans* is normally a strongly mesotrophic species and the anomaly of its presence here is discussed later.

TABLE 3. Phytosociological parameters for the species sampled in mesotrophic Cerradão (woodland) on Red Latosol in Paraopeba National Forest, Brazil

Species	*N*	AD	RD	AF	RF	ADo	RDo	IV (%)
Luehea divaricata Mart.*	140	700	14.61	100	5.00	7.917	19.71	13.11
Alibertia edulis (Rich.) A.Rich. ex DC.	174	870	18.16	95	4.75	3.806	9.47	10.8
Magonia pubescens A.St.-Hil.*	120	600	12.53	100	5.00	3.222	8.02	8.52
Myracrodruon urundeuva Allemão*	32	160	3.34	80	4.00	2.822	7.02	4.79
Dilodendron bipinnatum Radlk.*	26	130	2.71	65	3.25	1.555	3.87	3.28
Terminalia argentea Mart.**	16	80	1.67	60	3.00	1.665	4.15	2.94
Myrcia tomentosa (Aubl.) DC.	31	155	3.24	70	3.50	0.742	1.85	2.86
Bowdichia virgilioides Kunth	13	65	1.36	45	2.25	1.614	4.02	2.54
Platypodium elegans Vogel*	15	75	1.57	40	2.00	1.584	3.94	2.50
Tabebuia roseoalba (Ridl.) Sandwith**	13	65	1.36	50	2.50	1.270	3.16	2.34
Protium heptaphyllum (Aubl.) Marchand	29	145	3.03	45	2.25	0.494	1.23	2.17
Erythroxylum sp.	23	115	2.40	60	3.00	0.438	1.09	2.16
Myrcia splendens (Sw.) DC.	23	115	2.40	50	2.50	0.456	1.13	2.01
Astronium fraxinifolium Schott ex Spreng.**	17	85	1.77	50	2.50	0.683	1.70	1.99
Roupala montana Aubl.	18	90	1.88	55	2.75	0.490	1.22	1.95
Casearia rupestris Eichler*	19	95	1.98	45	2.25	0.624	1.55	1.93
Qualea parviflora Mart.	10	50	1.04	35	1.75	0.616	1.53	1.44
Machaerium opacum Vogel	9	45	0.94	30	1.50	0.675	1.68	1.37
Leptolobium dasycarpum Vogel	12	60	1.25	40	2.00	0.317	0.79	1.35
Guettarda viburnoides Cham. & Schltdl.*	8	40	0.84	30	1.50	0.658	1.64	1.32
Styrax camporum Pohl	10	50	1.04	40	2.00	0.266	0.66	1.23
Pseudobombax tomentosum (Mart. & Zucc.) A.Robyns*	10	50	1.04	40	2.00	0.239	0.59	1.21
Qualea grandiflora Mart.	8	40	0.84	35	1.75	0.361	0.90	1.16
Callisthene sp.	5	25	0.52	25	1.25	0.689	1.72	1.16
Rudgea viburnoides (Cham.) Benth.	10	50	1.04	35	1.75	0.280	0.70	1.16
Qualea multiflora Mart.	11	55	1.15	35	1.75	0.183	0.46	1.12
Copaifera langsdorffii Desf.	5	25	0.52	25	1.25	0.621	1.55	1.11
Vochysiaceae sp.	8	40	0.84	35	1.75	0.197	0.49	1.03
Handroanthus ochraceus (Cham.) Mattos	6	30	0.63	25	1.25	0.427	1.06	0.98
Machaerium villosum Vogel	5	25	0.52	25	1.25	0.457	1.14	0.97
Campomanesia velutina (Cambess.) O.Berg	8	40	0.84	25	1.25	0.249	0.62	0.90
Rhamnidium elaeocarpum Reissek*	9	45	0.94	30	1.50	0.085	0.21	0.88
Caryocar brasiliense Cambess.	5	25	0.52	15	0.75	0.551	1.37	0.88
Eugenia dysenterica DC.	6	30	0.63	30	1.50	0.185	0.46	0.86
Trichilia pallida Sw.	7	35	0.73	30	1.50	0.107	0.27	0.83
Pera glabrata (Schott) Poepp. ex Baill.	6	30	0.63	20	1.00	0.343	0.85	0.83
Myrcia guianensis (Aubl.) DC.	7	35	0.73	30	1.50	0.073	0.18	0.80
Aspidosperma subincanum Mart.*	6	30	0.63	20	1.00	0.296	0.74	0.79
Lithraea molleoides (Vell.) Engl.**	7	35	0.73	20	1.00	0.175	0.44	0.72

TABLE 3. (*Cont'd*)

Pseudobombax longiflorum (Mart. & Zucc.) A.Robyns	5	25	0.52	15	0.75	0.310	0.77	0.68
Machaerium sp.	4	20	0.42	20	1.00	0.216	0.54	0.65
Hymenaea stigonocarpa Mart. ex Hayne	6	30	0.63	15	0.75	0.214	0.53	0.64
Kielmeyera coriacea Mart. & Zucc.	5	25	0.52	25	1.25	0.064	0.16	0.64
Aspidosperma tomentosum Mart.	4	20	0.42	20	1.00	0.135	0.34	0.58
Banisteriopsis anisandra (A.Juss.) B.Gates	5	25	0.52	20	1.00	0.051	0.13	0.55
Myrsine sp.	5	25	0.52	20	1.00	0.032	0.08	0.53
Couepia grandiflora (Mart. & Zucc.) Benth. ex Hook.f.	3	15	0.31	15	0.75	0.187	0.47	0.51
Myrtaceae sp.	4	20	0.42	15	0.75	0.040	0.10	0.42
Pouteria gardneri (Mart. & Miq.) Baehni	1	5	0.10	5	0.25	0.313	0.78	0.38
Undetermined 1	2	10	0.21	10	0.50	0.058	0.15	0.28
Syagrus flexuosa (Mart.) Becc.	2	10	0.21	10	0.50	0.048	0.12	0.28
Erythroxylum suberosum A.St.-Hil.	2	10	0.21	10	0.50	0.037	0.09	0.27
Trichilia claussenii C.DC.	2	10	0.21	10	0.50	0.019	0.05	0.25
Plathymenia reticulata Benth.	1	5	0.10	5	0.25	0.153	0.38	0.25
Ocotea sp.	2	10	0.21	10	0.50	0.010	0.02	0.24
Dimorphandra mollis Benth.	1	5	0.10	5	0.25	0.109	0.27	0.21
Undetermined 2	1	5	0.10	5	0.25	0.104	0.26	0.20
Tachigali aurea Tul.	1	5	0.10	5	0.25	0.101	0.25	0.20
Cybistax antisyphilitica (Mart.) Mart.	1	5	0.10	5	0.25	0.084	0.21	0.19
Zeyheria montana Mart.	1	5	0.10	5	0.25	0.062	0.16	0.17
Senegalia polyphylla (DC.) Britton & Rose	1	5	0.10	5	0.25	0.045	0.11	0.16
Tapirira guianensis Aubl.	1	5	0.10	5	0.25	0.055	0.14	0.16
Symplocos nitens (Pohl) Benth.	1	5	0.10	5	0.25	0.039	0.10	0.15
Dalbergia miscolobium Benth.	1	5	0.10	5	0.25	0.043	0.11	0.15
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	1	5	0.10	5	0.25	0.011	0.03	0.13
Agonandra brasiliensis Miers ex Benth. & Hook.f.	1	5	0.10	5	0.25	0.009	0.02	0.13
Ouratea castaneifolia (DC.) Engl.	1	5	0.10	5	0.25	0.018	0.04	0.13
Connarus suberosus Planch.	1	5	0.10	5	0.25	0.007	0.02	0.12
Brosimum gaudichaudii Trécul	1	5	0.10	5	0.25	0.004	0.01	0.12
Guapira noxia (Netto) Lundell	1	5	0.10	5	0.25	0.008	0.02	0.12
Casearia sylvestris Sw.	1	5	0.10	5	0.25	0.006	0.01	0.12
Total	958	4790	99.94		100	40.18	100.0	100.0

N – number of individuals; AD – absolute density; RD – relative density; AF – absolute frequency; RF – relative frequency; ADo – absolute dominance; RDo – relative dominance; IV – importance value. * = mesotrophic species; ** = weakly mesotrophic species.

TABLE 4. Phytosociological parameters for the species sampled in Cerrado *sensu stricto* on Yellow Latosol in Paraopeba National Forest, Brazil

Species	*N*	AD	RD	AF	RF	ADo	RDo	IV (%)
Pera glabrata (Schott) Poepp. ex Baill.	87	435	12.93	95	5.69	2.236	11.60	10.07
Trichilia pallida Sw.	63	315	9.36	90	5.39	1.915	9.94	8.23
Salvertia convallariodora A.St.-Hil.	15	75	2.23	50	2.99	3.243	16.83	7.35
Miconia albicans (Sw.) Steud.	66	330	9.81	100	5.99	0.525	2.72	6.17
Eugenia dysenterica DC.	24	120	3.57	70	4.19	1.614	8.37	5.38
Byrsonima cydoniifolia A.Juss.	50	250	7.43	85	5.09	0.650	3.37	5.30
Symplocos nitens Benth.	28	140	4.16	70	4.19	1.074	5.57	4.64
Erythroxylum sp.	39	195	5.79	80	4.79	0.501	2.60	4.39
Qualea parviflora Mart.	22	110	3.27	65	3.89	0.757	3.93	3.70
Rudgea viburnoides (Cham.) Benth.	29	145	4.31	55	3.29	0.446	2.31	3.31
Xylopia aromatica (Lam.) Mart.	21	105	3.12	60	3.59	0.534	2.77	3.16
Alibertia edulis (Rich.) A.Rich. ex DC.	17	85	2.53	45	2.69	0.278	1.44	2.22
Curatella americana L.	7	35	1.04	25	1.50	0.690	3.58	2.04
Leptolobium dasycarpum Vogel	14	70	2.08	45	2.69	0.206	1.07	1.95
Labiatae sp.	14	70	2.08	30	1.80	0.273	1.42	1.76
Baccharis sp.	14	70	2.08	45	2.69	0.079	0.41	1.73
Erythroxylum suberosum A.St.-Hil.	10	50	1.49	40	2.40	0.161	0.83	1.57
Bowdichia virgilioides Kunth	6	30	0.89	30	1.80	0.348	1.81	1.50
Hymenaea stigonocarpa Mart. ex Hayne	6	30	0.89	25	1.50	0.381	1.97	1.45
Siparuna guianensis Aubl.	10	50	1.49	35	2.10	0.128	0.66	1.41
Tibouchina sp.	9	45	1.34	30	1.80	0.207	1.07	1.40
Qualea grandiflora Mart.	7	35	1.04	25	1.50	0.281	1.46	1.33
Styrax camporum Pohl	7	35	1.04	35	2.10	0.151	0.78	1.31
Caryocar brasiliense Cambess.	3	15	0.45	15	0.90	0.386	2.00	1.11
Myrsine sp.	6	30	0.89	30	1.80	0.120	0.62	1.10
Byrsonima coccolobifolia Kunth	5	25	0.74	25	1.50	0.196	1.02	1.09
Kielmeyera sp.	7	35	1.04	25	1.50	0.102	0.53	1.02
Erythroxylum tortuosum Mart.	8	40	1.19	25	1.50	0.064	0.33	1.01
Myrcia guianensis (Aubl.) DC.	7	35	1.04	20	1.20	0.089	0.46	0.90
Machaerium opacum Vogel	3	15	0.45	10	0.60	0.299	1.55	0.87
Ouratea castaneifolia (DC.) Engl.	5	25	0.74	20	1.20	0.085	0.44	0.79
Myrcia tomentosa (Aubl.) DC.	6	30	0.89	15	0.90	0.063	0.33	0.71
Byrsonima crassifolia (L.) Kunth	3	15	0.45	15	0.90	0.140	0.73	0.69
Plathymenia reticulata Benth.	3	15	0.45	15	0.90	0.114	0.59	0.64
Guapira noxia (Netto) Lundell	3	15	0.45	15	0.90	0.114	0.59	0.64
Stryphnodendron adstringens (Mart.) Coville	4	20	0.59	15	0.90	0.078	0.41	0.63
Guapira cf. *ferruginea* (Klotzsch ex Choisy) Lundell	4	20	0.59	15	0.90	0.071	0.37	0.62
Tachigali aurea Tul.	2	10	0.30	10	0.60	0.168	0.87	0.59
Schefflera macrocarpa (Cham. & Schltdl.) Frodin	3	15	0.45	15	0.90	0.040	0.21	0.52
Zeyheria montana Mart.	3	15	0.45	10	0.60	0.066	0.34	0.46
Myrcia splendens (Sw.) DC.	3	15	0.45	10	0.60	0.038	0.20	0.41
Ouratea hexasperma (A.St.-Hil.) Baill.	2	10	0.30	10	0.60	0.048	0.25	0.38
Piptocarpha rotundifolia (Less.) Baker	2	10	0.30	10	0.60	0.043	0.22	0.37

TABLE 4. (*Cont'd*)

Roupala montana Aubl.	2	10	0.30	10	0.60	0.027	0.14	0.35
Tocoyena formosa (Cham. & Schltdl.) K.Schum.	2	10	0.30	10	0.60	0.027	0.14	0.34
Palicourea rigida Kunth	2	10	0.30	10	0.60	0.026	0.14	0.34
Myrcia formosiana DC.	2	10	0.30	10	0.60	0.024	0.13	0.34
Neea theifera Oerst.	2	10	0.30	10	0.60	0.009	0.05	0.31
Myrsine umbellata Mart.	3	15	0.45	5	0.30	0.026	0.13	0.29
Vochysia tucanorum Mart.	1	5	0.15	5	0.30	0.043	0.22	0.22
Davilla rugosa Poir.	2	10	0.30	5	0.30	0.012	0.06	0.22
Xylopia cf. *brasiliensis* Spreng.	1	5	0.15	5	0.30	0.011	0.06	0.17
Tapirira guianensis Aubl.	1	5	0.15	5	0.30	0.014	0.07	0.17
Casearia sylvestris Sw.	1	5	0.15	5	0.30	0.011	0.06	0.17
Annona crassiflora Mart.	1	5	0.15	5	0.30	0.013	0.07	0.17
Qualea multiflora Mart.	1	5	0.15	5	0.30	0.006	0.03	0.16
Myrtaceae sp.	1	5	0.15	5	0.30	0.007	0.03	0.16
Tachigali rubiginosa (Mart. & Tul.) Oliveira-Filho	1	5	0.15	5	0.30	0.005	0.03	0.16
Dimorphandra mollis Benth.	1	5	0.15	5	0.30	0.004	0.02	0.16
Melastomataceae sp.	1	5	0.15	5	0.30	0.005	0.02	0.16
Banisteriopsis anisandra (A.Juss.) B.Gates	1	5	0.15	5	0.30	0.004	0.02	0.16
Total	673	3365	100		100	19.28	100	100

N – number of individuals; AD – absolute density; RD – relative density; AF – absolute frequency; RF – relative frequency; ADo – absolute dominance; RDo – relative dominance; IV – importance value.

Dystrophic Cerradão on Red Latosol

This area had lower density than the other environments – 556 individuals (2780 individuals/ha) – and also low basal area (25.49 m^2/ha). There were 57 species from 32 families; the Shannon diversity index was 3.26 and the equability was 0.80.

The vegetation is characterised by the presence of *Bowdichia virgilioides*, which has the greatest importance value and basal area value (Table 7). The other species that have high importance values are *Styrax camporum*, *Xylopia aromatica*, *Alibertia edulis*, *Miconia albicans*, *Roupala montana* and *Plathymenia reticulata* Benth.

The inclusion criterion of a basal circumference ≥ 10 cm led to the inclusion of smaller species such as *Cybianthus detergens* Mart., *Bauhinia rufa* (Bong.) Steud. and another, as yet unidentified, *Bauhinia* species.

Soil and vegetation correlations

It was possible to determine a correlation between soil variables and species richness of each environment by calculating Pearson's correlation coefficient. There was a positive correlation ($P < 0.05$) between species richness and pH ($r_s = 0.49$), K ($r_s = 0.43$), Ca ($r_s = 0.57$), Mg ($r_s = 0.58$) and P-rem ($r_s = 0.51$), while there was a negative correlation between species richness and Al ($r_s = -0.41$; $P < 0.05$).

Table 5. Phytosociological parameters for the species sampled in Cerrado *sensu stricto* on Haplic Cambisol Tb Dystrophic in Paraopeba National Forest, Brazil

Species	*N*	AD	RD	AF	RF	ADo	RDo	IV (%)
Miconia albicans (Sw.) Steud.	243	1215	31.07	100	7.09	2.063	10.68	16.28
Eugenia dysenterica DC.	61	305	7.80	90	6.38	2.105	10.89	8.36
Pera glabrata (Schott) Poepp. ex Baill.	54	270	6.91	65	4.61	1.518	7.86	6.46
Erythroxylum sp.	49	245	6.27	90	6.38	0.965	4.99	5.88
Byrsonima cydoniifolia A.Juss.	48	240	6.14	95	6.74	0.653	3.38	5.42
Qualea grandiflora Mart.	25	125	3.20	60	4.26	1.546	8.00	5.15
Qualea parviflora Mart.	28	140	3.58	65	4.61	1.366	7.07	5.09
Erythroxylum suberosum A.St.-Hil.	29	145	3.71	60	4.26	0.752	3.89	3.95
Curatella americana L.	22	110	2.81	60	4.26	0.922	4.77	3.95
Salvertia convallariodora A.St.-Hil.	6	30	0.77	20	1.42	1.521	7.87	3.35
Kielmeyera coriacea Mart. & Zucc.	23	115	2.94	60	4.26	0.398	2.06	3.09
Terminalia argentea Mart.**	13	65	1.66	50	3.55	0.651	3.37	2.86
Tibouchina cf. *granulosa* (Desr.) Cogn.	23	115	2.94	35	2.48	0.598	3.10	2.84
Machaerium opacum Vogel	15	75	1.92	30	2.13	0.792	4.10	2.71
Zeyheria montana Mart.	14	70	1.79	45	3.19	0.307	1.59	2.19
Alibertia edulis (Rich.) A.Rich. ex DC.	14	70	1.79	35	2.48	0.274	1.42	1.90
Dimorphandra mollis Benth.	10	50	1.28	35	2.48	0.293	1.52	1.76
Annona crassiflora Mart.	5	25	0.64	25	1.77	0.309	1.60	1.34
Rudgea viburnoides (Cham.) Benth.	12	60	1.53	15	1.06	0.256	1.33	1.31
Schefflera macrocarpa (Cham. & Schltdl.) Frodin	7	35	0.90	30	2.13	0.120	0.62	1.21
Stryphnodendron adstringens (Mart.) Coville	6	30	0.77	30	2.13	0.101	0.52	1.14
Myrcia guianensis (Aubl.) DC.	7	35	0.90	20	1.42	0.203	1.05	1.12
Byrsonima coccolobifolia Kunth	5	25	0.64	20	1.42	0.199	1.03	1.03
Erythroxylum tortuosum Mart.	5	25	0.64	20	1.42	0.072	0.37	0.81
Melastomataceae sp.	5	25	0.64	20	1.42	0.040	0.21	0.76

TABLE 5. (*Cont'd*)

Tapirira guianensis Aubl.	4	20	0.51	15	1.06	0.100	0.52	0.70
Trichilia pallida Sw.	5	25	0.64	15	1.06	0.076	0.39	0.70
Tachigali aurea Tul.	2	10	0.26	10	0.71	0.200	1.04	0.67
Piptocarpha rotundifolia (Less.) Baker	3	15	0.38	15	1.06	0.078	0.41	0.62
Tocoyena formosa (Cham. & Schltdl.) K.Schum.	3	15	0.38	15	1.06	0.033	0.17	0.54
Baccharis sp.	3	15	0.38	15	1.06	0.013	0.07	0.50
Qualea multiflora Mart.	1	5	0.13	5	0.35	0.181	0.94	0.47
Styrax camporum Pohl	3	15	0.38	10	0.71	0.052	0.27	0.45
Byrsonima verbascifolia (L.) DC.	2	10	0.26	10	0.71	0.070	0.36	0.44
Hyptidendron canum (Pohl ex Benth.) Harley	3	15	0.38	10	0.71	0.028	0.15	0.41
Xylopia aromatica (Lam.) Mart.	2	10	0.26	10	0.71	0.032	0.17	0.38
Leptolobium dasycarpum Vogel	2	10	0.26	10	0.71	0.027	0.14	0.37
Handroanthus ochraceus (Cham.) Mattos	2	10	0.26	10	0.71	0.011	0.06	0.34
Plathymenia reticulata Benth.	2	10	0.26	10	0.71	0.009	0.05	0.34
Erythroxylum daphnites Mart.	2	10	0.26	10	0.71	0.011	0.05	0.34
Byrsonima crassa Nied.	2	10	0.26	5	0.35	0.056	0.29	0.30
Ouratea castaneifolia (DC.) Engl.	1	5	0.13	5	0.35	0.054	0.28	0.25
Ouratea hexasperma (A.St.-Hil.) Baill.	1	5	0.13	5	0.35	0.043	0.22	0.24
Roupala montana Aubl.	1	5	0.13	5	0.35	0.046	0.24	0.24
Guapira noxia (Netto) Lundell	1	5	0.13	5	0.35	0.047	0.25	0.24
Vochysia thyrsoidea Pohl	1	5	0.13	5	0.35	0.033	0.17	0.22
Neea theifera Oerst.	1	5	0.13	5	0.35	0.024	0.13	0.20
Kielmeyera sp.	1	5	0.13	5	0.35	0.018	0.09	0.19
Lafoensia pacari A.St.-Hil.	1	5	0.13	5	0.35	0.016	0.08	0.19
Bowdichia virgilioides Kunth	1	5	0.13	5	0.35	0.015	0.08	0.19
Myrcia tomentosa (Aubl.) DC.	1	5	0.13	5	0.35	0.010	0.05	0.18
Palicourea rigida Kunth	1	5	0.13	5	0.35	0.007	0.03	0.17
Aegiphila verticillata Vell.	1	5	0.13	5	0.35	0.006	0.03	0.17
Total	782	3910	100		99.94	19.32	100	100

N – number of individuals; AD – absolute density; RD – relative density; AF – absolute frequency; RF – relative frequency; ADo – absolute dominance; RDo – relative dominance; IV – importance value.
** = weakly mesotrophic species.

TABLE 6. Phytosociological parameters for the species sampled in dense Cerrado *sensu stricto* on Red Yellow Latosol in Paraopeba National Forest, Brazil

Species	*N*	AD	RD	AF	RF	ADo	RDo	IV (%)
Platypodium elegans Vogel*	114	570	9.60	90	3.83	7.026	18.27	10.57
Vochysia tucanorum Mart.	81	405	6.82	75	3.19	3.095	8.05	6.02
Alibertia edulis (Rich.) A.Rich. ex DC.	96	480	8.09	85	3.62	1.921	4.99	5.57
Xylopia aromatica (Lam.) Mart.	76	380	6.40	95	4.04	1.738	4.52	4.99
Roupala montana Aubl.	72	360	6.07	85	3.62	1.635	4.25	4.64
Qualea grandiflora Mart.	51	255	4.30	90	3.83	1.478	3.84	3.99
Qualea parviflora Mart.	39	195	3.29	70	2.98	1.673	4.35	3.54
Styrax camporum Pohl	42	210	3.54	85	3.62	1.164	3.03	3.39
Rudgea viburnoides (Cham.) Benth.	33	165	2.78	60	2.55	1.198	3.12	2.82
Myrcia guianensis (Aubl.) DC.	37	185	3.12	85	3.62	0.578	1.50	2.75
Leptolobium dasycarpum Vogel	39	195	3.29	60	2.55	0.827	2.15	2.66
Terminalia argentea Mart.**	28	140	2.36	65	2.77	0.832	2.16	2.43
Erythroxylum sp.	28	140	2.36	65	2.77	0.776	2.02	2.38
Tapirira guianensis Aubl.	29	145	2.44	65	2.77	0.725	1.89	2.37
Eugenia dysenterica DC.	27	135	2.27	65	2.77	0.653	1.70	2.25
Copaifera langsdorffii Desf.	3	15	0.25	5	0.21	2.343	6.09	2.19
Myrcia tomentosa (Aubl.) DC.	27	135	2.27	75	3.19	0.388	1.01	2.16
Miconia albicans (Sw.) Steud.	32	160	2.70	65	2.77	0.256	0.66	2.04
Pera glabrata (Schott) Poepp. ex Baill.	19	95	1.60	60	2.55	0.754	1.96	2.04
Machaerium opacum Vogel	17	85	1.43	55	2.34	0.795	2.07	1.95
Kielmeyera coriacea Mart. & Zucc.	22	110	1.85	50	2.13	0.554	1.44	1.81
Erythroxylum suberosum A.St.-Hil.	24	120	2.02	50	2.13	0.423	1.10	1.75
Siparuna guianensis Aubl.	23	115	1.94	55	2.34	0.287	0.75	1.67
Annona crassiflora Mart.	9	45	0.76	35	1.49	0.950	2.47	1.57
Bowdichia virgilioides Kunth	9	45	0.76	35	1.49	0.928	2.41	1.55
Myrsine sp.	18	90	1.52	50	2.13	0.233	0.61	1.42
Guapira noxia (Netto) Lundell	14	70	1.18	50	2.13	0.275	0.72	1.34
Hymenaea stigonocarpa Mart. ex Hayne	19	95	1.60	35	1.49	0.330	0.86	1.32
Byrsonima cydoniifolia A.Juss.	18	90	1.52	40	1.70	0.200	0.52	1.25
Callisthene sp.	12	60	1.01	40	1.70	0.119	0.31	1.01
Zeyheria montana Mart.	10	50	0.84	40	1.70	0.124	0.32	0.96
Aspidosperma tomentosum Mart.	11	55	0.93	35	1.49	0.150	0.39	0.94
Curatella americana L.	4	20	0.34	20	0.85	0.613	1.59	0.93
Tachigali aurea Tul.	6	30	0.51	25	1.06	0.402	1.05	0.87
Handroanthus sp.	6	30	0.51	25	1.06	0.336	0.87	0.81
Caryocar brasiliense Cambess.	6	30	0.51	20	0.85	0.398	1.03	0.80
Myrcia splendens (Sw.) DC.	5	25	0.42	25	1.06	0.330	0.86	0.78
Dimorphandra mollis Benth.	5	25	0.42	25	1.06	0.219	0.57	0.68
Coussarea cornifolia (Benth.) Benth. & Hook.f.	7	35	0.59	30	1.28	0.062	0.16	0.68
Baccharis sp.	7	35	0.59	15	0.64	0.317	0.82	0.68
Couepia grandiflora (Mart. & Zucc.) Benth. ex Hook.f.	8	40	0.67	20	0.85	0.146	0.38	0.64
Myrtaceae sp.	6	30	0.51	20	0.85	0.131	0.34	0.57
Handroanthus serratifolius (Vahl) S.O.Grose**	6	30	0.51	20	0.85	0.140	0.37	0.57
Protium heptaphyllum (Aubl.) Marchand	5	25	0.42	20	0.85	0.125	0.32	0.53

TABLE 6. (*Cont'd*)

Banisteriopsis anisandra (A.Juss.) B.Gates	6	30	0.51	20	0.85	0.086	0.22	0.53
Lafoensia pacari A.St.-Hil.	2	10	0.17	10	0.43	0.108	0.28	0.29
Undetermined 3	1	5	0.08	5	0.21	0.158	0.41	0.24
Piptocarpha rotundifolia (Less.) Baker	2	10	0.17	10	0.43	0.037	0.10	0.23
Symplocos nitens Benth.	2	10	0.17	10	0.43	0.039	0.10	0.23
Erythroxylum tortuosum Mart.	2	10	0.17	10	0.43	0.037	0.10	0.23
Handroanthus ochraceus Mattos	2	10	0.17	10	0.43	0.025	0.07	0.22
Neea theifera Oerst.	2	10	0.17	5	0.21	0.037	0.10	0.16
Agonandra brasiliensis Miers ex Benth. & Hook.f.	1	5	0.08	5	0.21	0.025	0.06	0.12
Rourea induta Planch.	1	5	0.08	5	0.21	0.022	0.06	0.12
Trichilia pallida Sw.	1	5	0.08	5	0.21	0.014	0.04	0.11
Ouratea castaneifolia (DC.) Engl.	1	5	0.08	5	0.21	0.017	0.04	0.11
Labiatae sp.	1	5	0.08	5	0.21	0.010	0.03	0.11
Campomanesia velutina (Cambess.) O.Berg	1	5	0.08	5	0.21	0.008	0.02	0.11
Psidium salutare (Kunth) O.Berg	1	5	0.08	5	0.21	0.010	0.03	0.11
Byrsonima coccolobifolia Kunth	1	5	0.08	5	0.21	0.011	0.03	0.11
Zanthoxylum sp.	1	5	0.08	5	0.21	0.014	0.04	0.11
Casearia sylvestris Sw.	1	5	0.08	5	0.21	0.014	0.04	0.11
Vernonia sp.	1	5	0.08	5	0.21	0.008	0.02	0.11
Undetermined 4	1	5	0.08	5	0.21	0.013	0.03	0.11
Ocotea sp.	1	5	0.08	5	0.21	0.006	0.02	0.10
Undetermined 5	1	5	0.08	5	0.21	0.007	0.02	0.10
Brosimum gaudichaudii Trécul	1	5	0.08	5	0.21	0.005	0.01	0.10
Lithraea molleoides (Vell.) Engl.**	1	5	0.08	5	0.21	0.005	0.01	0.10
Total	1187	5935	99.97		99.98	38.46	100	100

N – number of individuals; AD – absolute density; RD – relative density; AF – absolute frequency; RF – relative frequency; ADo – absolute dominance; RDo – relative dominance; IV – importance value.
* = mesotrophic species; ** = weakly mesotrophic species.

Pearson's correlation showed that absolute dominance has a positive correlation with soil fertility. The attributes of soil that had the most significant correlations were P (r_s = 0.70), Mg (r_s = 0.71), Ca (r_s = 0.58) and T (base saturation) (r_s = 0.64). The correlation between absolute dominance and Al was negative (r_s = –0.62).

The correlations between absolute density and soil features were not as strong as those with absolute dominance, but were still within 95% significance. This variable displayed positive correlation with Mg (r_s = 0.59) and negative correlation with Al (r_s = –0.55). However, the density did not show significant correlation with P and Ca.

The species and the scores of axes 1 and 2 used in the canonical correspondence analysis are shown in Table 8. In the CCA the first canonical axis explained 25.5% of the variance and the second axis explained 16.2%, together accounting for 41.7% of the total variance (Table 9). In Fig. 3 we show the CCA ordination of 44 species and in Fig. 4 we show the ordination of 25 plots with intra-set correlations of soil

Table 7. Phytosociological parameters for the species sampled in dystrophic Cerradão (woodland) on Red Latosol in Paraopeba National Forest, Brazil

Species	*N*	AD	RD	AF	RF	ADo	RDo	IV (%)
Bowdichia virgilioides Kunth	51	255	9.17	90	6.82	9.447	37.07	17.69
Styrax camporum Pohl	53	265	9.53	75	5.68	2.801	10.99	8.73
Xylopia aromatica (Lam.) Mart.	35	175	6.29	80	6.06	2.087	8.19	6.85
Alibertia edulis (Rich.) A.Rich. ex DC.	57	285	10.25	60	4.55	0.763	2.99	5.93
Miconia albicans (Sw.) Steud.	54	270	9.71	60	4.55	0.536	2.10	5.45
Roupala montana Aubl.	29	145	5.22	80	6.06	0.683	2.68	4.65
Plathymenia reticulata Benth.	13	65	2.34	45	3.41	1.724	6.76	4.17
Brosimum gaudichaudii Trécul	28	140	5.04	75	5.68	0.179	0.70	3.81
Syagrus flexuosa (Mart.) Becc.	32	160	5.76	15	1.14	0.750	2.94	3.28
Machaerium opacum Vogel	17	85	3.06	45	3.41	0.739	2.90	3.12
Myrcia splendens (Sw.) DC.	20	100	3.60	55	4.20	0.218	0.86	2.88
Astronium fraxinifolium Schott ex Spreng.**	12	60	2.16	50	3.79	0.509	2.00	2.65
Ocotea sp.	16	80	2.88	45	3.41	0.277	1.09	2.46
Hymenaea stigonocarpa Mart. ex Hayne	12	60	2.16	35	2.65	0.294	1.15	1.99
Cabralea canjerana (Vell.) Mart.	11	55	1.98	40	3.03	0.111	0.43	1.81
Aspidosperma tomentosum Mart.	8	40	1.44	40	3.03	0.061	0.24	1.57
Caryocar brasiliense Cambess.	4	20	0.72	15	1.14	0.728	2.86	1.57
Qualea multiflora Mart.	6	30	1.08	30	2.27	0.162	0.63	1.33
Siparuna guianensis Aubl.	6	30	1.08	30	2.27	0.148	0.58	1.31
Dalbergia miscolobium Benth.	4	20	0.72	15	1.14	0.458	1.80	1.22
Cybianthus detergens Mart.	7	35	1.26	25	1.89	0.037	0.15	1.10
Neea theifera Oerst.	6	30	1.08	25	1.89	0.043	0.17	1.05
Annona crassiflora Mart.	5	25	0.90	15	1.14	0.281	1.10	1.05
Leptolobium dasycarpum Vogel	6	30	1.08	15	1.14	0.230	0.90	1.04
Erythroxylum sp.	6	30	1.08	20	1.52	0.115	0.45	1.01
Senegalia polyphylla (DC.) Britton & Rose	7	35	1.26	15	1.14	0.119	0.47	0.95
Guapira noxia (Netto) Lundell	3	15	0.54	15	1.14	0.263	1.03	0.90
Diospyros hispida A.DC.	4	20	0.72	20	1.52	0.081	0.32	0.85
Couepia grandiflora (Mart. & Zucc.) Benth. ex Hook.f.	4	20	0.72	20	1.52	0.041	0.16	0.80
Eugenia dysenterica DC.	1	5	0.18	5	0.38	0.434	1.70	0.75
Connarus suberosus Planch.	2	10	0.36	5	0.38	0.287	1.13	0.62
Qualea grandiflora Mart.	2	10	0.36	10	0.76	0.142	0.56	0.56
Rudgea viburnoides (Cham.) Benth.	3	15	0.54	10	0.76	0.041	0.16	0.49
Myrcia guianensis (Aubl.) DC.	3	15	0.54	10	0.76	0.037	0.15	0.48
Pouteria ramiflora (Mart.) Radlk.	1	5	0.18	5	0.38	0.206	0.81	0.46
Campomanesia velutina (Cambess.) O.Berg	4	20	0.72	5	0.38	0.041	0.16	0.42
Annona coriacea Mart.	1	5	0.18	5	0.38	0.173	0.68	0.41
Zeyheria montana Mart.	2	10	0.36	10	0.76	0.019	0.07	0.40
Rubiaceae sp.	2	10	0.36	5	0.38	0.019	0.07	0.27
Byrsonima cydoniifolia A.Juss.	2	10	0.36	5	0.38	0.008	0.03	0.26
Guapira sp.	1	5	0.18	5	0.38	0.044	0.17	0.24

TABLE 7. (*Cont'd*)

Handroanthus ochraceus Mattos	1	5	0.18	5	0.38	0.033	0.13	0.23
Agonandra brasiliensis Miers ex Benth. & Hook.f.	1	5	0.18	5	0.38	0.025	0.10	0.22
Enterolobium gummiferum (Mart.) J.F.Macbr.	1	5	0.18	5	0.38	0.009	0.04	0.20
Tontelea micrantha (Mart. ex Schult.) A.C.Sm.	1	5	0.18	5	0.38	0.007	0.03	0.20
Lacistema hasslerianum Chodat	1	5	0.18	5	0.38	0.007	0.03	0.20
Ouratea castaneifolia (DC.) Engl.	1	5	0.18	5	0.38	0.014	0.05	0.20
Aegiphila verticillata Vell.	1	5	0.18	5	0.38	0.009	0.04	0.20
Cybistax antisyphilitica (Mart.) Mart.	1	5	0.18	5	0.38	0.007	0.03	0.20
Agonandra cf. *engleri* Hoehne	1	5	0.18	5	0.38	0.005	0.02	0.19
Casearia sylvestris Sw.	1	5	0.18	5	0.38	0.004	0.02	0.19
Erythroxylum suberosum A.St.-Hil.	1	5	0.18	5	0.38	0.006	0.02	0.19
Ouratea hexasperma (A.St.-Hil.) Baill.	1	5	0.18	5	0.38	0.005	0.02	0.19
Stryphnodendron adstringens (Mart.) Coville	1	5	0.18	5	0.38	0.004	0.02	0.19
Bauhinia cf. *rufa* (Bong.) Steud.	1	5	0.18	5	0.38	0.006	0.02	0.19
Bauhinia sp.	1	5	0.18	5	0.38	0.006	0.02	0.19
Hyptidendron canum (Pohl ex Benth.) Harley	1	5	0.18	5	0.38	0.004	0.02	0.19
Total	556	2780	100.00		100	25.49	100	100

N – number of individuals; AD – absolute density; RD – relative density; AF – absolute frequency; RF – relative frequency; ADo – absolute dominance; RDo – relative dominance; IV – importance value.
** = weakly mesotrophic species.

properties. The correlation between the two matrices, of species and of soil variables, was measured as axes correlations. Thus, the correlation between the first axis and species–environmental variables was 0.985, and between the second axis and species–environmental variables was 0.968, both highly significant. Monte Carlo tests showed significance ($P = 0.01$) for the species–environmental correlations between the first and second axes.

The CCA ordination (Fig. 3) indicates that the distribution of species is correlated with the soil fertility gradient. In this analysis we identified three groups of species: one group of species that correlated with high soil fertility and low concentration of Al, a second with intermediate soil fertility, and a third with low soil fertility and high concentration of Al. The species correlated with high soil fertility are those present only in the mesotrophic Cerradão. On the other hand, the species that seem to be related with intermediate fertility are present in areas of both high and low soil fertility.

TABLE 8. The species, abbreviated species name and scores of axes 1 and 2 used in the canonical correspondence analysis

Species	Abbr. species name	'Scores' Axis 1	Axis 2
Annona crassiflora Mart.	Ann cra	0.443	0.872
Casearia rupestris Eichler*	Cas rup	–2.244	–1.287
Salvertia convallariodora A.St.-Hil.	Sal con	1.380	–1.441
Guapira noxia (Netto) Lundell	Gua nox	0.266	0.739
Aspidosperma tomentosum Mart.	Asp tom	–0.335	1.354
Tibouchina cf. *granulosa* (Desr.) Cogn.	Tib gra	1.404	–1.456
Symplocos nitens Benth.	Sym nit	1.204	–1.248
Dilodendron bipinnatum Radlk.*	Dil bip	–2.200	–1.373
Myrsine sp.	Myr sp	0.169	–0.002
Protium heptaphyllum (Aubl.) Marchand	Pro hep	–2.088	–1.456
Brosimum gaudichaudii Trécul	Bro gau	–0.320	2.692
Astronium fraxinifolium Schott ex Spreng.**	Ast frax	–1.317	0.493
Myracrodruon urundeuva Allemão	Myr uru	–2.177	–1.332
Curatella americana L.	Cur ame	1.225	–1.043
Syagrus flexuosa (Mart.) Becc.	Sya fle	–0.511	2.830
Tapirira guianensis Aubl.	Tap gui	0.369	0.654
Siparuna guianensis Aubl.	Sip gui	0.502	0.624
Hymenaea stigonocarpa Mart. ex Hayne	Hym sti	0.030	0.944
Terminalia argentea Mart.**	Ter arg	–0.559	0.298
Myrcia splendens (Sw.) DC.	Myr spl	–0.919	0.379
Kielmeyera coriacea Mart. & Zucc.	Kie cor	0.512	–0.130
Machaerium opacum Vogel	Mac opa	0.062	0.588
Myrcia guianensis (Aubl.) DC.	Myr gui	0.224	0.506
Myrcia tomentosa (Aubl.) DC.	Myr tom	–0.801	–0.290
Erythroxylum suberosum A.St.-Hil.	Ery sub	0.775	–0.186
Leptolobium dasycarpum Vogel	Lep das	0.087	0.385
Trichilia pallida Sw.	Tri pal	1.114	–1.461
Bowdichia virgilioides Kunth	Bow vir	–0.370	1.626
Vochysia tucanorum Mart.	Voc tuc	0.124	1.611
Rudgea viburnoides (Cham.) Benth.	Rud vib	0.529	–0.402
Qualea grandiflora Mart.	Qua gran	0.350	0.283
Qualea parviflora Mart.	Qua par	0.576	–0.385
Styrax camporum Pohl	Sty cam	–0.076	1.479
Byrsonima cydoniifolia A.Juss.	Byr cyd	1.138	–0.838
Eugenia dysenterica DC.	Eug dys	0.811	–0.517
Magonia pubescens A.St.-Hil.*	Mag pub	–2.169	–1.431
Platypodium elegans Vogel*	Plat ele	–0.149	1.312
Roupala montana Aubl.	Rou mon	–0.255	1.360
Xylopia aromatica (Lam.) Mart.	Xyl aro	0.286	1.327
Luehea divaricata Mart.*	Lue div	–2.207	–1.346
Erythroxylum sp.	Eryt sp	0.457	–0.544
Pera glabrata (Schott) Poepp. ex Baill.	Per gla	1.130	–1.117
Alibertia edulis (Rich.) A.Rich. ex DC.	Ali edu	–0.960	0.100
Miconia albicans (Sw.) Steud.	Mic alb	0.987	–0.469

* = mesotrophic species; ** = weakly mesotrophic species.

TABLE 9. Statistical summary of canonical correspondence analysis; 44 species and 25 plots of Cerrado in Paraopeba, Minas Gerais, Brazil

	Axis 1	Axis 2
Eigenvalue	0.567	0.360
Variance in species data % of explained	25.5	16.2
Cumulative % explained	25.5	41.7
Pearson correlation, Spp.–Envt*	0.985	0.968
Kendall (Rank) correlation, Spp.–Envt	0.693	0.640
Monte Carlo test (species–environmental correlations)	0.01	0.01

*Correlation between sample scores for an axis derived from the species data and the sample scores that are linear combinations of the environmental variables.

DISCUSSION

At landscape level, there is a clear trend of increasing biomass and density of vegetation on the redder soils, both dystrophic and mesotrophic. These soils are influenced by colluvial materials from weathered limestone or *in situ* alteration of such calcareous rocks. On the other hand, the savannic cerrados are related to either shallow or deep yellowish soils (Cambisols/Latosols) developed from slate, a pellitic Al-rich, nutrient-poor, metamorphic rock. The soil–landform variations are, therefore, closely related to local geological structures that control soil drainage and weathering, since limestone lenses occur throughout the pellitic sequence.

The species that were observed in all the environments can be regarded as generalists exhibiting a great deal of tolerance of soil variation. Because of their ecological plasticity such generalists should be useful in reforestation of degraded areas in the FLONA and in other areas with typical dystrophic soils.

The species of the mesotrophic Cerradão are the most characteristic and exclusive occurring in the study. It has been demonstrated in many areas that the occurrence of these characteristic species of this environment is due to the chemical properties of the soil, providing better nutritional conditions (see, for example, Furley & Ratter, 1988). This is the most fertile environment in the FLONA with the highest levels of Ca and Mg and lowest levels of Al, and its flora identifies it as a classic example of mesotrophic Cerradão.

Mesotrophic Cerradão was formerly found in a vast Cerrado area. There are studies in the states of Goiás, Minas Gerais, Mato Grosso, Maranhão, Mato Grosso do Sul and Piauí (Ratter *et al.*, 2011). It is often associated with the margins of Deciduous and Semideciduous Seasonal Forests and indicates an intermediate condition between soils of dystrophic Cerradão and those of more fertile seasonal forests. Many species indicative of mesotrophic Cerradão also occur in Deciduous Seasonal Forests (Ratter *et al.*, 1977; Furley & Ratter, 1988).

The floristic richness among the studied environments varied from 53 species in the Cerrado *sensu stricto* on Cambisol to 72 species in the mesotrophic Cerradão.

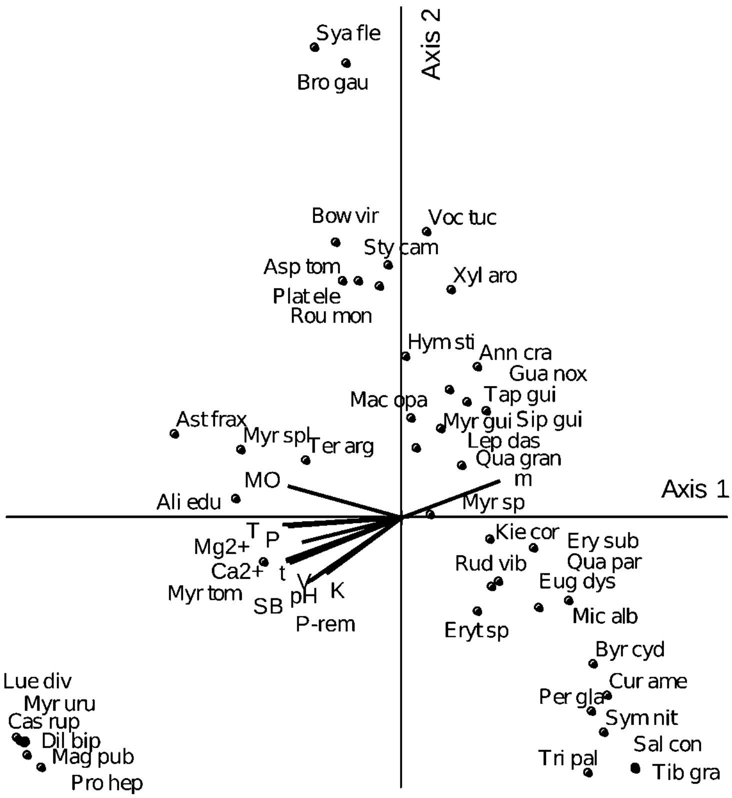

FIG. 3. Canonical correspondence analysis ordination showing the distribution of species in relation to soil properties: pH – active acidity; P – phosphorus; K – potassium; Ca^{2+} – exchangeable calcium; Mg^{2+} – exchangeable magnesium; SB – sum of bases; t – effective cation exchange capacity; T – cation exchange capacity for pH 7; V – base saturation; m – aluminium saturation; MO – organic matter; P-rem – remaining phosphorus. See Table 8 for complete species names.

However, this is an exception to the more normal situation as dystrophic cerradões are usually more species diverse than mesotrophic ones. This is because the latter often show dominance of a few characteristic species (Ratter *et al.*, 2011).

It was possible to investigate the influence of soil characteristics on floristic composition and vegetation structure in the area studied. Beyond the correlation with species richness, the chemical characteristics of the soil were possibly responsible for limiting the occurrence of some species, such as the absence of *Miconia albicans* in the mesotrophic Cerradão. This species is common in open areas of Cerrado (Costa & Araújo, 2001; Neri *et al.*, 2005). In Costa & Araújo (2001) it was common in disturbed areas of Cerrado and in Neri *et al.* (2005) it was abundant as homogeneous stands of understorey regeneration in Cerrado. In the present study this species was found in open vegetation associated with low soil fertility and high

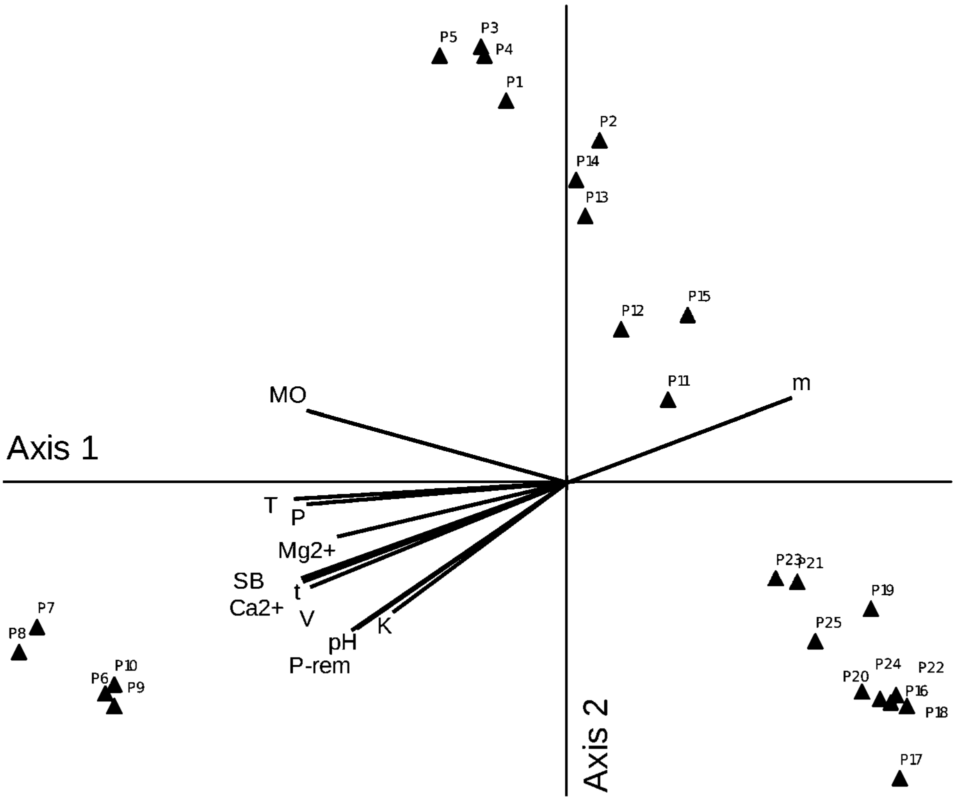

FIG. 4. Canonical correspondence analysis ordination showing the distribution of plots (dystrophic Cerradão: P1, P2, P3, P4, P5; mesotrophic Cerradão: P6, P7, P8, P9, P10; Cerrado *sensu stricto* on Red Yellow Latosol: P11, P12, P13, P14, P15; Cerrado *sensu stricto* on Yellow Latosol: P16, P17, P18, P19, P20; Cerrado *sensu stricto* on Cambisol: P21, P22, P23, P24, P25) in relation to soil properties: pH – active acidity; P – phosphorus; K – potassium; Ca^{2+} – exchangeable calcium; Mg^{2+} – exchangeable magnesium; SB – sum of bases; t – effective cation exchange capacity; T – cation exchange capacity for pH 7; V – base saturation; m – aluminium saturation; MO – organic matter; P-rem – remaining phosphorus. See Table 8 for complete species names.

concentration of Al. It is also an aluminium accumulator (Haridasan, 1982; Haridasan & Araújo, 1988).

Comparing the density and the basal area in our study with those from other areas shows our values are relatively high (e.g. Haridasan & Araújo, 1988).

The occurrence of species which accumulate Al can be explained by competitive advantage in areas with dystrophic soil. The main accumulator species in Cerrado belong to the Vochysiaceae, Melastomataceae and a number of other groups (Haridasan & Araújo, 1988; Haridasan, 2000). These plants accumulate Al in leaves as part of their physiology (Haridasan, 1982). Ruggiero *et al.* (2002) suggested that the high aluminium concentration in the soil surface is associated with the transference of this element from plant to soil by litter decomposition.

Goodland (1969) was the first to point out the relationship between biomass and soil fertility gradient in the Cerrado and emphasised the importance of aluminium in this ecosystem. Subsequent studies showed low nutritional status and high levels of Al in forest compared to Cerrado (Haridasan, 1982; Silva-Júnior, 1987; Oliveira-Filho *et al.*, 1989). Ruggiero *et al.* (2002) found the converse. Probably the answer to this lies in different forest and Cerrado types being studied by different authors. Comparison of very dystrophic evergreen forest with a richer more mesotrophic Cerrado would give the result found by the first group of workers, while Ruggiero's result would be replicated by comparing a forest on richer soil with a dystrophic Cerrado. It would not be difficult to find areas that would give either of the two results.

The CCA showed a difference between the dystrophic Cerradão and the mesotrophic Cerradão. In the literature, the difference between these two woodlands has been demonstrated by the presence of indicator species (Ratter, 1971; Ratter *et al.*, 1973; Furley & Ratter, 1988; Oliveira-Filho & Martins, 1991). The dystrophic Cerradão is widely found in the Cerrado biome and tends to be associated with Cerrado–forest transitions on poor and commonly sandy soils (Oliveira-Filho & Ratter, 2002). This is in contrast to what was found in the FLONA of Paraopeba, where the soil of the dystrophic Cerradão exhibited a high concentration of clay.

The CCA also shows that there is a high correlation between soil variables and vegetation (the abundance of species). Species that were correlated with a high concentration of Al and low soil fertility include obligate aluminium accumulators (Haridasan & Araújo, 1988; Haridasan, 2000). On the other hand some studies (Ratter, 1971, 1992; Ratter *et al.*, 1997; Oliveira-Filho & Ratter, 2002) have found species that are indicators of high soil fertility in Cerrado; some of these species (*Casearia rupestris*, *Dilodendron bipinnatum*, *Luehea divaricata*, *Magonia pubescens*, *Myracrodruon urundeuva* and *Protium heptaphyllum* (Aubl.) Marchand) were sampled in our study area and correlated with higher soil fertility and lower aluminium concentration.

The overall characteristics of mesotrophic Cerradão were confirmed by the analysis. This vegetation is related to higher soil fertility in the Cerrado and displays a characteristic flora and vegetation structure.

The soil attributes have influenced the diversity and structure of the community. The analysis confirms previous scientific observations indicating a relationship between the vegetation and soil fertility gradient in the Cerrado, well understood by native small agriculturists in the *sertão* (the Brazilian backlands) in the 1960s, and no doubt for centuries before (J. Ratter, pers. comm.).

In conclusion, the results of the vegetation and soil analyses of the present research conform almost exactly to those of previous works on differentiation of Cerrado communities. They agree with previous descriptions of mesotrophic and dystrophic Cerrado communities.

There is only one anomaly where the present results diverge from those expected. This is in the dense Cerrado *sensu stricto* on the Yellow Red Latosol, where soil analysis showed a dystrophic soil with low availability of Ca and Mg but the species with the highest importance value (10.57%) and number of individuals (114) was *Platypodium elegans*, one of the classic indicator species of mesotrophic Cerradão (Furley & Ratter, 1988). However, there is very little occurrence of other mesotrophic indicator species in the species list and those present are mainly of the weaker type (e.g. *Terminalia argentea*). A possible explanation is that one part of this plot is composed of more mesotrophic soil and the rest is dystrophic, and the subsequent analysis of mixed soil samples has distorted the overall figures. This situation has been observed in other localities, for example at Fazenda Palestina in the Federal District in an area consisting of a mosaic of patches of mesotrophic and dystrophic Cerradão below a limestone escarpment (J. Ratter, pers. comm.).

Acknowledgements

The authors would like to thank CNPq, CAPES and FAPEMIG for support and grants, and the Paraopeba National Forest Office (ICMBio-MMA/Brazilian Environmental Ministry) for permission for this study and for logistical support. We also thank the anonymous referees for their important contribution.

References

APG II [Angiosperm Phylogeny Group II] (2003). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Bot. J. Linn. Soc.* 141: 399–436.

Cientec (2002). Software Mata Nativa 2.0: *Sistema para Análise Fitossociológica, Elaboração de Inventários e Planos de Manejo de Florestas Nativas*. Viçosa – MG: Cientec.

Cole, M. M. (1986). *The Savannas: Biogeography and Geobotany*. London: Academic Press.

Costa, A. A. & Araújo, G. M. (2001). Comparação da vegetação arbórea de cerradão e de cerrado na Reserva do Panga, Uberlândia, Minas Gerais. *Acta Bot. Brasil.* 15: 63–72.

Eiten, G. (1972). The cerrado vegetation of Brazil. *Bot. Rev.* 38: 201–341.

EMBRAPA [Empresa Brasileira de Pesquisa Agropecuária] (1997). *Manual de métodos de análises de solo*. Rio de Janeiro: Ministério da Agricultura e do Abastecimento.

Felfili, J. M. & Silva-Júnior, M. C. (2001). *Biogeografia do Bioma Cerrado: estudo fitofisionômico da Chapada do Espigão Mestre do São Francisco*. Brasília: UNB.

Furley, P. A. (1999). The nature and diversity of neotropical savanna vegetation with particular reference to the Brazilian cerrados. *Global Ecol. Biogeogr.* 8: 223–241.

Furley, P. A. & Ratter, J. A. (1988). Soil resources and plant communities of the central Brazilian cerrado and their development. *J. Biogeogr.* 15: 97–108.

Goodland, R. (1969). Análise ecológica da vegetação de cerrado. In: Goodland, R. & Ferri, M. G., *Ecologia do cerrado*, pp. 61–161. Belo Horizonte, Itatiaia and São Paulo: EDUSP.

Goodland, R. (1971). Oligotrofismo e alumínio no cerrado. In: Ferri, M. G. (ed.) *III Simpósio sobre cerrado*, pp. 44–60. São Paulo: EDUSP.

GOODLAND, R. & POLLARD, R. (1973). The Brazilian cerrado vegetation: a fertility gradient. *J. Ecol.* 61: 219–224.

HARIDASAN, M. (1982). Aluminium accumulation by some cerrado native species of Central Brazil. *Plant and Soil* 65: 265–273.

HARIDASAN, M. (2000). Nutrição mineral de plantas nativas do cerrado. *Revista Brasil. Fisiol. Vegetal* 12: 54–64.

HARIDASAN, M. & ARAÚJO, G. M. (1988). Aluminium-accumulating species in two forest communities in the cerrado region of central Brazil. *Forest Ecol. Manag.* 24: 15–26.

IBGE [INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA] (2007). Mapa de Climas (http://mapas.ibge.gov.br/clima/viewer.htm; accessed 24 January 2007).

LOPES, A. S. & COX, F. R. (1977). Cerrado vegetation in Brazil: an edaphic gradient. *Agronom. J.* 69: 828–831.

MCCUNE, B. & MEFFORD, M. J. (1997). *PC-ORD: Multivariate Analysis of Ecological Data, version 3.0*. Gleneden Beach, OR: MjM Software Design.

MÉIO, B. B., FREITAS, C. V., JATOBÁ, L., SILVA, M. E. F., RIBEIRO, J. F. & HENRIQUES, R. (2003). Influência da flora das florestas Amazônica e Atlântica na vegetação de cerrado. *Revista Brasil. Bot.* 26: 437–444.

MUELLER-DOMBOIS, D. Y. & ELLENBERG, M. (1974). *Aims and Methods in Vegetation Ecology*. New York: Wiley & Sons.

NERI, A. V. (2007). *Gradiente pedológico–vegetacional de Cerrado em Paraopeba, MG*. DSc thesis, Universidade Federal de Viçosa, Viçosa.

NERI, A. V., CAMPOS, E. P., DUARTE, T. G., MEIRA NETO, J. A. A., SILVA, A. F. & VALENTE, G. E. (2005). Regeneração de espécies nativas lenhosas sob plantio de *Eucalyptus* em área de Cerrado na Floresta Nacional de Paraopeba, MG, Brasil. *Acta Bot. Brasil.* 19: 369–376.

OLIVEIRA-FILHO, A. T. & MARTINS, F. R. (1991). A comparative study of five cerrado areas in southern Mato Grosso, Brazil. *Edinburgh J. Bot.* 48: 307–322.

OLIVEIRA-FILHO, A. T. & RATTER, J. A. (1995). A study of the origin of Central Brazilian forests by the analysis of plant species distribution patterns. *Edinburgh J. Bot.* 52: 141–194.

OLIVEIRA-FILHO, A. T. & RATTER, J. A. (2002). Vegetation physiognomies and woody flora of the Cerrado biome. In: OLIVEIRA, P. S. & MARQUIS, R. J. (eds) *The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna*, pp. 91–121. New York: Columbia University Press.

OLIVEIRA-FILHO, A. T., SHEPHERD, G. J., MARTINS, F. R. & STUBBLEBINE, W. H. (1989). Environmental factors affecting physiognomic and floristic variation in an area of cerrado in central Brazil. *J. Trop. Ecol.* 5: 413–431.

RATTER, J. A. (1971). Some notes on two types of Cerradão occurring in North Eastern Mato Grosso. In: FERRI, M. G. (Co-ord.) *III Simpósio Sobre o Cerrado*, pp. 100–102. Brazil: Universidade de São Paulo.

RATTER, J. A. (1992). Transitions between cerrado and forest vegetation in Brazil. In: FURLEY, P. A., PROCTOR, J. & RATTER, J. A. (eds) *Nature and Dynamics of Forest–Savanna Boundaries*, pp. 51–76. London: Chapman & Hall.

RATTER, J. A., RICHARDS, P. W., ARGENT, G. & GIFFORD, D. R. (1973). Observations on the vegetation of northeastern Mato Grosso I. The woody vegetation types of the Xavantina–Cachimbo Expedition area. *Philos. Trans., Ser. B* 266: 449–492.

RATTER, J. A., ASKEW, G. P., MONTGOMERY, R. F. & GIFFORD, D. R. (1977). Observações adicionais sobre o cerradão de solos mesotróficos no Brasil Central. In: FERRI, M. G. (Co-ord.) *IV Simpósio sobre o Cerrado*, pp. 303–316. São Paulo, Brazil: Ed. Universidade de São Paulo.

Ratter, J. A., Askew, G. P., Montgomery, R. F. & Gifford, D. R. (1978). Observations on forest of some mesotrophic soils in Central Brazil. *Revista Brasil. Bot.* 1: 47–58.

Ratter, J. A., Ribeiro, J. F. & Bridgewater, S. (1997). The Brazilian Cerrado vegetation and threats to its biodiversity. *Ann. Bot.* 80: 223–230.

Ratter, J. A., Bridgewater, S., Ribeiro, J. F., Fonsêca-Filho, J., Rodrigues da Silva, M., Milliken, W. *et al.* (2011). Analysis of the Floristic Composition of the Brazilian Cerrado IV: Presentation of a Revised Database of 367 Areas (http://cerrado.rbge.org.uk).

Ribeiro, J. F. & Haridasan, M. (1990). Comparação fitossociológica de um cerrado e um cerradão em solos distróficos no Distrito Federal. In: *Congresso Nacional de Botânica, 35*, pp. 342–353. 1984, Manaus. Anais. Brasília: IBAMA.

Ribeiro, J. F., Silva, J. C. S. & Batmanian, G. J. (1985). Fitossociologia de tipos de cerrado em Planaltina-DF. *Revista Brasil. Bot.* 8: 131–142.

Rizzini, C. T. (1992). *Tratado de fitogeografia do Brasil*, 2nd edition. Rio de Janeiro: Âmbito Cultural.

Rosot, N. C., Amaral-Machado, S. & Figueiredo Filho, A. (1982). Análise estrutural de uma floresta tropical como subsídio básico para elaboração de um plano de manejo florestal. V. 16 P. 1. In: *Anais do Congresso Nacional Sobre Essências Nativas*, pp. 468–490. Campos do Jordão, Silvicultura em São Paulo – Instituto Florestal.

Ruggiero, P. G. C., Batalha, M. A., Pivello, V. R. & Meireles, S. T. (2002). Soil–vegetation relationships in cerrado (Brazilian savanna) and semideciduous forest, Southeastern Brazil. *Plant Ecol.* 160: 1–16.

Silva-Júnior, M. C. (1984). *Composição florística, estrutura e parâmetros fitossociológicos do cerrado e sua relação com o solo na Estação Florestal de Experimentação de Paraopeba-MG.* Masters thesis, Universidade Federal de Viçosa, Viçosa, Brazil.

Silva-Júnior, M. C. (1987). Relações entre parametros do solo e da vegetação de cerrado na Estação Florestal de Experimentação de Paraopeba, MG. *Revista Brasil. Bot.* 10: 125–137.

SNUC [Sistema Nacional de Unidades de Conservação da Natureza] (2000). Lei N° 9.985, de 18 de julho de 2000. MMA/SBF.

Souza, V. C. & Lorenzi, H. (2005). *Botânica Sistemática guia ilustrado para identificação das Famílias de Angiosermas da flora brasileira, baseado em APG II.* Nova Odesa: Instituto Plantarum.

Vanzolini, P. E. (1963). Problemas faunísticos do cerrado. In: Ferri, M. G. (ed.) *Simpósio sobre o Cerrado*, pp. 211–232. São Paulo: Ed. Universidade de São Paulo.

Received 6 January 2011; accepted for publication 4 October 2011