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Ground-dwelling ant Assemblages and Soil Attributes Relationship in Roraima Savanna, Brazilian Amazon

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Abstract

Ants are among the most abundant soil invertebrates and provide important ecosystem services. We evaluated the relationship between ant assemblages and soil attributes in a Brazilian savanna area within the Amazon biome (Roraima State). Ground ants were sampled using baits and pitfall traps across five pedoenvironments: *Latossolo Amarelo*, *Latossolo Vermelho*, *Argissolo Vermelho-Amarelo*, *Argissolo Amarelo*, and *Gleissolo* Háplico. In total, 48 species, 22 genera, and seven subfamilies were recorded, with *Pheidole* (Myrmicinae) exhibiting the highest richness. The ant assemblage in *Gleissolo Háplico* showed high dissimilarity compared to the other pedoenvironments, characterized by lower richness and abundance of key groups like Dolichoderinae, *Dorymyrmex*, *Nylanderia*, and *Tapinoma*. This pattern was mainly attributed to the high levels of soil moisture, organic matter, and extractable acidity, resulting from Gleissolo's location at the lowest point of the toposequence. These findings can help identify bioindicators for environmental quality and support conservation measures in this savanna threatened by agricultural expansion.

Keywords: Ants distribution, Brazilian savanna, edaphic attributes, Formicidae, Insecta.

1. INTRODUCTION AND OBJECTIVES

Species distribution in ecosystems is governed by a complex interplay of physical barriers, habitat fragmentation, and various abiotic factors, including soil type and vegetation cover, and also biotic factors, including competition and symbiosis (Pearson & Dawson, 2003). Understanding these distribution patterns remains a critical ecological challenge, particularly as agricultural expansion across Latin America continues to drive high levels of habitat fragmentation (Moulatlet et al., 2023; Krögen & Nygren, 2020). This is especially evident in the Cerrado, or Brazilian savanna, which constitutes one of Brazil's largest natural resource frontiers alongside the Amazon (Krögen & Nygren, 2020).

Rapid deforestation driven by soybean and pasture expansion has led to severe environmental degradation and soil erosion (Krögen & Nygren, 2020; Nunes & Castro, 2021). Due to its high biodiversity, endemism, and advanced degradation, the Cerrado is recognized as a global conservation hotspot (Kiataki et al., 2022). Consequently, investigating the links between species distribution and soil attributes is essential for understanding pre-disturbance patterns and guiding recovery efforts.

Ants are ideal bioindicators for such studies; they are the most abundant soil invertebrates (Aguilar-Colorado & Rivera-Chávez, 2023), possess high biomass, and respond rapidly to climate change, fragmentation, or invasive species (Longino et al., 2002). Additionally, ants are easily sampled (Magalhães et al., 2022) and serve as vital dispersal agents for the maintenance of Cerrado ecosystems (Fagundes et al., 2022). Ants have been used in the Cerrado to indicate degrees of human degradation (Ramos et al., 2003), vertical stratification (Campos et al., 2008), natural regeneration (Tibcherani et al., 2020), conversion of natural habitats into anthropogenic areas (Carvalho et al., 2022), and fire effects (Costa et al, 2022). Despite this, the specific relationship between ant assemblages and different pedoenvironments (soil classes) remains poorly understood in Cerrado native ecosystems (Costa et al., 2010; Silva et al., 2017).

Based on these gaps, this study evaluated the relationship between soil attributes and ground-dwelling ant assemblages across different pedoenvironments in an Amazonian Cerrado area. The study tested the hypothesis that the richness, abundance, and composition of these ant assemblages do not differ significantly across different pedoenvironments.

2. MATERIALS AND METHODS

2.1. *Study area*

The study was conducted at the 498-ha Monte Cristo Experimental Field, located on the Cauamé Campus (02°56’47”N, 60°43’02”W) 15 km north of Boa Vista, Roraima, Brazil. The site is part of the Biodiversity Research Program (PPBio) and features 12 permanent 250 m transects installed along contour lines to minimize the effects of topographic variation (Magnusson et al., 2005). Regional climate is classified as Aw (tropical wet and dry), characterized by minimum temperatures ≥ 18ºC (Alvares et al., 2013). Annual precipitation averages 1,925 mm, with approximately 82% occurring during the rainy season from April to September, peaking in June (rainy season) (Barni et al., 2020). The relief is predominantly flat to gently undulating, with slopes between 1.5% and 8% and elevations ranging from 60 to 160 m (Benedetti et al., 2011).

The vegetation belongs to a disjoint savanna patch of approximately 43,281 km² within the Amazon forest biome, locally known as “lavrado” (Nascimento and Carvalho, 2016). The flora is dominated by herbaceous plants, followed by subshrubs, trees, and shrubs (Araújo et al., 2017). These elements form a mosaic without a true canopy, where the distribution of woody plants is largely determined by soil conditions, which defines distinct pedoenvironments along the toposequence (Benedetti et al., 2011).

The lowest areas contain hydromorphic *Gleissolo Háplico* (GS) (Entisol) whose vegetation lacks woody individuals (Barbosa et al., 2012) and is dominated by grassy pioneer vegetation, mostly Cyperaceae and also Poaceae (Benedetti et al., 2011), normally submerged for one to four months during the wet season and the palm *Mauritia flexuosa* L. (Araújo et al., 2017). Conversely, the well-drained upper portions support dry shrubby savanna with trees like *Curatella americana* L., *Byrsonima* spp., and *Bowdichia virgilioides* Kunth (Benedetti et al., 2011; Barbosa et al., 2012). These soils include *Latossolo Amarelo* (YL) and *Latossolo Vermelho* (RL), both Oxisols, besides *Argissolo Vermelho-Amarelo* (RYA) and *Argissolo Amarelo* (YA), both Ultisols (Benedetti et al., 2011).

2.2. *Ant assemblages*

Ground-dwelling ants were sampled every 25 m along 250-m transects, resulting in 10 sampling points per pedoenvironment (50 units total). Each point utilized a composite sampling design combining a pitfall trap and an adjacent sardine bait. This dual-method approach is recommended to provide a more comprehensive characterization of ant assemblages (Longino et al., 2002; Lopes & Vasconcelos, 2008; Oliveira et al., 2009; Costa et al., 2010; Miranda et al., 2022). For analysis, the results from both capture techniques were combined into a single sampling unit per point.

The pitfall traps consisted of 500-mL plastic containers installed flush with the ground level for 48 hours (Campos et al., 2008). Containers were partially filled with a water, detergent, and salt solution to kill and preserve the specimens (Boscardin et al., 2012). Sardine baits (approximately 4 g) were placed on white paper (10 x 10 cm) during the morning (between 8:00 and 11:00 AM), and ants observed on or under the paper were manually collected (Lopes & Vasconcelos, 2008) 40 minutes after the initial bait exposure (Oliveira et al., 2009; Costa et al., 2010) and placed into identified plastic bags.

Sampling occurred in non consecutive six days between December 2010 and January 2011, under uniform climatic conditions. In the laboratory, ants were identified to genus and then sorted into species or morphospecies using taxonomic keys (Baccaro, 2006; Baccaro et al., 2015) and reference collections. Voucher specimens were deposited in the Invertebrate Collection of the Instituto Nacional de Pesquisas da Amazônia (INPA).

Abundance was determined using the relative frequency of occurrence (RFi) (Equation 1) (Ramos et al., 2003; Campos et al., 2008; Tibcherani et al., 2020; Souza & Araújo, 2020; Miranda et al., 2022) which is more appropriate than the raw number of individuals for ant studies, as it minimizes the influence of foraging habits and varying nest sizes on the data (Romero & Jaffe, 1989). Presence in all units represented maximum abundance (100%) and capture in a single unit represented the minimum (10%).

$$RFi = \left(\frac{AFi}{n}\right) * 100 \; (Equation\ 1)$$

in which: RF_i = relative frequency of occurrence of taxon; Af_i = absolute frequency of occurrence (number of sampling units in which individuals of taxon *i* were recorded); n = total number of sampling units.

Average Richness (AR_i) (Equation 2) and Total Richness (TR_i) were estimated using identification across three taxonomic levels: subfamily, genus, and species.

$$ARi = \frac{(\sum_{i=1}^{n} Si)}{n} \; (Equation\ 2)$$

in which: AR_i = average richness of taxa at the identified level (subfamily, genus, or species); S_i = number of taxa at the identified level (subfamily, genus, or species) observed in the *i*-th sampling unit; n = total number of sampling units.

Sampling effort completeness for ant species richness was evaluated through species accumulation curves (Longino et al., 2002; Ramos et al., 2003; Campos et al., 2008; Lopes & Vasconcelos, 2008). These curves were developed and organized using Microsoft Excel spreadsheets.

2.3. Soil degree of compaction and soil moisture content

Soil degree of compaction (SDC) and soil moisture content (SMC) were determined at five random points within each pedoenvironment at depths of 0-10 cm and 0-5 cm, respectively. SDC was evaluated by measuring soil resistance to penetration (MPa) utilizing a hydraulic penetrometer with a 10 MPa capacity, featuring a dynamometric ring, an analog dial indicator, and a 6.33 cm^2 conical tip. SMC was determined as soil gravimetric moisture content ($g\ kg^{-1}$) after samples were oven-dried (105 °C, 24 h) (Sousa et al., 2022).

2.4. Statistical data analyzes

2.4.1. Ant assemblages, soil degree of compaction, and soil moisture content individually

Data for ant taxa (abundance and richness) and soil attributes were $\ln(X_i) + 1$ transformed to standardize values, minimize distortions from dominant species (Rodrigues et al., 2007), and strengthen statistical robustness (Greenacre et al., 2022).

We compared the mean values of abundance and richness for taxa at each level of identification (subfamily, genus, or species), soil degree of compaction, and soil moisture content between the pedoenvironments using One-way ANOVA. If a significant difference ($p < 0.05$) was detected among the pedoenvironments, the mean values were compared using the parametric LSD post-hoc test, provided that the assumption of homogeneity of variances, as evaluated by Levene's test, was met. Otherwise, the non-parametric Kruskal-Wallis test was used to compare the means. These univariate analyses were performed using STATISTICA software version 14.0.0.15.

2.4.2. Relationship between ant assemblage and soil attributes

Soil attributes included SDC, SMC, and those obtained from a previous study at 0-10 cm depth, such as texture, organic matter, density, porosity, pH, and fertility (Benedetti et al., 2011).

Principal Component Analysis (PCA) was performed to differentiate pedoenvironments and explore associations between ant assemblages and soil variables (Silva et al., 2017). PCA simplifies complex, intercorrelated variables into uncorrelated principal components (Hongyu et al., 2015; Greenacre et al., 2022), revealing patterns often missed by univariate methods (Ribeiro et al., 2018). Subfamilies or genera represented by single species were excluded to avoid redundancy. A preliminar PCA selected variables with correlations ≥ 0.70 absolute values with the first component (PC1) (Castro & Silva, 2024), followed by a definitive PCA visualized via biplot (Greenacre et al., 2022).

Non-parametric One-way Analysis of Similarities (ANOSIM) tested differences in ant assemblage composition between pedoenvironments using Euclidean distance (Westerbom et al., 2018). Relationship intensity was evaluated by the R-value, ranging from strong ($R > 0.75$) to scarcely discernible ($R < 0.25$) (Thompson et al., 2025). Significant ANOSIM results triggered Hierarchical Cluster Analysis (HCA) and Similarity Percentage Analysis (SIMPER). HCA utilized Euclidean distance and the single-linkage method to measure dissimilarity, computing a standardized linkage distance (LD) (Equation 3) where 0% indicates maximum similarity and 100% maximum dissimilarity (Matamoros-Jiménez & Hernández-Vega, 2021).

$$LD = \left(\frac{dlink}{dmax}\right) * 100\ (Equation\ 3)$$

in which: LD = standardized linkage distance; dlink = actual observed linkage distance (dissimilarity) calculated between two pedoenvironments; dmax = maximum possible linkage distance (dissimilarity) between two pedoenvironments.

Finally, SIMPER analysis, based on Euclidean distance, identified the specific taxa primarily responsible for the dissimilarity between pedoenvironments. PCA and HCA were executed using STATISTICA version 14.0.0.15, while ANOSIM and SIMPER were conducted using Past version 4.13.

3. RESULTS AND DISCUSSION

3.1. Ant assemblage

3.1.1. Ant assemblage assessment: general overview

A total of 9,184 individuals were collected, representing 48 species, 22 genera, and seven subfamilies. The subfamily Myrmicinae exhibited the highest richness for both genera (12) and species (27), accounting for approximately 55% and 56% of the total, respectively (Table 1). Regarding genera richness, the highest number of species (eight, 17% of total) was observed in *Pheidole*, followed by *Camponotus* and *Solenopsis* (six species, 13% of total, each), besides *Crematogaster* and *Dorymyrmex* (three species, 6% of total, each). These five genera accounted for 26 species (54% of total).

Table 1. Abundance (%) of ant species assemblages across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon, Boa Vista, Roraima State, Brazil[a].

Subfamily	Species	AV	RYA	YA	YL	RL	GS	General
Dolichoderinae	*Dorymyrmex bicolor*	Dobi	80 A	80 A	30 AB	20 B	0 B	80
	Dorymyrmex goeldii	Dogo	100 A	80 A	100 A	80 A	0 B	100
	Dorymyrmex richteri	Dori	100 A	50 BC	90 AB	50 ABC	0 C	100
	Forelius pruinosus	Fopr	0	0	20	10	0	20
	Tapinoma melanocephalum	Tame	10	0	10	0	0	10
	Tapinoma sp1	Ta01	100 A	100 A	90 B	100 AB	0 C	100
Dorylinae	*Labidus praedator*	Lapr	10	0	0	0	0	10
Ectatominae	*Ectatoma ruidum*	Ecru	30	20	60	50	20	60
Formicinae	*Brachymyrmex* sp1	Br01	50	20	10	20	10	50
	Brachymyrmex sp2	Br02	50	0	50	20	30	50
	Camponotus ager	Caag	50	30	30	20	0	50
	Camponotus atriceps	Caat	0	0	10	0	0	10
	Camponotus crassus	Cacr	90	40	40	20	10	90
	Camponotus fastigatus	Cafa	0	0	0	0	10	10
	Camponotus leydgi	Cale	70 AB	10 B	20 AB	80 A	20 AB	80
	Camponotus novogranadensis	Cano	100 A	100 AB	100 AB	80 AB	30 B	100
	Nylanderia guatemalensis	Nygu	100 A	100 A	80 AB	80 A	0 B	100
	Nylanderia sp1	Ny01	0	0	0	10	0	10
Myrmicinae	*Acromyrmex* sp1	Ac01	30	10	30	0	0	30
	Atta cephalotes	Atce	20	0	0	0	0	20
	Atta sexdens	Atse	30	10	0	40	0	40
	Cyphomyrmex peltatus	Chpe	0	0	0	0	10	10
	Crematogaster abstinens	Crab	60 B	60 B	40 B	80 A	90 A	90
	Crematogaster jardinero	Crja	90 A	50 AB	60 AB	90 A	10 B	90
	Crematogaster sp15	Cr15	10	0	0	0	0	10
	Kalathomyrmex emeryi	Kaem	10	10	0	10	0	10
	Myrmicocrypta sp1	My01	0	10	0	0	0	10
	Ochetomyrmex brasiliensis	Ocbr	0	0	0	0	10	10
	Pheidole radoszkowskii	Phra	60 B	60 B	30 B	30 B	80 A	80
	Pheidole vorax	Phvo	10	0	0	0	0	10
	Pheidole sp1	Ph01	0	0	10	0	0	10
	Pheidole sp12	Ph12	0	0	10	0	0	10
	Pheidole sp15	Ph15	0	0	0	10	0	10
	Pheidole sp32	Ph32	10	0	20	0	0	20
	Pheidole sp75	Ph75	60	60	60	50	10	60
	Pheidole sp105	Ph105	30 B	50 B	20 B	20 B	90 A	90
	Pogonomyrmex naegelii	Pona	60	50	40	40	40	60
	Solenopsis brevicornis	Sobr	0	10	0	0	10	10
	Solenopsis castor	Soca	0	0	0	0	0	10
	Solenopsis clytemnestra	Socl	100 A	80 B	50 B	40 B	40 B	100
	Solenopsis saevissima	Sosa	10	10	10	20	0	20
	Solenopsis sp3	So03	0	0	0	20	30	30
	Solenopsis sp6	So06	0	0	10	0	10	10
	Trachymyrmex sp1	Tr01	0	0	0	10	0	10
	Wasmannia auropunctata	Waau	30	20	30	40	0	40
Ponerinae	*Hypoponera* sp1	Hy01	0	0	0	0	10	10
Pseudomyrmicinae	*Pseudomyrmex flavidulus*	Psfl	40	20	10	10	10	40
	Pseudomyrmex sp5	Ps05	70 A	30 B	30 AB	70 AB	50 AB	70

[a] Average values from 10 sampling points followed by different letters indicate significant differences ($p < 0.05$) between the pedoenvironments, using the parametric LSD test or the non-parametric Kruskal-Wallis test. AV: abbreviation.

Maximum abundance, representing a 100% frequency of occurrence, was recorded for only 16 species (33% of the total) belonging to nine genera (41% of total) across four subfamilies (57% of total) (Figure 1). The maximum abundance set comprised seven species from four genera (*Pheidole*, *Crematogaster*, *Pogonomyrmex*, and *Solenopsis*) of Myrmicinae; four species from two genera (*Camponotus* and *Nylanderia*) of Formicinae; four species from two genera (*Dorymyrmex* and *Tapinoma*) of Dolichoderinae; and one single species from genus *Pseudomyrmex* of Pseudomyrmicinae (Table 1).

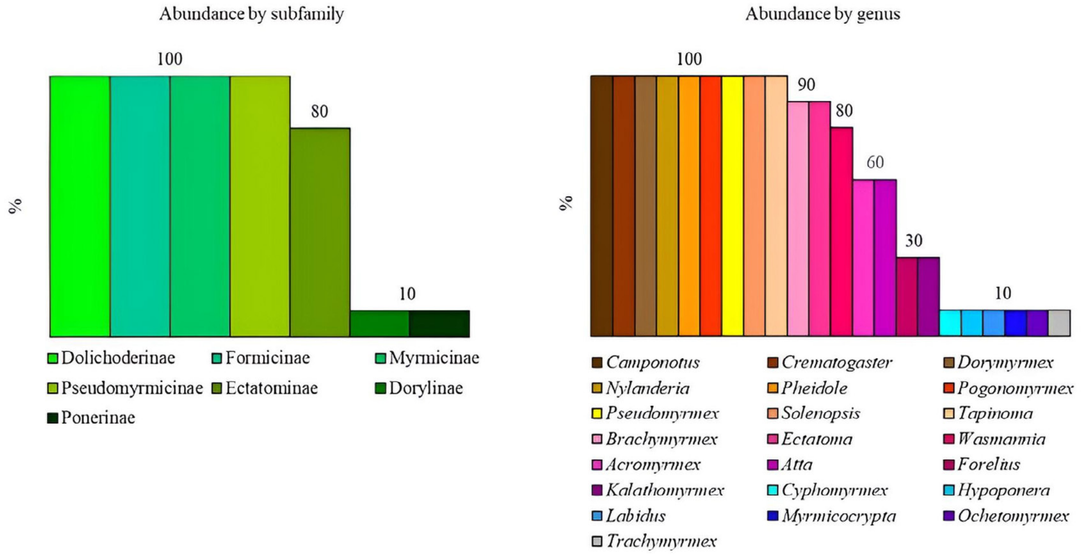

Figure 1. Abundance (%) of ant subfamilies, genera, and species across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

Generalism, competitive ability, and resilience are advantageous characteristics that explain the prominence of these genera in the study (Franco & Feitosa, 2018). *Crematogaster*, *Pheidole*, *Solenopsis*, and *Camponotus* are largely generalists, exploiting diverse resources through large colonies, aggressive interspecific behavior, and efficient patrolling (Silvestre et al., 2003; Fernández et al., 2021). The predominance of *Pheidole* is expected, as it is the most species-rich genus globally, though many species in South American savannas remain undescribed (Casadei-Ferreira et al., 2020). In the Cerrado biome, high species richness of such genera is a common soil pattern across various Brazilian states (Ramos et al., 2003; Silvestre et al., 2003; Campos et al., 2008; Costa et al., 2010; Miranda et al., 2022; Costa et al., 2025).

The high abundance of *Tapinoma* sp1 is attributed to its high ecological performance, characterized by a broad dietary spectrum, the ability to disperse over long distances via flight, defensive secretions toxic to all ant species, and supercolonies organization (Seifert et al., 2024). *Dorymyrmex* is primarily associated with savanna rather than forest phytophysiognomies in some Brazilian states (Costa et al., 2025).

Conversely, low richness (frequency of occurrence between 10-30%) was observed for 22 species (46% of total) belonging to 15 genera (68% of total) across five subfamilies (71% of total) (Figure 1). This group included three species from two genera (*Atta* and *Solenopsis*) of Myrmicinae and one species from the genus *Tapinoma* of Dolichoderinae, each with 20% of relative abundance; 10 species from seven genera of Formicinae, a single species from the genus *Labidus* of Dorylinae, and one species from the genus *Hypoponera* of Ponerinae, each with only 10% of relative abundance (Table 1). Such rarity often stems from specific microclimatic requirements or limited foraging capacities related to small body size, while only a few species are rare due to their restricted geographic distribution (Longino et al., 2002; Jeliazkov et al., 2022).

To overcome "methodological effects" in detecting rare species, combining capture methods is essential to provide a more complete inventory of ant assemblage (Longino et al., 2002; Tibcherani et al., 2018; Souza & Araújo, 2020). While sardine baits and pitfall traps captured similar individual numbers (4,741 and 4,443 individuals, respectively), pitfall traps detected higher richness than sardine baits (47 vs. 27 species). Twenty species were captured exclusively by pitfall, while *Forelius pruinosus* was exclusive to sardine baits. Integrated methods provide a more complete inventory, as environmental conditions, such as seasonality, soil texture, flooding, vegetation, and litter influence capture efficiency (Longino et al., 2002; Lopes & Vasconcelos, 2008; Oliveira et al., 2009; Costa et al., 2010; Tibcherani et al., 2018, 2020; Souza & Araújo, 2020; Miranda et al., 2022).

Finally, the underrepresentation of *Cyphomyrmex*, *Hypoponera*, *Myrmicocrypta*, and *Trachymyrmex* is linked to their cryptic, hypogaeic habits, and small colony sizes, which are more typical of dense forests (Silvestre et al., 2003). Similarly, *Kalathomyrmex emeryi* is rarely collected due to its restriction to specific dry habitats (Klingenberg & Brandão, 2009), while *F. pruinosus* typically builds small, inconspicuous nests (Koptur & Keeler, 2024).

3.1.2. Ant assemblage comparison across pedoenvironments

Total subfamily richness remained stable among pedoenvironments (5-6), while total genus (14-16) and species richness (27-32) showed minor variations across RYA, YA, YL, and RL (Figure 2). However, the GS pedoenvironment exhibited lower total richness for both genus (11) and species (22), largely due to the absence of 26 species (54% of the total), including all representatives of Dolichoderinae and Dorylinae, 15 species of Myrmicinae, and four species of Formicinae (Figure 2, Table 1).

GS expressed significantly lower values of ants richness (subfamilies, genera, and species), compared to well-drained pedoenvironments (RYA, YA, YL, and RL) (Figure 2). Regarding distribution, 14 species (29% of total) were present in all pedoenvironments, whereas 16 species (33% of total) were restricted to a single area, often as singletons or doubletons with low frequency of occurrence. Species accumulation curves indicated sufficient sampling effort in YA, RL, and GS as they reached an asymptote, whereas RYA and YL curves did not stabilize, suggesting potential for additional records (Figure 3).

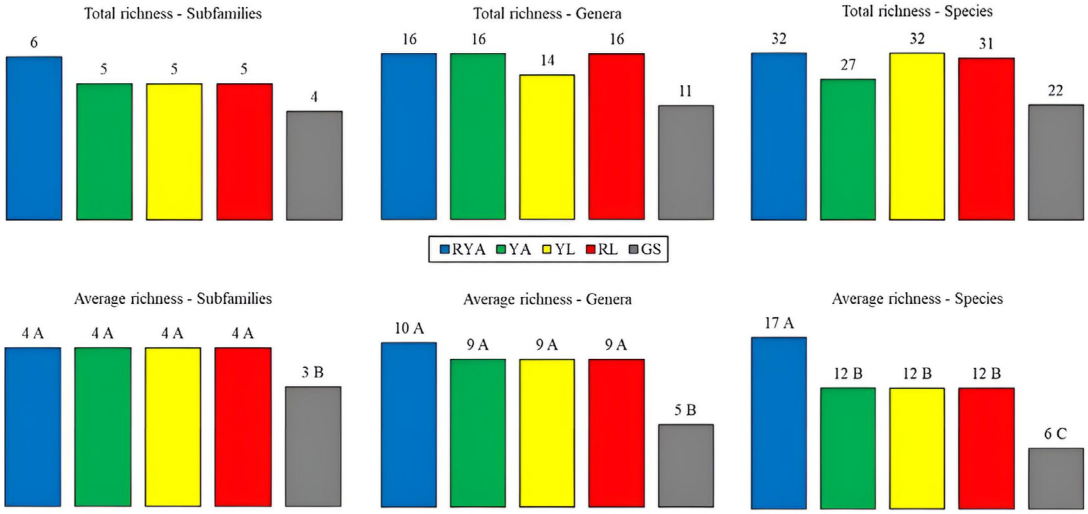

Figure 2. Total and average taxonomic richness (subfamilies, genera, and species) of the ant assemblage across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

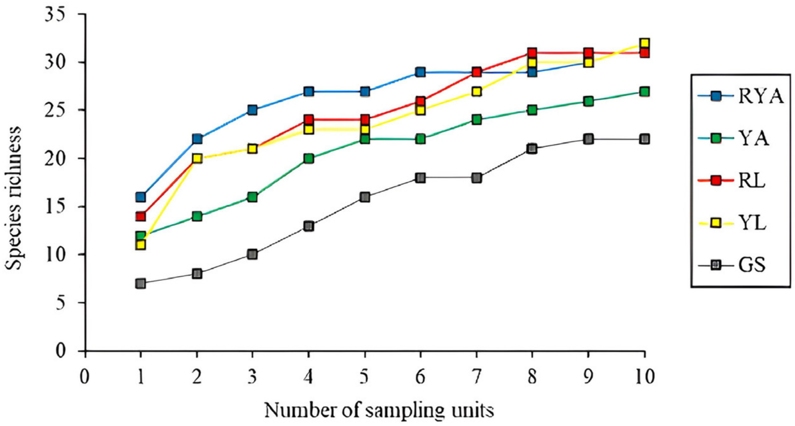

Figure 3. Ant species accumulation curve across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

Significant differences in abundance were observed, with GS showing lower values for Dolichoderinae, *Dorymyrmex*, *Nylanderia*, and *Tapinoma* compared to well-drained pedoenvironments (Figure 4). Ectatominae presented lower abundance in GS and YA, compared to RYA, and nine species (19% of the total) exhibited lower abundance in GS compared to at least one other pedoenvironment. Conversely, *Pheidole radoszkowskii* showed higher abundance in GS compared to YL and RL.

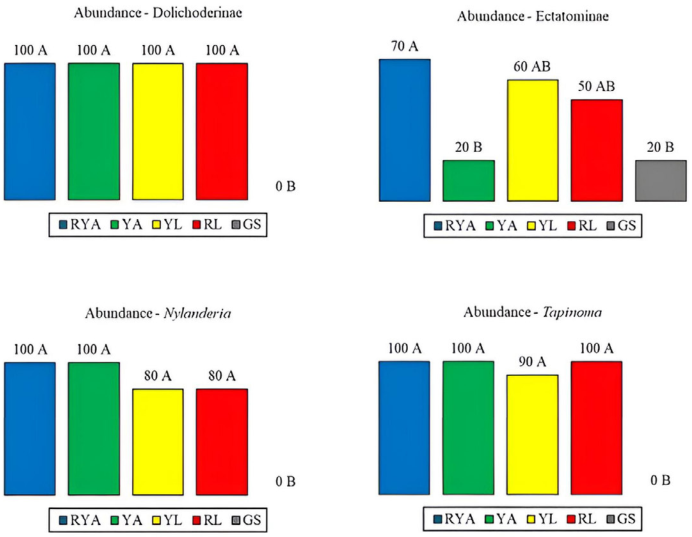

Figure 4. Abundance of selected ant taxa (Dolichoderinae, Ectatominae, *Dorymyrmex*, *Nylanderia*, and *Tapinoma*) across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

Variations in ant assemblage richness and abundance are influenced by sampling effort (Falcão et al., 2016), collection methods (Lauchande et al., 2024), trap spacing (Longino et al., 2002; Baccaro et al., 2011), and capture efficiency (Costa et al., 2010). Environmental factors such as climatic seasonality (Miranda et al., 2022), habitat complexity (Costa et al., 2025), and anthropogenic disturbance (Tibcherani et al., 2018) also play critical roles. Additionally, activity periods (Lancellotti et al., 2022; Domingos-Melo et al., 2022) and sampling area size (Siqueira & Silva, 2024) affect captures. In this study, the significant impact of the pedoenvironment on ant assemblages was primarily driven by relief, soil attributes, and plant richness.

3.1.3. Soil degree of compaction and soil moisture content

Higher soil degree of compaction (SDC) values were recorded in YA, RYA, and YL (0.94-0.97 MPa), followed by RL (0.56 MPa), while GS showed the lowest value (0.33 MPa) (Figure 5). Conversely, the highest soil moisture content (SMC) was found in GS (27.81 g kg^{-1}) and the lowest in RYA (14.24 g kg^{-1}). This inverse relationship suggests that lower compaction increases macroporosity and moisture availability (Silva et al., 2022), complemented by the direct influence of the water table on Gleissolos in lower topographic positions.

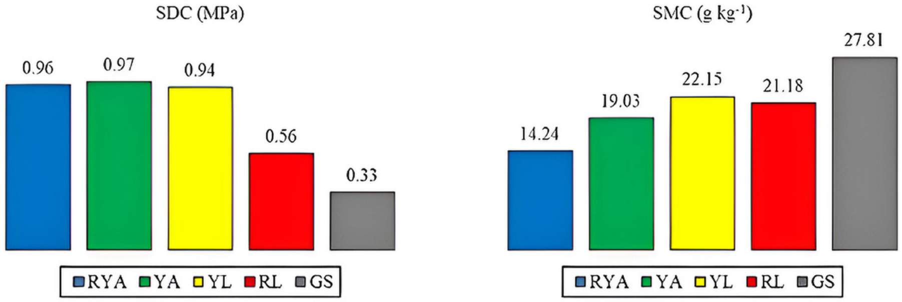

Figure 5. Soil degree of compaction (SDC, 0-10 cm depth) and soil moisture content (SMC, 0-5 cm depth) across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

3.1.4. Relationship between ant assemblages and soil attributes

Based on a preliminary PCA, only 19 variables, 11 from ant assemblages and eight soil attributes, exhibited strong correlation coefficients (absolute value ≥ 0.70) with PC1 (Table 2) and were retained for the definitive analysis (Castro & Silva, 2024). The definitive PCA generated 11 principal components (PCs) explaining 100% of the total variance; however, only PC1, PC2, and PC3 met Kaiser's criterion with eigenvalues > 1.00 (Kaiser, 1974). These three PCs explained approximately 86% of the accumulated variance, which is considered highly acceptable (Batista & Gomes, 2021). PC1 was the most significant, explaining nine to 14 times more variance than PC2 or PC3, respectively, thus representing the maximum intensity of variable influence and identifying result patterns efficiently (Schaefer et al., 2021; Greenacre et al., 2022; Castro & Silva, 2024).

Table 2. Correlation coefficients of the variables (VR) with the first Principal Component (PC1) of the preliminary PCA (Principal Component Analysis) for data obtained across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil. Coefficients with strong intensity (≥ 0.70 in absolute value) are highlighted in bold.

VR	PC1	VR	PC1	VR	PC1
Dolichoderinae	**0.94**	*C. leydigi*	0.26	*Solenopsis* sp3	-0.38
Formicinae	0.58	*C. novogranadensis*	**0.71**	*Solenopsis* sp6	-0.13
Pseudomyrmicinae	0.23	*N. guatemalensis*	**0.81**	*Trachymyrmex* sp1	0.02
Atta	0.33	*Nylanderia* sp1	0.05	*W. auropunctata*	0.32
Brachymyrmex	0.12	*Acromyrmex* sp1	0.29	*Hypoponera* sp1	-0.28
Camponotus	0.65	*A. cephalotes*	0.22	*P. flavidulus*	0.16
Crematogaster	0.13	*A. sexdens*	0.24	*Pseudomyrmex* sp5	0.08
Dorymyrmex	**0.94**	*C. abstinens*	-0.32	Average richness of Subfamilies	**0.76**
Nylanderia	**0.80**	*C. jardinero*	-0.29	Average richness of Genera	**0.80**
Pheidole	-0.23	*Crematogaster* sp15	0.55	Average richness of Species	**0.82**
Pseudomyrmex	0.16	*C. peltatus*	0.14	Total clay content	**0.90**
Solenopsis	0.36	*K. emeryi*	0.10	Silt content	0.15
Tapinoma	**0.89**	*Myrmicocrypta* sp1	0.05	Total sand content	**-0.88**
D. bicolor	0.49	*O. brasiliensis*	-0.30	Soil degree of compaction	**0.89**
D. goeldii	**0.81**	*P. radoszkowskii*	-0.27	Soil moisture content	**-0.82**
D. richteri	0.68	*P. vorax*	0.19	Soil organic matter content	**-0.77**
F. pruinosus	0.13	*Pheidole* sp1	0.07	Soil bulk density	-0.28
T. melanocephalum	0.15	*Pheidole* sp12	0.10	Soil particle density	0.17
Tapinoma sp1	**0.88**	*Pheidole* sp15	0.03	Total soil porosity	0.46
L. praedator	0.19	*Pheidole* sp32	0.17	pH (H_2O)	-0.23
E. ruidum	0.16	*Pheidole* sp75	0.40	Ca^{2+}	-0.25
Brachymyrmex sp1	0.24	*Pheidole* sp105	-0.49	Mg^{2+}	0.01
Brachymyrmex sp2	0.15	*P. naegelii*	0.09	K^+	**-0.84**
C. ager	0.38	*S. brevicornis*	-0.18	Sum of bases	-0.35
C. atriceps	0.08	*S. castor*	0.05	Al^{3+}	0.66
C. crassus	0.41	*S. clytemnestra*	0.32	H+Al	**-0.73**
C. fastigatus	-0.25	*S. saevissima*	0.17	P	**-0.90**

Relevant soil attributes influencing ant assemblages included available phosphorus, exchangeable potassium, degree of compaction, clay, organic matter, sand, moisture, and extractable acidity. PCA proved effective in identifying these key variables while suggesting that others, such as silt, density, and pH, could be excluded (Table 3) in future studies to save resources without significant information loss (Hongyu et al., 2015; Zhang et al., 2023).

The relationship between PC1 and PC2 (explaining approximately 81% of the accumulated variance) indicated the formation of two groups. The first group, comprising RYA, YA, YL, and RL, was positioned on the positive side (on the right) of the PC1 axis (Figure 6A). Vectors for Dolichoderinae, *Dorymyrmex*, *Nylanderia*, *Tapinoma*, *D. goeldii*, *C. novogranadensis*, *N. guatemalensis*, *Tapinoma* sp1, average richness (subfamily, genera, species), clay content, and soil degree of compaction formed acute angles (< 90°) and pointed toward this group (Figure 6B). This arrangement suggested a strong positive correlation between these ant assemblage variables and specific soil physical and chemical attributes (Rodrigues et al., 2007).

Table 3. Eigenvalues (EG), total variance (%TV), and cumulative variance (%CV) explained by the Principal Components (PCs) in the definitive Principal Component Analysis (PCA) correlation matrix for data obtained across five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

Measure	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
EG	13.78	1.56	1.00	0.73	0.57	0.42	0.39	0.26	0.19	0.08	0.03
%TV	72.53	8.19	5.28	3.85	2.98	2.21	2.04	1.36	0.98	0.42	0.17
%CV	72.53	80.72	85.99	89.84	92.82	95.03	97.07	98.43	99.41	99.83	100.00

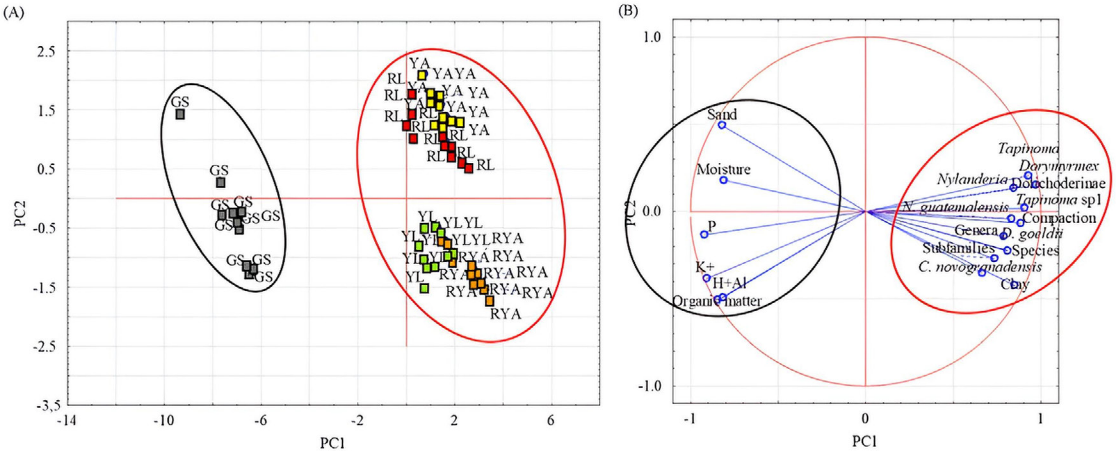

Figure 6. Ordination diagram from definitive Principal Component Analysis (PCA) showing: distribution of the five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS); and (B) selected variables (ant assemblages and soil attributes), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

Clay, which exhibited a strong positive correlation with PC1 (Table 2), favored certain *Atta* species in the Brazilian Neotropics (Schaefer et al., 2021). Higher clay content enhanced particle cohesion, resulting in greater soil penetration resistance (Gaia-Gomes et al., 2021) that is soil compaction in RYA, YA, YL, and RL compared to GS, as these variables are positively correlated (Rodrigues et al., 2007).

In contrast, the second group comprised only GS sampling units, positioned on the negative side (on the left) of the PC1 axis (Figure 6A). Vectors for soil moisture, organic matter, sand content, available phosphorus, potassium, and extractable acidity formed acute angles toward GS (Figure 6B). These conditions did not favor the selected ant assemblage attributes (Table 1; Figures 2, 3, 4). The spatial ordination highlighted contrasting abiotic conditions between the two groups (Souza et al., 2023), with RYA, YA, YL, and RL being similar to each other but highly dissimilar to GS, as indicated by vectors forming angles between 90º and 180º, respectively, thus suggesting negative correlation (Abreu et al., 2020) between ants, soil drainage, and fertility.

Increased soil moisture in GS for most of the year enables intense grass root biomass production and significantly higher carbon input (Barbosa et al., 2012), resulting in higher organic matter content compared to other pedoenvironments (Benedetti et al., 2011). Furthermore, high water availability reduces decomposing microbiota activity, leading to organic matter accumulation (Marschner, 2021; Benedetti et al., 2011). Consequently, GS exhibited greater availability of nutrients like potassium and phosphorus (Delarmelina et al., 2022; Silva et al., 2021; Benedetti et al., 2011). However, the decomposition of accumulated organic matter releases weak acids, accelerating cation leaching and soil acidification (Liang et al., 2023), which explains the higher extractable acidity recorded in GS (Benedetti et al., 2011; Nascimento et al., 2024).

ANOSIM revealed significant differences between pedoenvironments (p = 0.0001), with high dissimilarity indicated by an R-value of 0.94 (Thompson et al., 2025; Westerbom et al., 2018). HCA corroborated this, showing RYA, YA, YL, and RL linked at a standardized distance of ~60%, while this group linked to GS at ~100%, nearly doubling the internal linkage distance (Figure 7A).

HCA indicated that soil moisture, organic matter, phosphorus, and extractable acidity exerted a higher impact on ant richness and abundance than clay, sand, or potassium (Figure 7B). This underscores the relevance of GS's topographical position, where seasonal submersion (Benedetti et al., 2011) filters ant populations by hindering foraging and compromising nest construction (Lin et al., 2024; Costa et al., 2010). Conversely, higher clay content in RYA, YA, YL, and RL (Benedetti et al., 2011) positively impacts assemblages, as clay acts as a vital cementing material for nests (Yang et al., 2022).

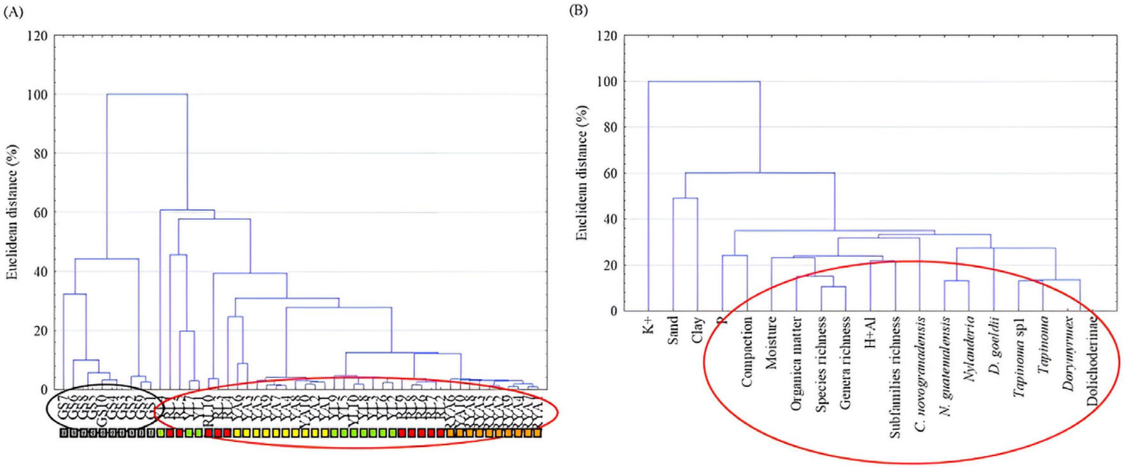

Figure 7. Hierarchical Cluster Analysis (HCA) dendrograms showing: (A) clustering of the five pedoenvironments, *Argissolo Vermelho-Amarelo* (RYA), *Argissolo Amarelo* (YA), *Latossolo Amarelo* (YL), *Latossolo Vermelho* (RL), and *Gleissolo Háplico* (GS); and (B) selected variables (ant assemblages and soil attributes), at a patch of savanna in the Brazilian Amazon), Boa Vista, Roraima State, Brazil.

Differences in plant diversity also influenced ant assemblages. While all pedoenvironments share some floristic elements, GS is distinct, lacking the tree and shrub cover found in well-drained soils (Araújo et al., 2017). This wet grassland physiognomy features lower structural complexity and plant richness compared to RYA, YA, YL, and RL (Araújo et al., 2017). Environments with reduced vertical strata and lower plant diversity generally do not support diverse ant assemblages (Amaral et al., 2019), whereas complex environments provide heterogeneous microhabitats and food resources through varied litterfall (Souza & Araújo, 2020; Lobo et al., 2023; Costa et al., 2025).

Roraima's savannas have faced rapid agribusiness expansion, transforming the landscape fourfold between 2000 and 2014 (Silva & Oliveira, 2018). Factors such as low land costs and flat topography accelerate this process, necessitating urgent mitigation and conservation measures (Silva & Oliveira, 2018; Barni et al., 2020). Evaluating ant assemblages can help identify indicator species and monitor the impacts of converting native vegetation into agricultural land (Costa et al., 2025).

SIMPER analysis showed that 11 species accounted for 46% of the dissimilarity among pedoenvironments. Most taxa, including *D. richteri*, *C. crassus*, *P. naegelii*, *S. clytemnestra*, *D. bicolor*, *C. jardinero*, *Pseudomyrmex* sp5, and *Pheidole* sp75, showed the lowest abundance in GS and the highest in Argissolos (RYA, YA) or Latossolos (YL, RL). In contrast, *P. radoszkowskii* and *Pheidole sp105* reached their highest abundance in GS, while *C. leydgi* peaked in RL.

4. CONCLUSIONS

The tested hypothesis was partially corroborated, as no significant differences were found in richness, abundance, and composition of the ground-dweling ant assemblages between *Argissolo* (*Argissolo Vermelho-Am*arelo, *Argissolo Am*arelo,) and Latossolo (*Latossolo Amarelo*, *Latossolo Vermelho*).

Conversely, the ant assemblage in *Gleissolo Háplico* exhibited high and relevant dissimilarity compared to the other pedoenvironments, showing significantly lower richness and abundance of key groups, such as the subfamily Dolichoderinae and the genera *Dorymyrmex*, *Nylanderia*, and *Tapinoma*.

This pattern was predominantly attributed to higher levels of soil moisture, organic matter, extractable acidity, and available phosphorus, as well as sand and exchangeable potassium, and lower clay content, which are a direct reflection of the location of Gleissolo Háplico at the lowest point of the toposequence.

These results highlight the potential of ants as bioindicators of environmental quality and reinforce the urgent need for conservation measures in the Roraima savanna, a region severely threatened by accelerating agricultural expansion.

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DATA AVAILABILITY

All data that support the findings of this study are included within the article.

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