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RESEARCH ARTICLE - ANTS

Association of the Occurrence of Ant Species (Hymenoptera: Formicidae) with Soil Attributes, Vegetation, and Climate in the Brazilian Savanna Northeastern Region

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Abstract

Ants occur in all tropical forest strata by nesting, foraging, and interacting with plants and other residents from these habitats. Most ants build their nests in the soil. Selecting the proper soil for nesting depends on soil attributes and other factors. The question is: Which of these attributes can affect more strongly the decision for nest installation? This study aims to discover if the occurrence of some species of ants from Cerrado, in the Northeastern State of Maranhão, depends on attributes of soils and climatic factors. We found 48 species of ants, of which ten had the highest importance value. These are correlated with soil properties, litter biomass, basal area, humidity, and temperature by using the principal component analysis (PCA). The soil properties, vegetation (basal area and dry mass of litter), temperature, and humidity had an impact on the occurrence of the ten studied species of ants. *Camponotus comatulus* (Mackay, 2010), *Ectatomma muticum* (Mayr, 1870), *Solenopsis substituta* (Santschi, 1925), *Pseudomyrmex termitarius* (Smith, 1855) and *Pheidole casta* (Wheeler 1908) were associated with sites of arbustive vegetation, poorly and acidic chemical and physical limited (dense, high micro-pores volume) soils. *Pseudomyrmex boopis* (Roger, 1863), *Dinoponera gigantea* (Perty, 1833), *Ochetomyrmex neopolitus* (Fernández, 2003) are found in fertile soils, covered by arboreal forest, while *Crematogaster cf acuta*, *Solenopsis bruesi* (Creighton, 1930) was mainly found in saturated soil, and covered with palm trees. The species of ants recorded in this study are strongly associated with soil properties, as well as vegetation parameters, air temperature, and relative humidity at soil level.

Introduction

Ants are the most widely distributed and abundant social insects. They are found in almost all Earth habitats, except the Earth Poles (Harada & Ketelhut, 2009). Ants can be found in canopies, litter, and soil. Many species use the interface between soil and litter for foraging and building their nests (Hölldobler & Wilson, 1990; Longino & Nadkarni, 1990). Ants have high economic and ecological value because they can significantly influence their environments by incorporating nutrients, aerating soils, and regulating populations of other organisms (Nakano et al., 2013). Identification and ecological characterization of ant communities, as well as studies designed for controlling pest species, have been the subject of both basic and applied research in most of the Brazilian ecosystems, particularly in Savanna areas (Cerrado Biome).

However, most studies carried out in the Brazilian Cerrado Biome addressed the geographical distribution of ants, associated with the qualitative effects of vegetation, air temperature, and humidity (Caldeira et al., 2005; Campos et al., 2008; Cantarelli et al., 2006; Fonseca & Dihel, 2004; Lopes & Vasconcelos, 2008).

Some papers analyzed the relation between ants and environmental factors, and many of them associate the

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occurrence of ants with different environments. However, they do not present the environmental factors that affect the distribution pattern of ant species. The genus *Camponotus*, for example, is usually associated with different vegetation types of phytophysiognomies in the Cerrado biome, and the ants of *Ectatomma* found in Cerrado areas are poorly covered by plants (Pacheco & Vasconcelos, 2012).

Pseudomyrmex is a genus of large distribution and high diversity that usually builds nests on arboreal substrates and dead logs (Ward & Downie, 2005); but there are a few species of *Pseudomyrmex* that nest on soils (Dejean et al., 2014). The ants of the Myrmicinae subfamily, like the *Pseudomyrmex*, are found in the Neotropical region, and the main studies with Myrmicinae establish a relation between the geographic distribution and environmental factors with discrete discussions on specific environmental factors that affect the distribution of these ants, mainly the Myrmicinae that nest underground.

The Myrmicinae is a megadiverse subfamily in tropical areas, especially the *Pheidole* (Rodríguez et al., 2011; Selvarani & Amutha, 2013). Usually, the Myrmicinae ants are opportunistic and capable of massive foraging (Sant'ana et al., 2008), remarkably in warm and rich leaf-litter areas (Theunis et al., 2005). They can occupy both natural and anthropogenic environments (Calle et al. 2013; Franklin, 2012). The majority of Myrmicinae species build their nests in the soil where there is a high content of food, mainly proteins.

Many ant species nest on the soil (Campos et al., 2008; Jaime 2010), where they can have stable shelters and abundant food supply, more specifically, and protein sources with low C:N ratio. The latter plays an important role in the stratification and complexity of ant communities nesting on the ground or tree canopies (Kaspari & Yanoviak, 2001).

Studies about ant species that live on soil horizons are quite restricted, since the majority of studies that approach soil ants deal with species from epigeic substrates collected with pitfall traps, besides the methodological difficulties in obtaining samples of ant species on the soil. Ryder-Wilkie et al. (2007) found 47 ant species at a 50-cm soil depth in the Ecuadorian Amazon. These authors recorded the following genera: *Wasmannia* Forel (1893), *Strumigenys* Smith (1860), *Pachycondyla* Smith (1858), *Gnamptogenys* Roger (1853), *Hypoponera* Santschi (1938), and *Solenopsis* Westwood (1840). However, there was not a relation between ants and soil attributes, only 3.0% of the species were found in the three studied layers: leaf litter, soil, and trees (Ryder-Wilkie et al., 2010). Vegetation and soil attributes like silt, organic matter, nitrogen and water content have a significant impact on the frequency of ant nest in a transitional steppe and desert area in Southwestern China (Li et al., 2011). Therefore, soil attributes seem to influence the distribution of ants. However, on what level and intensity do they do it? Thus, a hypothesis of the present paper is that the occurrence of ants is probably associated with soil attributes, vegetation, and climatic factors. Hence, the present study aimed to identify the relation between ant community and soil attributes in a Cerrado area from the Northeastern region of Brazil.

Material and methods

Description of sites

The study sites were located in Chapadinha County, (3º44'31 'S and 43 21'36''W, DATUM), Maranhão State, Northeastern Brazil, at an altitude of approximately 100 m. According to Thornthwaite climate classification, the regional climate is tropical sub-humid B1WA'a, with an annual temperature of 29±1 °C, annual rainfall of about 1,600 to 2,000 mm, and distinct dry (July-November) and wet (December-June) seasons (Nogueira et al., 2012). The experimental area is included in the Cerrado biome (Savanna-like vegetation), which is the second largest biome in Brazil, covering around 25.0% of the Brazilian total area (Sano et al., 2008).

Based on the US Soil Taxonomy (Soil Survey Staff, 2010), the soil vegetation, slope class, and slope position of each site selected for the present study are presented in Table 1 and Figure 1.

Table 1. Soil types, slope position, slope class, drainage class, and vegetation of the sites (S1, S2, S3, S4, S5, and S6) at Cerrado, in Maranhão, Northeastern Region of Brazil.

Sites	Soil	Slope position	Slope class	Drainage class	Vegetation
S1	Xanthic Hapludox	Summit	Gently sloping	Poorly drained	Shrub
S2	Xanthic Hapludox	Summit	Very gently sloping	Moderately well drained	Cerrado (Shrub and trees)
S3	Oxyaquic Udipsamments	Footslope	Depressional level	Poorly drained	Mesophilic forest on secondary growth (dense vegetation and leaf litter),
S4	Petroferric Hapludox	Summit	Moderately sloping	Somewhat excessively drained	Mesophilic forest on secondary growth with less dense leaf-litter
S5	Arenic Kanhapludults	Footslope	Depressional level	Very poorly drained	Babaçu palm forest *Orbignya phalerata* Mart
S6	Lithic Hapludults	Summit	Strongly sloping	Somewhat excessively drained	Mesophilic forest on secondary growth with scattered Babaçu palm trees

Ant field collection

Ants were collected in six sites, each with four plots (40 x 40 m). The ants were attracted using sets of protein and carbohydrate baits (sardine and honey, respectively), each had a distance of 0.2 m from one another. Nine sets of baits with a 10-m space from one another were distributed into every plot (Figure 1). Each set of bait was individually monitored for one hour from 8 to 11 a.m. Ants that ate from the baits were followed to their nest and then collected. Collections of the ants were conducted from May to November of 2012. All plots were sampled together in each month. The collected ants were preserved in 70.0% alcohol in proportion (7.54:2.46 Alcohol 92.8°: water, v:v). Subsequently, they were identified in the laboratory at species level using stereomicroscope and available literature to be compared with the ant collection at Museu Paraense Emílio Goeldi. The abundance of ant species was considered as the number of nests observed. Temperature and humidity at soil level were measured every 30 minutes in the center of each plot using a digital thermos hygrometer (ICEL HT-208).

Vegetation analysis

The basal vegetation area was calculated for every living tree trunk or dead log with a circumference at breast height (CBH) > 0.15 m and height > 1.0 m. The vegetal basal area was defined as the area occupied by the plant divided by the total soil surface area. The total vegetation basal area of each plot for all sites was estimated using Fitopac 2.0. (Shepherd, 2008). Additionally, leaf-litter biomass on the soil surface was obtained at three randomly chosen 1.0 m^2 (1.0 x 1.0 m) in each plot of all sites. The material was placed in an oven at 60°C to dry until constant weight was reached. The dried leaf-litter materials were weighed to calculate the biomass ($kg.ha^{-1}$).

Soil sampling and analysis

Damaged soil samples were obtained in each plot of all sites, varying from 0.0-0.1, 0.11-0.2, and 0.21-0.3 m depth. Twenty-four samples were randomly collected and mixed for each soil layer in order to obtain a composite sample, in which the following were determined: pH ($CaCl_2$), organic matter (OM), P (resin method), K^+, Ca^{2+}, Mg^{2+} (H + Al), based on the procedures proposed by Raij et al. (2001). Also, sand, silt, and clay contents and water clay dispersion were determined according to Gee and Or (2002). The degree of clay flocculation was obtained by FD = (CDW – clay dispersion in water/total clay) x 100. Furthermore, the aggregate stability index (ASI) considering aggregate diameters between 1.0 and 2.0 mm was

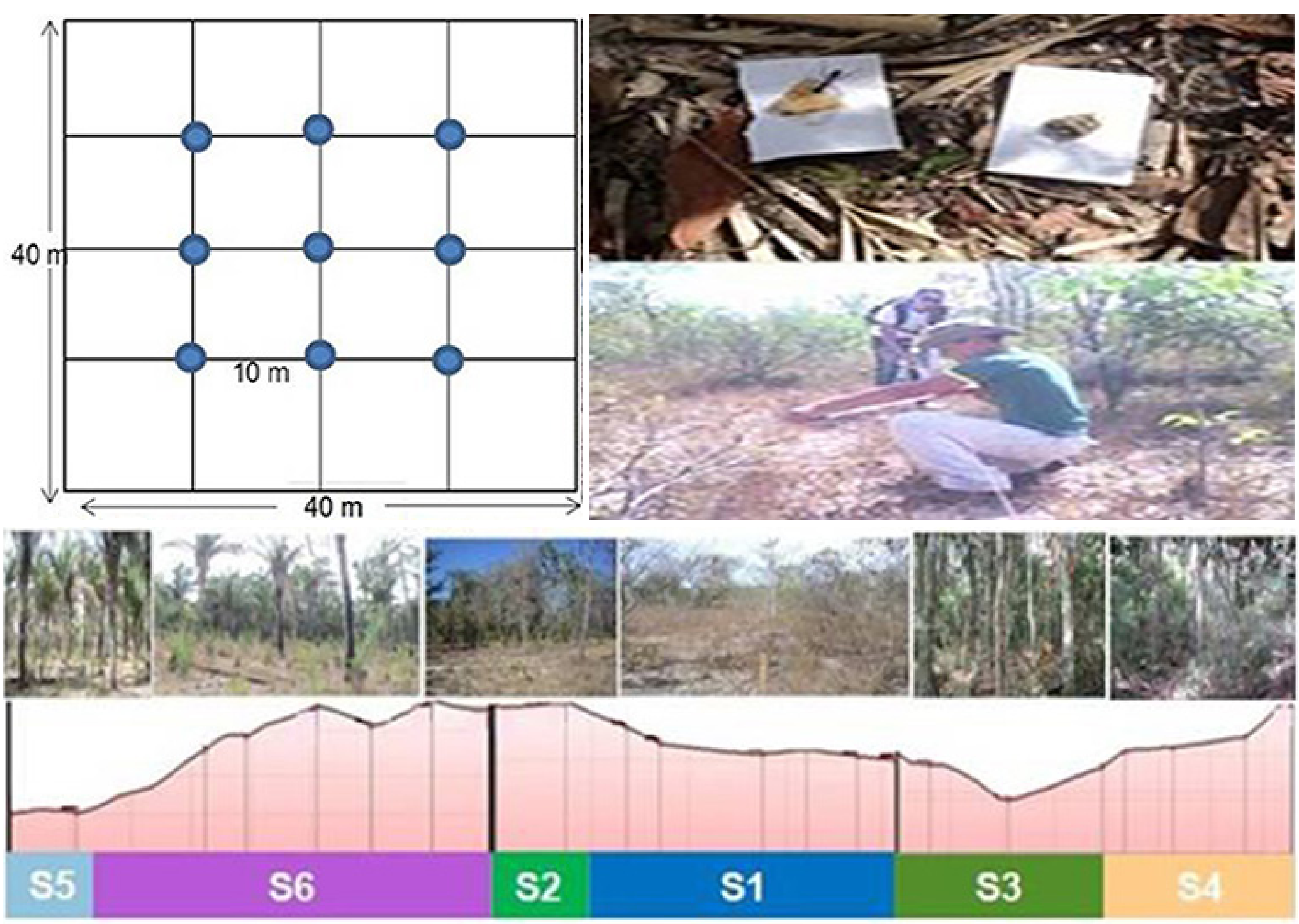

Fig 1. Distribution of the baits (honey and sardines) at the plots of 40 x 40 m. Elevation profile and prevailing vegetation on sites S1, S2, S3, S4, S5, and S6.

determined in the 24 samples of each soil layer, as described by Nimmo and Perkins (2002).

Additionally, 16 undamaged samples were collected in volumetric rings (5 x 5 cm) in each plot from 0.0-0.1 m, 0.11-0.20 m, and 0.21-0.30 m depth – site 6 was not because undamaged samples were obtained only from 0.0-0.1 m depth due to rock fragments on the soil profile. In each undamaged sample, soil bulk (Grossman & Reinsch, 2002), total porosity, macroporosity and microporosity (Claessen et al., 1997) were measured.

Statistical analysis

Vegetation data were analyzed using Fitopac 2.0 (Shepherd, 2008), which generates the basal area and importance value index (IVI).

Data of the relation between soil attributes, the occurrence of ant species, and vegetation was obtained through the PCA using the Infostat 2012 version (Di Rienzo et al., 2008). Ten ant species were selected for the PCA, based on the IVI, which is the sum of the relative frequency, density, and dominance of each ant species obtained using Fitopac 2.0 (Shepherd, 2008). In addition, the ten selected ant species were divided into two subgroups to keep 70.0% as minimum inertia in the PCA. The two groups of ants were formed considering the phylogenetic and phylogeographic relation of ants and the preservation of at least 70.0% of system inertia. The species in each subgroup are as follows: subgroup A – *Crematogaster cf. acuta*, *Pheidole casta*, *Solenopsis bruesi* and *S. substituta*; and subgroup B – *Camponotus comatulus*, *Dinoponera gigantea*, *Ectatomma muticum*, *Ochetomyrmex neopolitus*, *Pseudomyrmex boopis* and *P. termitarius*.

Results

The species in the subfamily Myrmicinae (*Crematogaster cf. acuta*, *Ochetomyrmex neopolitus*, *Pheidole casta*, *Solenopsis bruesei* and *Solenopsis substitute*) were found in specific sites (Table 2). Similarly, *Ectatomma muticum*, *Camponotus comatulus*, *Pseudomyrmex termitarius*,

Table 2. Number of nests, importance value index (IVI) of ants species from sites S1, S2, S3, S4, S5 and S6 at Cerrado, Maranhão, Northeastern Region of Brazil.

Species	S1	S2	S3	S4	S5	S6	IVI
Dinoponera gigantea (Perty, 1833)	8	3	15	20	-	15	17.30
Camponotus comatulus (Mackay, 2010)	41	19	-	-	-	5	16.37
Pseudomyrmex termitarius (Smith, 1855)	40	7	-	-	4	2	14.46
Ectatomma muticum (Mayr, 1870)	45	3	-	-	-	-	11.88
Ochetomyrmex neopolitus (Fernández, 2003)	1	-	7	10	-	4	8.47
Pheidole casta (Wheeler, 1908)	5	-	4	-	6	9	6.87
Pseudomyrmex boopis (Roger, 1863)	-	-	3	5	-	2	6.40
Solenopsis bruesi (Creighton, 1930)	-	8	1	-	6	-	6.04
Crematogaster cf. acuta	-	1	-	-	17	1	5.68
Solenopsis substituta (Santschi, 1925)	11	-	-	-	1	-	5.63

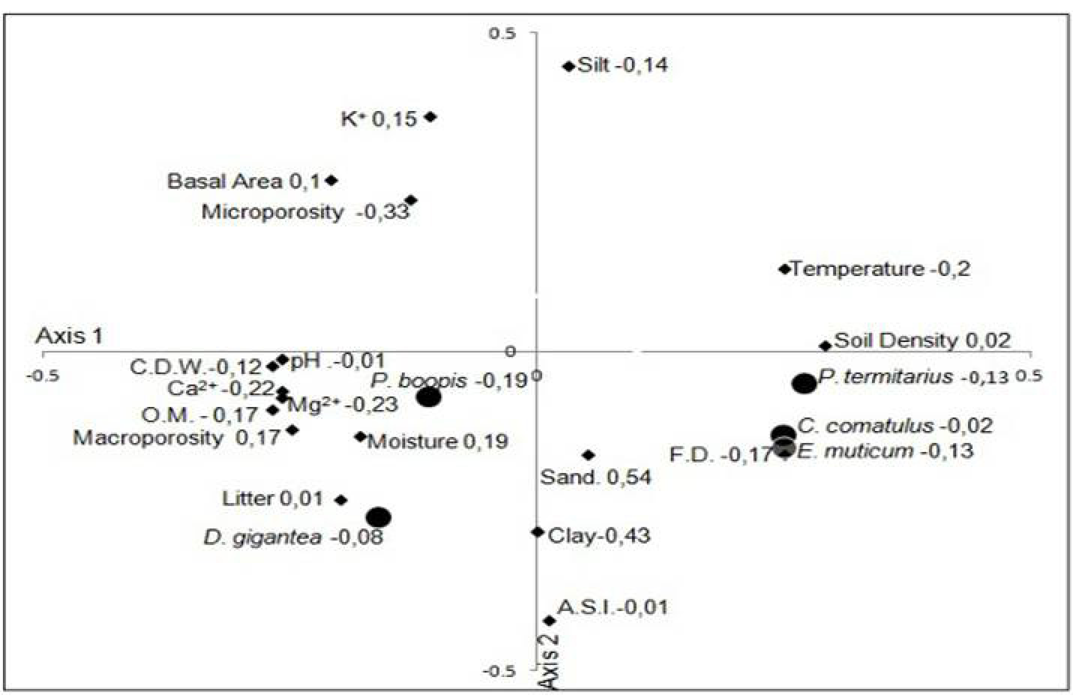

Fig 2. Principal component analysis of soil, vegetation and climate variables related to the occurrence of *Camponotus comatulus*, *Ectatomma muticum*, *Pseudomyrmex boopis*, *Dinoponera gigantea* and *P. termitarius* ants species collected in a domain of Cerrado, Northeastern Region of Maranhão, Brazil. Circle refers to ants and diamond refers to variables. OM: organic matter; FD: flocculation degree; CDW: clay disperse water; ASI: aggregate stability index. The numerical labels beside variables show the third axis in the three-dimensional system. 74.0% system inertia.

Pseudomyrmex boopis and *Dinoponera gigantea* were more specific for habitat use. They nested under very specific conditions of soil attributes, vegetation, humidity, and temperature at the soil level. Thus, those species are more demanding for habitat use.

The species *E. muticum*, *C. comatulus* and *P. termitarius* found in S1 and S2 sites were positively associated with higher soil densities, soil air temperatures, soil micropores and lower soil pH (Figure 2 and Table 3). However, in this open area of the Cerrado, *P. termitarius* was also quite common. Its nesting was more observed in the S1, S2, S5 and S6 sites.

Pseudomyrmex boopis was found exclusively in shady places and was more abundant on S3, S4 and S6 sites (Table 2), where the soils presented high clay, Mg^{2+}, Ca^{2+} and OM contents, as well as high pH values (Table 3). Positive associations among those variables and *P. boopis* are shown in Figure 2.

Ochetomyrmex neopolitus and *Dinoponera gigantea* nests were predominantly observed at S3, S4, and S6 sites, where leaf litter dry mass was higher, and soils presented high macroporosity and moisture (Figures 2, 3 and Table 3). The presence of *D. gigantea* at S1, S2, S3, S4 and S6 sites was associated with mild temperatures and high leaf-litter biomass, possibly under woody vegetation (sites S3, S4, and S6), providing favorable conditions for *D. gigantea* occupation. *Dinoponera gigantea* nests were not found at S5, where there is high soil water content, low leaf-litter biomass, and low soil macroporosity (Figure 2, Table 3).

Nests of *Crematogaster cf. acuta* and *Solenopsis bruesi* were observed at S5, where soils presented low clay and organic matter contents, high silt content, and low percentages of ASI, CDW (Figure 3, Table 3). These conditions were mainly found in S5, which is located at a depressional area, which soil is very poorly drained (Figure 1, Table 1).

Pheidole casta nests were observed at S1, S3, S5, and S6. The *Pheidole* occurrence showed a strong association with low basal area values, low soil micropores, and low soil pH (Figure 3). Spots with these features should also have high sand content, high-density values and high temperatures at soil level (Figure 3, Table 3).

Nests of *Solenopsis substituta* were observed at S1 and S5. These sites present plants with low potential for shading and soils with high bulk density, low clay, organic matter, Ca^{+2} and Mg^{+2} contents, low soil macroporosity, and low leaf litter biomass, as well as the high temperature at soil level (Table 3). Myrmicinae species were observed at all sites, especially at S6, where the soil has a high amount of lateritic concretions, which provides stable galleries under a thick layer of leaf litter.

Discussion

The occurrence of Myrmicinae and other species of ants in specific habitats of the Cerrado show the high capacity of these ants to live in different types of sites, with the possibility of building their nests under very specific conditions of soil attributes, vegetation, humidity, and temperature. The associations of these ants to different conditions found in Cerrado can be an adjustment or response to its diversity of habitats because the selectivity of ants from such habitat described by Pacheco and Vasconcelos (2012) show that Cerrado physiognomies are richer in ant species than in homogeneous forest formations.

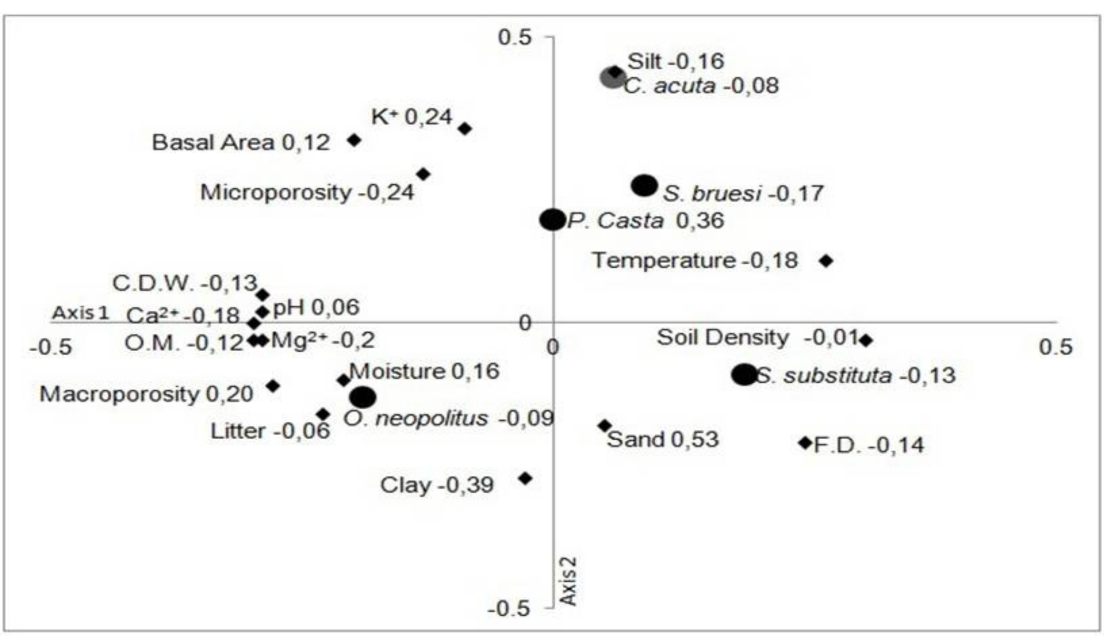

Fig 3. Principal component analysis of variables of soil, vegetation and climate factors related to the occurrence of *Crematogaster cf. acuta*, *Solenopsis substituta*, S. *bruesi* and *Pheidole casta* ant species collected in a domain of Cerrado, Northeastern Region of Maranhão, Brazil. Circle refers to ants and diamond refers to variables. OM: organic matter; FD: flocculation degree; CDW: clay disperse water; ASI: aggregate stability index. The numerical labels besides variables show the third axis in the three-dimensional system. 71.0% system inertia.

Table 3. Litter biomass, basal area, humidity, and temperature at soil level and physical and chemical layer parameters of 0.0 to 0.3 m soil in sites S1, S2, S3, S4, S5 and S6 in a domain of Cerrado, Maranhão, Northeastern Region of Brazil.

	Mic.	Mac.	FD	ASI	S. dens.	CDW	Clay	Silt	Sand	OM	pH	K^+	Ca^{2+}	Mg^{2+}	(H+Al)	T	U	Litter	BA
N = 30	...$m^3.m^{-3}$....		.......%....		$Kg.m^{-3}$	...................$g.kg^{-1}$....................					KCl	...........$mmol_c.kg^{-1}$.............				°C	%	$kg.ha^{-1}$	$m^2.ha^{-1}$
S1 (Xanthic Hapludox)																			
Mean	0.3	0.1	20	93	1790	176	220	117	662	14.6	3.95	0.3	1.92	1.49	31	37.37	28.9	2212	0.23
SD	0	0.01	7.9	1.1	0.02	30.8	29.8	5	30.2	1.96	0.06	0.1	0.3	0.5	2.42	2.71	5.16	15.01	0.26
S2 (Xanthic Hapludox)																			
Mean	0.2	0.11	24	89	1670	141	185	99	715	17.9	3.7	0.4	2.13	1.46	51.1	35.35	32.2	6430	0.95
SD	0	0.01	12	1.7	0	27.6	7.7	11	17.2	0.24	0.05	0.1	0.06	0.41	3.61	1.12	3.4	50.01	0.89
S3 (Oxyaquic Udipsamments)																			
Mean	0.3	0.21	38	92	1410	145	234	88	678	33.8	4.48	0.7	18.2	14.6	66.3	29.69	52.9	16644	2.42
SD	0	0.02	7.3	2.7	0.05	33.5	60.5	21	79.9	10.8	0.24	0.2	8.39	7.34	17.8	2.01	15.2	107.98	0.31
S4 (Petroferric Hapludox)																			
Mean	0.3	0.19	27	92	1280	190	219	108	590	49.4	4.62	0.5	25.6	28.8	87.5	31.49	41.1	14815	2.19
SD	0	0.02	7.2	0.7	0.08	14.7	41	14	30.6	5.49	0.21	0.1	6.52	6.6	9.01	1.71	11.4	45.53	0.73
S5 (Arenic Kanhapludults)																			
Mean	0.3	0.08	26	63	1620	88	121	295	584	14.2	4.19	1.6	7.51	8.31	35.5	36.78	30.9	2033	3.63
SD	0	0.04	5.2	27	0.02	16.6	14.5	128	14.2	2.36	0.28	0.5	1.67	3.73	7.13	2.55	2.03	65.5	0.2
S6 (Lithic Hapludults)																			
Mean	0.3	0.21	27	84	1430	115	160	145	695	38.1	4.43	1.5	10.2	10.8	49.4	32.07	35.6	5177	1.91
SD	0.1	0.02	4.1	11	0.09	16.9	30	35	65.4	9.94	0.27	0.4	3.12	3.36	19.8	1.86	6.84	23.91	0.94

Footnotes Table 2
- Absent species.

Footnotes Table 3
N: number of observations; Mic: microporosity; Mac: macroporosity; FD: flocculation degree; ASI: aggregate stability index; S. dens.: soil density; CDW: clay dispersed in water; OM: organic matter; T: temperature; U: atmospheric humidity at soil level; BA: basal area; SD: standard deviation.

The presence of *E. muticum, C. comatulus* and *P. termitarius* in acidic, dense soils with the high bulk of micropores shows the adherence of these ant species to soils of xerophytic environments. *Ectatomma* species were observed in open areas under sandy soils with low pH (Pacheco & Vasconcelos, 2012). Melo et al. (2014) and Soares et al. (2003) highlighted the occurrence of *E. muticum* in damaged habitats, more specifically in xerophytic environments like Caatinga and in open areas from Cerrado.

The nests of *P. termitarius* found in open areas from Cerrado, mainly in soil, contradict the results found by Dejean et al. (2014), Ward and Downie (2005). The predominance of most of the *Pseudomyrmex* genus and *P. boopis* nesting typically occur on rotten wood or near the ground (Antwiki). In the present study, the highest occurrence of *P. termitarius* was observed in soil and areas with lower basal area and scarce vegetation. The record of *P. termitarius* in sites with the high basal area only occurred in sites covered mainly by palm trees. The high basal area value of sites where the nests of *P. termitarius* was registered is the result of the dominance of palm trees. The monopodial canopy growth of palm trees concentrates the leaves around a central point, which reduces shading on the ground, recreating strong insolation conditions as occurs in sites with the lower basal area and scarce vegetation. The fact that *P. termitarius* has been observed in different soil conditions, but under similar plant shading conditions, suggests that plant shading conditions play a more important role for the colonization by this species than soil attributes.

Pseudomyrmex termitarius is smaller and darker in black and red pigments of the gaster and mesossoma. *P. termitarius* was the only active species throughout all days, despite the fact that the air temperature on ground level reached 59.4° C and humidity was smaller than 20.0%. The darkest black and red pigmentation and the smallest thermic inertia, due to small body size, probably, are the reason the *P. termitarius* is tolerant to high temperatures, compared to other species in the present study. For instance, a less pigmented ant – *P. boopis* – was observed only in more shaded conditions.

The register in the present study of *P. termitarius* exclusively in open areas is supported in other works, such as in Mil (1981) in Brazil and Jaff et al. (1985) in Venezuela. Both authors reported the occurrence of *P. termitarius* on less shaded conditions (scarce vegetation). Besides these authors, Kemp (1960) also mentions the occurrence of *P. termitarius* in sunny sites, including inside termite nests. Opposite areas where *P. boopis* nests were found have soils rich in nutrients and arboreal vegetation with great soil shading potential. Fertile and moist soils can support a greater number of woodland communities (Haridassan, 2000), which provides more shadow and consequently a good condition not only for *P. boopis* nesting but also for other ants like Myrmicinae and Ponerinae.

Soils under woodland habitats usually present high leaf-litter dry mass and low C:N ratio. Arboreal habitats often have large leaf-litter supplies and therefore low C:N ratio, and high content of protein available in the soil (Kaspari & Yanoviak, 2001). Thus, the preference of *O. neopolitus* for soils under woodland with high-protein concentration potential corroborates the observations of Rodríguez et al. (2011), who argued that habitats with these features are suitable for opportunistic and generalist ants, as Myrmicinae species.

Dinoponera gigantea was associated with mild temperatures and high leaf-litter biomass, which is usually found on woody vegetation. However, this ant was also seen in sunny sites. In such climate condition, the nests of *D. gigantea* were always observed at the bottom of the trunk of trees and shrubs, which is possibly a strategy that reduces the effects of high temperatures as argued by Lenhart et al. (2013) and Vasconcellos et al. (2004). Despite the preference of *D. gigantea* for mild temperatures and humidity sites, the excess of humidity is a limitation for the occurrence of *D. gigantea*, because these ants were not found in sites where there is high soil water content (close to saturation).

Poorly drained and structured soils may limit the survival of large ants. Those found in these soils build their nests in petioles and stems above the ground. Nevertheless, these environments are suitable for small ants like *C. cf. acuta*. Costa-Milanez et al. (2014) emphasize the occurrence of *C. cf. acuta* in wetlands by showing the versatility of these species in different habitats, especially in wetlands. The occurrence of *C. cf. acuta* and *S. bruesi* on poorly drained and structured sites emphasizes the adaptive capacity of many Myrmicinae subfamily ant species to live in habitats that have not been occupied by other ants (Calle et al., 2013).

The association of *Pheidole casta* with extreme climatic and pedological conditions, such as high sand content, soil density values, and temperatures at soil level, show these ants and other Flavens group species have high capacities of adjusting themselves to different environmental conditions. Therefore, they are widely distributed and can be found from North Carolina (USA) to Argentina (Wilson, 2003).

Ecological investigations addressing the possible relations between ants and soil attributes, vegetation, and climate are rather discrete, but some authors have made approaches with some of these parameters, such as: Vasconcelos et al. (2008) that observed high density of *S. substituta* nests in Amazonia's Cerrado; and Trager (1991) that mentions its occurrence is usually associated with areas with sites of scarce vegetation and uncovered soil.

Myrmicinae species were observed in all sites, mainly in those where the soil presents high amounts of lateritic concretions, which provide stable galleries under a thick layer of leaf litter. According to Theunis et al. (2005), this soil feature supports dense populations of Myrmicinae that allow vertical migrations when conditions become unsuitable for ground nesting, particularly during the rainy season when such soils become too wet.

Myrmicinae is a dominant group of ants of hyper-diversity that is found in tropical areas (Selvarani & Amutha, 2013), especially the genus *Pheidole* (Rodríguez et al., 2011). Franklin (2012) found Myrmicinae nests in the Mexican Sonoran desert. The opportunism of the Myrmicinae species was observed in the present study since Myrmicinae nests were observed on all sites.

Nevertheless, this paper showed lower abundance and distribution of Ecitoninae, Ectatomminae, Dolichoderinae, Formicinae, Ponerinae, and Pseudomyrmicinae when compared to Myrmicinae ant species. The occurrence of many ants species of the Myrmicinae subfamily was defined by specific soil attributes, vegetation, and microclimate, as observed in the present study.

Conclusions

The ants species registered herein are strongly associated with soil properties (bulk density, porosity, sand and silt content, aggregate stability index, Mg^{2+} and Ca^{2+} content, organic carbon, and pH), as well as vegetation parameters (basal area and dry mass of litter), air temperature and relative humidity at soil level. The soil, vegetation, and climate factors have an impact on the structure of ant communities because they define together the presence or absence of ants in specific sites. Thereby, these ants may be considered good indicators of soil quality, vegetation, and climate. In this study, *P. boopis* was mentioned for the first time in Brazil.

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