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Use of Soil and Litter Ants (Hymenoptera: Formicidae) as Biological Indicators of Soil Quality Under Different Land Uses in Southern Rwanda

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Abstract

The use of soil and litter arthropods as biological indicators is a way to assess environmental changes, where ant species in particular may serve as important indicators of soil quality. This study aimed at relating the abundance of soil and litter ant species to soil parameters under different tree species, both native and exotic, and varieties of coffee and banana plantations. Variations were found in soil physicochemical parameters. A total of 30 species belonging to 14 genera, and four subfamilies, the Formicinae, Dorylinae, Myrmicinae, and Ponerinae were identified. Higher abundance was found in coffee plantations compared to banana plantations, exotic and native tree species. Species of *Camponotus cinctellus* and *Odontomachus troglodytes* occurred in all land uses which is a sign of tolerance to a wide range of soil properties. In addition, these species, together with *Myrmicaria* SP02, *Phrynoponera gabonensis, Camponotus* SP06, *Myrmicaria opaciventris, Pheidole* SP03, *Tetramorium simillimum, Pheidole* SP01, and *Tetramorium laevithorax* were not strongly correlated with soil physicochemical parameters. Species of *Pheidole* SP02 and *Camponotus* SP05 were restricted to specific soil physicochemical properties, while species of *Tetramorium zonacaciae* and *Bothroponera talpa* discriminated between native tree species, coffee plantations, soil organic carbon, sandy soil texture, and aggregate stability. We concluded that these ant species can differently indicate the soil quality depending on the land use. We recommended further studies in order to generalize these findings.

Key words: Dorylinae, Formicinae, Myrmicinae, Ponerinae, physicochemical parameter

Soil is a fundamental natural resource supporting a variety of ecosystem goods and services beneficial to humankind (Laishram et al. 2012). Current statistics indicated that 11% of the globe's land surface (1.5 billion of hectares) is used for agriculture (Max and Ritchie 2018), while planted forests increased about 7% between 2010 and 2014 (Jürgensen et al. 2014) from 167.5 million of hectare to 277.9 million of hectare of the total global forest area (Payn et al. 2015). The main purposes for agriculture are to produce food and revenue, while forest plantations are used to produce food, timber, fuel wood, fodder, medicinal resources (Campos et al. 2005) and hold ecological and environmental roles including climate regulation, soil and water protection, biodiversity preservation, carbon sequestration, and soil erosion control (Mishra et al. 2003).

Despite its contribution to food and revenue production, agriculture contributes to extensive environmental change (Lal 2015). The misuse of pesticides has led to contamination of land and water resources, affects nontargeted plant and animal species and may favor the emergence of pesticide-resistant pests (Bedano and Anahi 2016). Frequent and deep tillage, inadequate soil cover and poor management of organic residues, physical degradation, and contamination by fertilizers and pollutants are other negative impacts of agriculture on soil quality (Lavelle et al. 2001). In addition, some tree species are often considered to deplete soil nutrients, reduce soil water reserves, acidifying soil (FAO 1985), and failing to provide food supplies and adequate habitat for soil wildlife (FAO 1988).

Key physicochemical parameters for soil quality assessment include the volume of organic matter, topsoil-depth, aggregation, texture, bulk density, infiltration, pH, electrical conductivity, suspected pollutants, soil respiration, and forms of nitrogen, extractable nitrogen, phosphorus, and potassium (Laishram et al. 2012).

Soil and litter arthropods were also identified as useful indicators of land use change on soil properties. They contribute to organic matter degradation, nutrient cycling, and have a quick response to changes in soil properties (McIntyre 2000). The assemblage of species of soil and litter arthropods could highlight changes in soil type and indicate the degree of soil pollution (Nahmani and Lavelle 2002).

Within soil and litter arthropods, insects have been the most commonly used biological indicators of a range of environmental attributes (Cairns and Pratt 1993), especially in aquatic systems (Resh and McElravy 1993). Some orders specifically Lepidoptera (Holloway and Stork 1991), Coleoptera (Kromp 1990), Odonata (Samways, 1981), and Isoptera (Williams, 1993) were used to indicate habitat changes, health of natural areas, farm management, biodiversity conservation planning, wetlands, and forest restoration after disturbances (Peck et al. 1998). Ants were one of the first and now most commonly used as biological indicators of minesite rehabilitation, land use, and land conservation status (Majer 1983).

Ants showed numerous advantages over vertebrates and other arthropods, mainly other insects, because they are extremely abundant, have a relatively high species richness and high trophic levels, and are responsive to changing environmental conditions (Majer 1983). In addition, ants are readily recognized, identified, and easily collected (Majer 1983). Further, ants constitute a large fraction of animal biomass in terrestrial ecosystems (Graham et al. 2009), and are the most divergent group among all social insects (Mahalakshimi and Channaveerapa 2016).

Ants play an important role in soil ecosystems by participating in leaf and litter decomposition, soil aeration, soil mixing, soil porosity, and texture (Fatima et al. 2008), and they contribute to nutrient transport at different soil horizons (Bagyaraj et al. 2016). Previous research has indicated that since ants respond in predicable ways to land changes, their abundance and species richness may predict soil conditions and they may be used to inform management of agricultural land to promote crop growth and ecosystem services (Peck et al. 1998). However, this might be challenged by a lack of their taxonomy to species level and the study of relationships between species of ants with soil physicochemical parameters.

This research fills the gap by focusing on the identification of soil and litter ants to species level and by studying their relationship with soil physicochemical parameters including pH, organic carbon, total nitrogen, available phosphorus, electrical conductivity, cation exchange capacity, bulk density, moisture, aggregate stability, and soil texture. The specific objectives were 1) to identify collected soil and litter ants to species level, 2) to test the variations in abundance, diversity, and evenness of identified soil and litter ant species, 3) to test the variations in soil physicochemical parameters, and 4) to study relationships between soil and litter ant species and soil parameters in native and exotic tree species and in banana and coffee plantations.

Materials and Methods

Study Sites

This study was conducted at the Arboretum of Ruhande and the Rubona agricultural research station, in southern Rwanda (Fig. 1). The Arboretum is located between 2°36′S and 29°44′E, at the

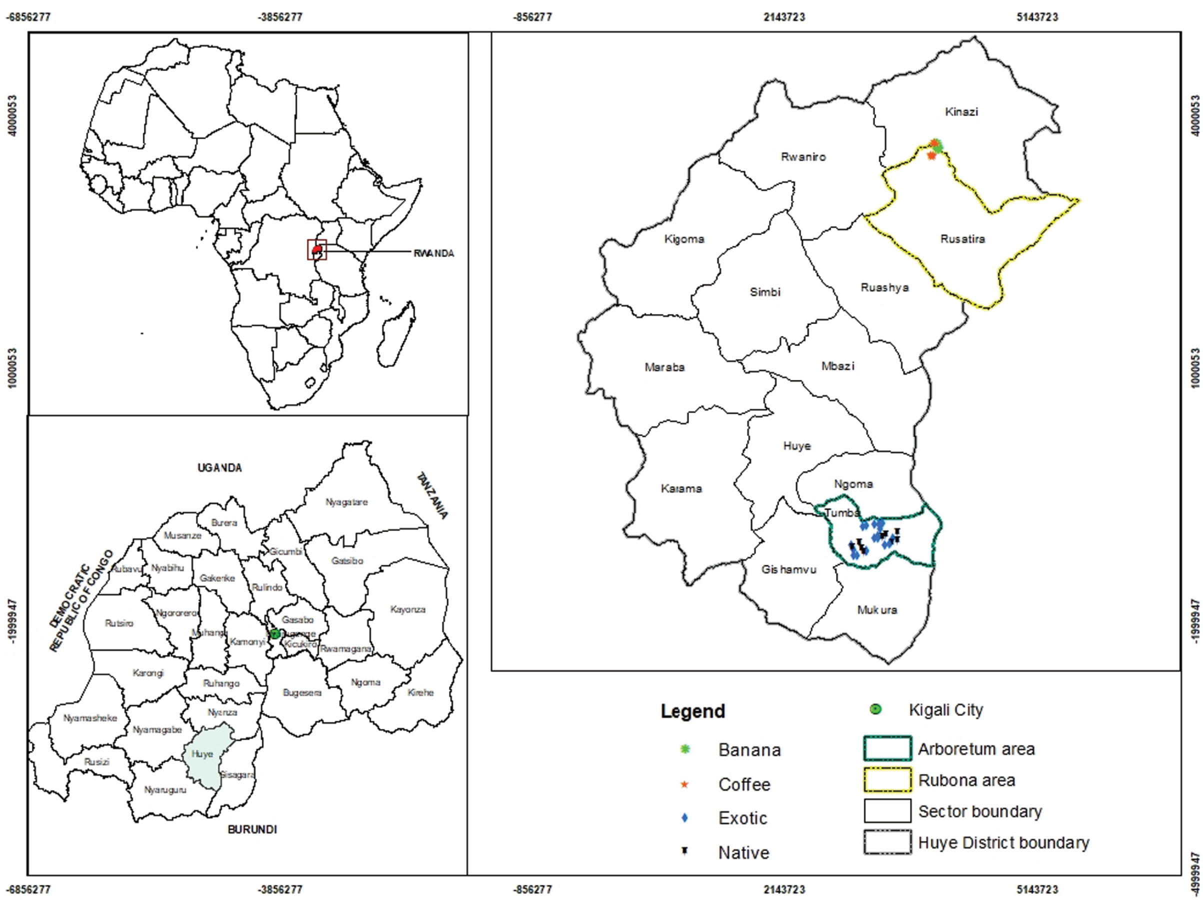

Fig. 1. Area of study (adapted from data of the Centre for Geographic Information System – University of Rwanda).

elevation of 1,737 m (Nsabimana et al. 2009), while the Rubona agricultural research station is located between 2°29′S and 29°46′E, at 1,750 m elevation (Karangwa 2007). Established in 1933, the Arboretum of Ruhande covers an area of 200 hectares (ha), divided into 504 plots of 50 × 50 m each, and hosts around 207 native, agroforestry, and exotic tree species (Nsabimana et al. 2008). Established in 1930, the Rubona agricultural research station is the first centre for agricultural research in Rwanda covering a surface of around 675 ha, including an agricultural research zone used for coffee and banana plantations (ISAR 1989).

Soil cores and soil and litter ants were sampled in mono-dominant stands of exotic and native tree species, and in varieties of coffee and banana plantations. In the Arboretum of Ruhande, a total of three different exotic tree species including *Eucalyptus globulus* subsp. *maideni* (F.Muell.) J.B Kirkp (Origin: Australia, Family: *Myrtaceae*), *Grevillea robusta* A. Cunn ex R. Br. (*Origin: Australia, Family: Proteaceae*), and *Cedrela serrata* Royle (Origin: Australia and Malaysia, Family: Meliaceae) were sampled, while three native tree species, namely *Entandrophragma excelsum* Dawe and Sprague (*Family: Meliaceae*), *Polyscias fulva* Hiern Harms (*Family: Alariaceae*), and *Podocarpus falcatus* (Thunb) Mirb. (*Family: Podocarpaceae*) were sampled. In the Rubona station, sampled coffee plantations included varieties of *HARRAR*, *JACKSON*, and *RABC15*, while banana plantations included *FHIA17*, *INJAGI*, and *MPOROGOMA* varieties. Sample locations within each plantation type were selected randomly and three replicates in each treatment were sampled. Each stand was 50 × 50 m and was separated by 10 m from another.

Sampling and Analysis of Soil Cores

Sampling of soil cores was done in May, 2017. Nine soil cores (10 × 10 cm, 0–5 cm soil layer depth) were collected for soil physicochemical analyses from each pseudo-replicate in the randomly selected locations, and bulked to give one sample after the removal of litter layer (Sayad et al. 2012), leaving 5 m from the edge of the sample plot (Nsabimana et al. 2009), and maintaining a minimum distance of 20 m between sampling points to avoid autocorrelation (Clark et al. 1996). Each collected sample was put in a 1,000 g plastic paper and analyzed for soil pH, soil organic carbon, soil total nitrogen, available phosphorus, electrical conductivity, cation exchange capacity, aggregate stability, and soil textures. Samples for bulk density and moisture were collected by and maintained in metal-cores. Each sample was transferred to the Laboratory of soil and plant analyses, College of Agriculture, Animal Science and Veterinary Medicine, University of Rwanda.

Prior to laboratory analysis soil samples were sieved, and air-dried (Nsabimana et al. 2008). Soil bulk density was determined by the use of core method (Black and Hartge 1986), soil texture was determined by hydrometer method (Bouyoucos 1962), the electrical conductivity was calculated by electrical conductivity meter (Okalebo et al. 2002), moisture was calculated by the ratio of dry weight and initial wet weight of soil sample (Yusuf et al. 2015), the aggregate stability was calculated by wet sieving method (Kemper and Rosenau 1986), while soil pH was calculated by using pH meter in a soil-water suspension in the ratio of 1:1.25 (Watson and Brown 1998). Further, total nitrogen was calculated by colorimetric method through ultraviolet visible spectrophotometer (Okalebo et al. 2002), available phosphorus was calculated by spectrophotometry at 884 nm wavelength (Bray and Kurtz 1945), soil organic carbon was calculated by wet oxidation method (Nelson and Sommers 1982), while cation exchange capacity was calculated by Kjeldahl distillation method (Chapman 1965).

Ant Sampling and Identification

Soil and litter ants were sampled between May and September, 2017. Nine pitfall traps were placed randomly in each sampling site for collecting soil and litter ants (Vasconcellos et al. 2013). Each trap consisted of a transparent plastic bottle (6 cm diameter, 10 cm depth), buried into the soil pit and partly filled with 20 ml of 75% of ethanol. Each trap was placed in the site after the removal of the leaf litter layer (Sabu and Shiju 2010). To avoid edge effects, traps were placed at least 5 m from the edge of the sample plot, and to avoid autocorrelation, traps were separated by at least 6 m (Clark et al. 1996). Traps were maintained in place for 24 h to avoid biases (Mommertz et al. 1996). After this period of time, the content of each trap was emptied into a separate plastic bottle filled with 20 ml of 75% ethanol for each plot, and kept in the laboratory of Biology, College of Education, University of Rwanda.

Ants were identified using Bolton (1994), and genus names were updated following Fisher and Bolton (2016). Within each genus, specimens were identified to species level by different identification keys (Bolton and Fisher 2008, Garcia et al., 2010, Rigato, 2016). Specimens were then compared with image banks (AntWeb 2002), and finally with the ant collection from the museum of Royal Belgium Institute of Natural Sciences (RBINS) for definitive species identification. When the name of the species was not found in the identification keys, it was designated by the abbreviation SP followed by the number from 01 (SP01). Reference collection is permanently housed at RBINS and at the Centre of Excellence for Biodiversity Conservation and Natural Resources Management, University of Rwanda.

Data Analysis

One-way analysis of variance was used to study variations in abundance of soil and litter ant species and soil physicochemical parameters under plots of forest tree species, coffee and banana plantations (Sayad et al. 2012). Only the most abundantly caught species were used for statistical analysis (Dekoninck et al. 2007) and rare species were down weighted by the use of the parallel discrimination rates calculated by taking the homogenized canonical coefficients times correlation coefficients. The greater the positive parallel discrimination rates value (Borcard et al. 1992), the more effective the variable is at discriminating between plots of native and exotic tree species and between coffee and banana plantations to reduce their influence on the ordination results (ter Braak and Smilauer 1998).

Treatment effects on ant species and soil physicochemical parameters were analyzed with nonmetric multidimensional scaling and the analysis of similarity based on Bray-Curtis similarity (Ashford et al. 2013). Shannon diversity and species evenness were calculated to provide more information on sampled soil and litter ant species (Dekoninck et al. 2010). The environmental variables which best explained ant species response to soil physicochemical parameters and land use were identified and illustrated using the canonical correspondence analysis (ter Braak 1986). All these statistics were performed using PAST software.

Results

Ant Community Composition

A total of 1,680 individuals comprising 30 species, 14 genera, and 4 subfamilies were identified in this study (Table 1). Within the subfamily Dorylinae, one genera *Dorylus* and two species including *Dorylus congolensis* and *Dorylus* SP02 were identified. Three genera namely *Polyrhachis, Lepisiota*, and *Camponotus*, comprising nine species were found in the subfamily of Formicinae. The genus *Polyrhachis* had only one species, *Polyrhachis militaris*, while

Table 1. Abundance (mean ± standard deviation) of identified ant species in different land uses in southern Rwanda

Subfamily and species	Abundance by land use (mean ± standard deviation)			
	Exotic tree species	Native tree species	Coffee plantations	Banana plantations
Subfamily: Dorylinae				
Dorylus congolensis		0.22 ± 0.67		
Dorylus SP02	0.11 ± 0.33			
Subfamily: Formicinae				
Camponotus cinctellus	5.00 ± 0.650	0.44 ± 0.73	2.00 ± 1.00	4.00 ± 3.61
Camponotus maculatus	0.11 ± 0.33	0.11 ± 0.33		
Camponotus SP03	0.56 ± 1.67	0.11 ± 0.33		
Camponotus SP04	0.33 ± 0.11			
Camponotus SP05	0.22 ± 0.67	0.11 ± 0.33		
Camponotus SP06	0.44 ± 0.73	0.22 ± 0.44		1.00 ± 1.73
Lepisiota SP01	0.22 ± 0.67			
Lepisiota SP02			0.33 ± 0.58	
Polyrhachis militaris	<0.00			
Subfamily: Myrmicinae				
Crematogaster SP01	0.33 ± 1.00			
Myrmicaria opaciventris	2.00 ± 3.16	19.11 ± 4.56	171.33 ± 137.41	
Myrmicaria SP02	15.33 ± 4.73	27.22 ± 6.35		
Pheidole SP01	1.00 ± 1.50	0.89 ± 1.36	10.33 ± 6.66	
Pheidole SP02	0.56 ± 0.01			1.67 ± 0.89
Pheidole SP03	0.33 ± 1.00	0.67 ± 1.32		6.67 ± 6.51
Tetramorium laevithorax	17.22 ± 24.31		2.33 ± 0.40	4.33 ± 0.51
Tetramorium zonacaciae	0.33 ± 1.00	1.56 ± 0.74		0.33 ± 0.58
Tetramorium mossamedense	0.33 ± 1.00			
Tetramorium dedefra		0.11 ± 0.33		
Tetramorium delagoense		0.12 ± 0.33		
Tetramorium simillimum			1.00 ± 0.73	
Meranoplus inermis		0.11 ± 0.33		
Monomorium SP01			0.33 ± 0.58	
Subfamily: Ponerinae				
Bothroponera talpa		0.22 ± 0.44		
Bothroponera crassa			0.11 ± 0.33	0.33 ± 0.58
Odontomachus troglodytes	13.22 ± 4.90	5.33 ± 4.30	1.67 ± 1.15	15.67 ± 8.96
Phrynoponera gabonensis	0.44 ± 0.08	0.56 ± 0.67		
Mesoponera subiridescens		0.11 ± 0.33		

the genus *Lepisiota* had two species, *Lepisiota* SP01 and *Lepisiota* SP02. The genus *Camponotus* had six species including *Camponotus cinctellus*, *Camponotus maculatus*, *Camponotus* SP03, *Camponotus* SP04, *Camponotus* SP05, and *Camponotus* SP06.

The subfamily Myrimicinae included 6 genera and 14 species. The genus *Crematogaster* had only one species, *Crematogaster* SP01, while the genus *Myrmicaria* had two species, *Myrmicaria opaciventris* and *Myrmicaria* SP02. Three species were found for the genus *Pheidole*. *Pheidole* SP01, *Pheidole* SP02, and *Pheidole* SP03. The genus *Meranoplus* and *Monomorium* each had one species including *Meranoplus inermis* and *Monomorium* SP01. The genus *Tetramorium* had six species. *Tetramorium laevithorax, Tetramorium zonacaciae, Tetramorium mossamedense, Tetramorium dedefra, Tetramorium delagoense*, and *Tetramorium simillimum*. The Ponerinae subfamily was represented by four genera. The genus *Bothroponera* had two species, *Bothroponera talpa* and *Bothroponera crassa*, while the genus *Odontomachus* had only one species *Odontomachus troglodytes*. The genus *Phrynoponera* and *Mesoponera* each had one species, *Phrynoponera gabonensis* and *Mesoponera subiridescens*.

Abundance, Diversity, and Evenness of Soil and Litter Ant Species

Higher abundance (total number of the mean individual ants collected) of collected soil and litter ant species was found in plots of coffee (6.32 ± 5.12) plantations than in the plots of exotic (1.93 ± 0.45) and native (1.91 ± 0.48) tree species. Lower abundance levels (1.12 ± 1.06) were found in plots of banana plantations. Species of *T. laevithorax* showed higher abundance in plots of exotic tree species, species of *Myrmicaria* SP02 showed higher abundance in plots of native tree species, species of *M. opaciventris* showed higher abundance in plots of coffee plantations, while species of *O. troglodytes* showed higher abundance in plots of banana plantations and occurred in all land uses (Table 1).

The test for treatment effects on soil and litter ant species indicated that there were no significant differences in abundance of collected soil and litter ant species in plots of exotic tree species ($F = 0.8$, df = 5, $P > 0.05$), native tree species ($F = 0.5$, df = 2, $P > 0.05$), coffee ($F = 0.2$, df = 2, $P > 0.05$), and banana ($F = 0.4$, df = 2, $P > 0.05$) plantations. The nonmetric multidimensional scaling based on the Bray-Curtis similarity index indicated greater conformity between samples (stress = 0.17), while the composition of ant species differed significantly among plots of exotic and native tree species and plots of coffee and banana plantations ($R = 33\%$, $P < 0.05$).

Higher diversity was found in plots of exotic tree species (H' = 1.99 ± 0.34) and banana plantations (H' = 1.53 ± 0.39) compared to plots of native tree species (H' = 1.34 ± 0.74) and coffee plantations (H' = 1.46 ± 0.43), while higher evenness was found in plots of coffee (E' = 0.66 ± 0.12) and banana plantations (E' = 0.33 ± 0.18) compared to plots of exotic tree species

(E' = 0.28 ± 0.22) and native tree species (E' = 0.24 ± 0.519). The average species diversity was lower (H' = 0.49 ± 0.54) and the average evenness was higher (E = 0.54 ± 0.15) in plots of native and exotic tree species, compared to the plots of coffee and banana plantations (H' = 0.52 ± 0.68 and E = 0.41 ± 0.0.46), but these differences were not significant ($F = 0.306$, $P > 0.05$).

The parallel discrimination rate indicated the species of *M. opaciventris, Myrmicaria* SP02, *O. troglodytes, T. laevithorax, C. cinctellus, Pheidole* SP01, *Pheidole* SP03, *T. zonacaciae, Pheidole* SP02, *Camponotus* SP06, *P. gabonensis, B. talpa, C. maculatus*, and *T. simillimum* to be more abundant than other identified ant species and to be the most highly collected species regardless of plot types.

Variation in Soil Physicochemical Parameters

Variations were found in soil physicochemical parameters (Table 2). Significant differences in soil physicochemical parameters were found among plot types: exotic ($F = 2.6$, df = 11, $P < 0.05$), native ($F = 2.8$, df = 11, $P < 0.05$), coffee ($F = 1.2$, df = 11, $P < 0.05$), and banana ($F = 2.0$, df = 11, $P < 0.05$) plantations. The test for treatment effects on soil physicochemical parameters indicated less conformity between samples (stress = 0.086), while the composition in soil physicochemical parameters differed significantly among plots of exotic and native tree species and plots of coffee and banana plantations ($R = 42.89\%$, $P < 0.05$).

Relationship Between Ant Species and Soil Physicochemical Parameters

The canonical correspondence analysis explained 85.94% (Eigen value 1 = 0.61, CCA1 = 60.6%, Eigen value 2 = 0.5, CCA 2 = 25.3%) of the response of soil and litter ant species to soil physicochemical parameters and land use. Plots of exotic tree species were rich in electrical conductivity, total nitrogen, soil moisture, bulk density, and clay and silt soil textures and were mainly inhabited by the species of *Camponotus* SP05 and *Tetramorium laevithorx* (Fig. 2).

Plots of native tree species were rich in soil organic carbon and mainly inhabited by the species of *Myrimicaria* SP02 and *P. gabonensis*. Plots of banana plantations had high levels of electrical conductivity and soil pH. They were mainly inhabited by the species of *O. troglodytes, C. cinctellus, Camponotus* SP06, *Pheidole* SP03, and *Pheidole* SP02. Plots of coffee plantations had higher levels of sandy soil texture, aggregate stability, and they were mainly inhabited by *C. maculatus, M. opaciventris*, and *Pheidole* SP01 ant species (Fig. 2).

Species of *Camponotus* SP05 were strongly associated with soil moisture. Species of *B. talpa* and *T. zonacaciae* discriminated between native tree species, coffee plantations, soil organic carbon, aggregate stability, and sandy soil texture, while species of *Pheidole* SP02 were strongly associated with soil cation exchange capacity. No strong correlations were found between soil physical chemical parameters and species of *C. cinctellus, O. troglodytes, Myrmicaria* SP02, *P. gabonensis, Camponotus* SP06, *M. opaciventris, Pheidole* SP03, *T. simillimum, Pheidole* SP01, *C. maculatus*, and *T. laevithorax* (Fig. 2).

Discussion

Results of this study indicated that soil and litter ant species are differently distributed in exotic and native tree species and plantations of coffee and banana. They are also differently associated to soil physicochemical parameters. Only species of *O. troglodytes* and *C. cinctellus* occurred in all land uses which is a sign of tolerance to a wide range of soil properties and land use changes (McIntyre et al., 2001, Vanthomme et al., 2016).

Exotic tree species had higher soil total nitrogen, electrical conductivity, moisture, bulk density, and silt and clay soil textures. Higher levels in total nitrogen found in this study were also found in other study and were probably related to the decomposition of the litter fall from trees, shrubs, and herbs (Kassa et al. 2017). The same study indicated that the relationship between soil electrical conductivity, moisture silt and clay soil textures might be due to the presence of tree branches, shrubs canopy, litter and root protection of the surface soil against leaching, soil erosion as well as less land management interventions (Kassa et al. 2017).

The strong association between *Camponotus* species with soil moisture might be due to the mode of nutrition of these ant species. The majority of the genus *Camponotus* are omnivores (Feldhaar et al. 2007). This mode of nutrition may speed up the return of the organic matter concentrated in tissues of animals and plants in the soil (Petal 1978). A previous study indicated the relationship between soil organic matter, soil conductivity, water holding capacity, soil and silt soil textures (Cardoso et al. 2013). For example, the greater levels of soil organic matter allow a better aggregation of soil particles resulting in an increase in soil porosity, which in turn improves soil permeability for water and air (Tejada et al. 2006).

Species of *B. talpa* and *T. zonacaciae* discriminated between soil organic carbon, sandy soil texture, aggregate stability, native tree species and coffee plantations. Soil organic carbon is an index of sustainable land management (Woomer et al. 1994) used to indicate the soil fertility, structure, stability, and extent of erosion (Laishram et al. 2012). The occurrence of higher topsoil organic carbon in

Table 2. Variations (mean ± standard deviation) in different land uses in southern Rwanda

		Soil pH	SOC (%)	Tot. N (%)	Av. P (mg/kg)	EC (mS/cm)	CEC (Meq)	BD (g/cm3)	H (%)	AS (%)	Clay (%)	Silt (%)	Sandy (%)
Exotic tree	Mean	5.30	7.57	0.62	4.03	0.28	7.30	0.92	23.10	0.55	14.57	17.45	68.02
species	st.dev	0.30	2.92	0.30	1.36	0.08	0.30	0.10	3.40	0.10	4.44	2.82	7.02
Native tree	Mean	5.87	6.43	0.53	3.70	0.40	7.77	0.93	25.17	0.57	13.67	16.43	69.90
species	st.dev	0.42	0.42	0.06	0.89	0.10	0.45	0.15	4.67	0.15	2.17	2.14	3.94
Coffee	Mean	5.80	3.30	0.30	15.50	0.27	7.67	0.77	12.07	0.70	12.67	11.00	76.33
plantations	st.dev	0.44	1.31	0.26	10.33	0.15	0.40	0.12	1.20	0.10	2.08	3.00	3.21
Banana	Mean	6.10	2.60	0.43	13.77	0.37	8.00	0.80	18.47	0.63	12.67	11.67	75.67
plantations	st.dev	0.53	0.72	0.12	8.01	0.15	0.36	0.30	0.76	0.06	1.53	1.15	2.52

AS = Aggregate stability; Av. P = Available phosphorus; BD = Bulk density; CEC = Cation exchange capacity; EC = Electrical conductivity; H = Moisture; SOC = Soil organic carbon; Tot. N = Total Nitrogen.

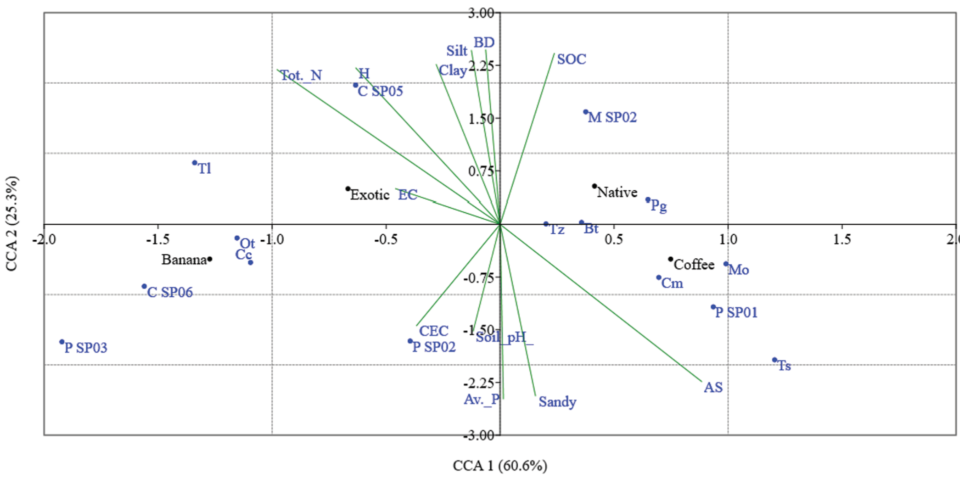

Fig. 2. Relationship between the abundance of soil and litter ant species, land use, and soil physicochemical parameters (SS: *Senna spectabilis*, EG: *Eucalyptus grandis*, EM: *Eucalyptus maideni*, CC: *Calliandra calothrysus*, CS: *Cedrela serrata*, GR: *Grevillea robusta*, EE: *Entandrophragma excelsum*, PF: *Polyscias fulva*, PFs: *Podocarpus falcatus, C1: HARRAR, C2: JACKSON, C3: RABC15, B1: FHIA17, B2: Injagi, B3: Mporogoma,* SOC: Soil Organic Carbon, Tot. N: Total Nitrogen, Av. P: Available phosphorus, EC: Electrical Conductivity, CEC: Cation exchange capacity, BD: Bulk Density, H: Moisture , AS: Aggregate Stability, Mo: *Myrmicaria opaciventris, M* SP02*: Myrmicaria* SP02*, Ot: Odontomachus troglodytes, Cc: Camponotus cinctellus, C* SP05*: Camponotus* SP05*, C* SP6*: Camponotus* SP06*, P* SP01*: Pheidole* SP01*, P* SP02*: Pheidole* SP02*, P* SP03*: Pheidole* SP03*, Tz: Tetramorium zonacaciae, Pg: Phrynoponera gabonensis, Bt: Bothroponera talpa, Cm: Camponotus maculatus, Tl: Tetramorium laevithorax, Ts: Tetramorium simillimum).*

native tree species can be due to the leaf litter fall from trees and shrubs added to the surface soil (Nsabimana et al. 2008) or from dead trees and shrub roots and mycorrhizal fungi contribution of organic matter in the subsoil (Yimer et al. 2007). However, little is known about the biology of *Phrynoponera* (Bolton and Fisher 2008) and *Bothroponera* (Joma and Mackay 2015) and less is known about their contribution to soil quality.

During our field data collection, we found that twice per year, each plot of coffee plantation is treated by organic fertilizers and this might be the cause of higher levels in available phosphorus. We also observed that the majority of coffee plots were weeded but not mulched and this practice might be the major cause of soil erosion and hence the source of higher levels in sandy soil texture (Kassa et al. 2017). The association of *M. opaciventris*, *C. maculatus*, *Pheidole* SP01, and *T. simillimum* ant species with soil aggregate stability might be due to the characteristics of soil aggregates which serve as refuge to some ants, which in turn affects soil aggregates through their secretions cementing substances, and the stimulation of microbial activities (Preston et al. 2001.

Higher levels of cation exchange capacity were found in banana plantations and showed strong association with species of *Pheidole* SP02. A recent study indicated that higher levels of cation exchange capacity vary with exchangeable base cations (Kassa et al. 2017). In native and agroforestry tree species, this soil parameter were found to be influenced by organic matter and clay contents in the topsoil, from which the organic matter formed by trees and shrubs litter underwent a complete microbial breakdown and decomposition (Nsabimana et al. 2008). For our study, higher levels in soil cation exchange capacity might be due to the decomposition of maize reserves and banana leaves used for mulching and to the application of organic manure, which is added in soil twice per year after weeding and before mulching activities.

Conclusion

Results of this study indicated variations in soil physicochemical parameters depending on the land use. Species of *C. cinctellus* and *O. troglodytes* occurred in all land uses which is a sign of tolerance to a wide range of soil properties and land use. In addition, these species, together with *Myrmicaria* SP02, *P. gabonensis*, *Camponotus* SP06, *M. opaciventris*, *Pheidole* SP03, *T. simillimum*, *Pheidole* SP01, *C. maculates*, and *T. laevithorax* were not strongly correlated with soil physicochemical parameters across all land uses. We conclude that they are not good indicators of soil quality for this study.

Species of *Pheidole* SP02 showed strong correlation with cation exchange capacity in plots of banana plantations, species of *Camponotus* SP05 showed strong correlation with soil humidity in plots of exotic tree species, while species of *T. zonacaciae* and *B. talpa* discriminated between native tree species and coffee plantations as well as between soil organic carbon, sandy soil texture and aggregate stability. We conclude that species of *Pheidole* SP02, *Camponotus* SP05, *T. zonacaciae* and *B. talpa* differently indicate soil quality depending on the land use.

The findings from this study indicated also a decreasing in diversity of soil and litter ant species from exotic tree species and coffee plantations to native tree species and varieties of banana plantations. This allows us to conclude that there is an important role of exotic tree species and coffee plantations in conservation of soil and litter ant species.

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