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Diversity and abundance of soil-litter arthropods and their relationships with soil physicochemical properties under different land uses in Rwanda

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ABSTRACT
Soil-litter arthropods are critical for ecosystem functioning and sensitive to land use change, and hence to the variations in soil physicochemical properties. The relationships between soil-litter arthropod communities and soil physicochemical properties, however, remain poorly studied in Rwanda. We explored the relationships between the families of soil-litter arthropods and soil properties in exotic and native tree species, and in varieties of coffee and banana plantations. Soil-litter arthropods were sampled by using Berlese funnels, hand sorting, and pitfall traps, and were identified to the family level. Soil cores were collected and analysed for soil pH, available phosphorus, total nitrogen, soil organic carbon, silt, clay and sand. A total of 3176 individuals of soil-litter arthropods were collected, identified and classified into 13 orders and 23 families. Higher abundance was found in soil and litter sampled in plots of native tree species and banana plantations compared to exotic tree species and coffee plantations. Higher diversity was found in plots of native and exotic tree species. The analysis of soil physicochemical properties indicated that native tree species offer suitable conditions of studied soil properties. The study of the relationships between the land use, soil properties and families of soil-litter arthropods indicated positive correlations and relationships mainly in native tree species. We conclude that forest with native tree species play an important role in the conservation of soil-litter arthropods and for maintenance of better soil conditions.

KEY WORDS
exotic; native; banana; coffee; soil-litter arthropod; soil properties

Introduction

The species diversity of soil and litter fauna is mainly dominated by arthropods (Yi and Moldenke 2005). Families of soil-litter arthropods occur in all land uses (Nsabimana 2013), and they contribute to soil ecosystem processes in different ways (Ashford et al. 2013). Some groups of soil-litter arthropods such as Collembola, Oribatida, Myriapoda and Isopoda, for example, decompose organic matter. They also recycle soil nutrients, improve agricultural productivity, plant growth, biological and physicochemical soil conditions (Culliney 2013). The breakdown of organic matter by soil-litter arthropods is essential for the production of organic matter used by other soil biodiversity, including Fungi, Bacteria, and plants (Conant 2010). Other groups such as ants and termites create galleries and pores in soil horizons that allow soil respiration and facilitate water infiltration (de Bruyn and Conacher 1990).

Different land uses, specifically forest plantations and intensive agriculture (Keenan et al. 2015), affect soil processes (Bini et al. 2013). Some exotic tree species are known to cause soil acidification, and to use high quantities of water and nutrients, for example in areas dominated by *Eucalyptus* plantations (Nsabimana 2013). In agriculture, tillage decreases soil organic matter, while fertilizers used to increase agricultural yields cause variations in soil ecological functions (Aspetti et al. 2010). Furthermore, tillage affects soil physicochemical properties, and hence soil quality and soil health (Laishram et al. 2012). The main agricultural practices considered to have negative effects on soil biota comprise the use of pesticides, frequent and deep tillage, inadequate soil cover and poor management of organic residues, physical degradation, soil contamination, and pollution (Siqueira, Silva, and Paz-Ferreiro 2014).

Most research on arthropods focussed on the effects of altitudinal variations, geographic distances and seasonal variations on the distribution of soil-litter arthropods (Basset et al. 2015). Some arthropods, including ants and wasps (Hymenoptera), butterflies and moths

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(Lepidoptera), beetles (Coleoptera), and spiders (Araneae), were mainly studied as biological indicators of the environmental change (Maleque, Maeto, and Ishii 2009; Nsengimana et al. 2018). To assess soil quality and soil health, studies often focus on springtails (Collembola) and ants (Peck and Carolina 1998; Wall 1999; Luke et al. 2014; Aspetti et al. 2010). Other studies focus on variations in soil properties such as soil pH, soil nutrients, soil texture, and the capacity of soils for water retention (Kassa et al. 2017). To date, few studies have focussed on the relationships between families of soil-litter arthropods and soil physicochemical properties under different land uses (Ashford et al. 2013; Culliney 2013). Findings of these studies indicate that soil-litter arthropods provide important soil ecosystem services; they maintain soil fertility, soil structure, and regulate hydrological processes, nutrient cycling and the decomposition of the leaf-litter.

In Rwanda, only one study dealt with effects of seasonal variations on families of soil-litter arthropods in monodominant plots of different tree species, and focussed on their relationships with soil pH (Nsabimana 2013). This study indicated positive relationships between the pH of soil and litter, and diversity indices of identified families of soil-litter arthropods. In addition to the little information about the biodiversity of soil fauna in this region, less is known about the relationships between the families of soil-litter arthropods and soil physicochemical properties, other than soil pH. Furthermore, land use change is on the rise in Rwanda, where natural lands are transformed into agricultural lands and forest plantations (Rushemuka, Bock, and Mowo 2014). Unfortunately, less is known about how land use change affects soil properties and the abundance and diversity of soil fauna, specifically families of soil-litter arthropods.

This research fills these gaps by investigating the relationships between soil-litter arthropods and soil physicochemical properties. It was done in forest and agricultural land use, dominated by exotic and native tree species, and by varieties of coffee and banana plantations. The main objectives were (1) to identify soil-litter arthropod diversity and abundance in each land use, (2) to study the variations in soil physicochemical properties, namely soil pH, soil organic carbon, soil total nitrogen, soil available phosphorus, and soil texture, (3) and to study the relationships between soil-litter arthropod abundance and soil physicochemical properties. We hypothesized that (1) native and exotic tree species have higher abundance and diversity of families of soil-litter arthropods than the varieties of coffee and banana plantations, and (2) these will be affected by differences in soil properties.

Materials and Methods

2.1. Study sites

Data were collected at the Arboretum of Ruhande and the Rubona agricultural research station (Figure 1). The Arboretum of Ruhande is located at 2°36’S and 29°44’E, at the elevation of 1737m (Nsabimana et al. 2009), while the Rubona agricultural research station is located at 2°29´S and 29°46´E, at 1750m elevation (Nsengimana et al. 2018). With its surface area of around 200ha, the Arboretum of Ruhande was used as human settlement and multiple crop land until 1933. After, it was subdivided into 504 plots, each of 50 x 50m. Different tree species were planted in each plot, totalling 207 native, agroforestry and exotic tree species, some of them being replicated (Nsabimana et al. 2008). The Rubona agricultural research station was established in 1930. It is the

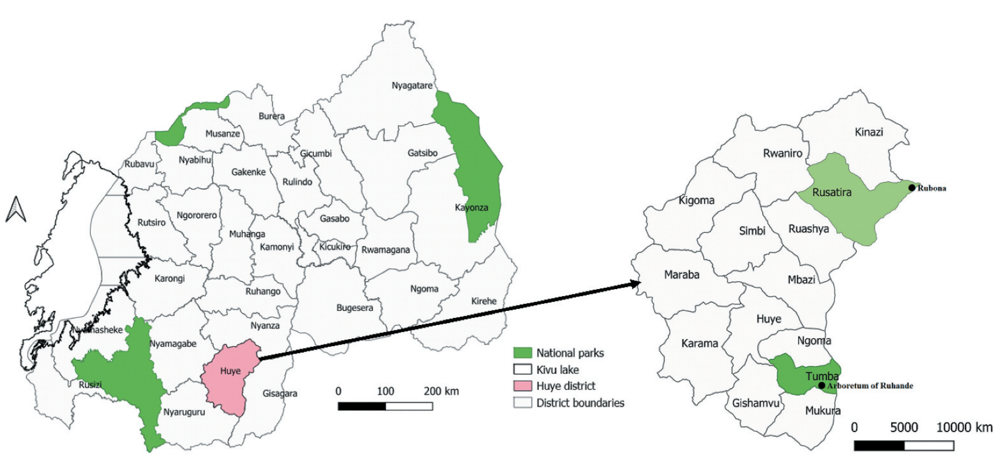

Figure 1. Area of study illustrated by the use of Quantum Geographic Information System 3.10 (Shapefiles were adapted from data of the Centre of Geographic Information System –College of Science and Technology, University of Rwanda)

first centre for agricultural research in Rwanda; it covers an area of around 675ha, including an agricultural research zone with different varieties of coffee and banana plantations (Nsengimana et al. 2018).

2.2. Experimental design and sampling

At the Arboretum of Ruhande, samples were taken in plots of exotic and native tree species. At the Rubona agricultural research station, samples were collected in plots of coffee and banana plantations (Table 1). Each land use type was replicated three times and plots of 50 x 50m were maintained. In each replicate, a total of 9 sampling points, each of 1m^2 (Figure 2), were selected. The distance of 5m from the edge of the sample plot was left outside of the area of study to avoid edge effects. To avoid autocorrelation, each sampling point was separated from the other by a distance of 16m (Figure 2). When the placement of the sampling point met an obstacle like a tree or marching columns of some soil-litter arthropods such as ants, a distance of 2m was maintained from the obstacle going inside the plot to avoid biases.

2.3. Arthropod collection and identification

Pitfall traps, hand sorting and Berlese funnels were used for sampling soil-litter arthropods. Data were collected between April and July, 2018. A total of nine pitfall traps (Figure 2) were placed in each sampling point (Vasconcellos et al. 2013). Each trap consisted of a transparent plastic bottle having the size of 6cm in diameter and 10cm in depth. The trap was buried into the soil pit and partly filled with 20ml of 75% ethanol. To prevent rainwater, leaves and debris from entering the trap, each trap was covered with a piece of 100cm^2 cardboard lid. Each trap was set after the removal of the leaf-litter layer and maintained in place for 24 hours to maximize chances of collecting soil-litter arthropods (Nsengimana et al. 2018).

Through hand sorting, soil-litter arthropods were collected using a 1m^2 pickup point in 10cm soil depth after the leaf-litter layer was removed (Sayad et al. 2012). Collected individuals of soil-litter arthropods were conserved in a plastic container filled with 20ml of 75% ethanol (Wang, Tong, and Wu 2014). Using Berlese funnels, soil cores and litter layers were collected in

Table 1. Treatment, category of each treatment, plot number of the replicate, stand age, geographic location (latitude and longitude), and altitude of replicates of exotic and native tree species and varieties of coffee and banana plantations.

Treatments	Category	Plot number	Stand age (years)	Latitude	Longitude	Altitude
Eucalyptus maidenii	Exotic	1	85	28.760190	-1.521690	1734
		179	73	28.758360	-1.521890	1702
		377	70	28.764000	-1.520890	1679
Cedrela serrata	Exotic	56	36	28.753000	-1.534060	1729
		111	74	28.764110	-1.528220	1731
		36	82	28.767190	-1.523360	1709
Grevillea robusta	Exotic	104	78	28.756310	-1.531170	1710
		150	35	28.769940	-1.527000	1727
		322	39	28.776310	-1.525720	1707
Entandrophragma excelsum	Native	44	70	28.753560	-1.536890	1734
		54	67	28.754920	-1.536860	1719
		78	67	28.768170	-1.520440	1708
Podocarpus falcatus	Native	156	72	28.752110	-1.531580	1708
		196	-	28.766690	-1.520640	1710
		226	67	28.765920	-1.526670	1697
Polyscias fulva	Native	240	69	28.759690	-1.534530	1713
		262	69	28.760030	-1.534940	1711
		268	69	28.773890	-1.527750	1700
HARRAR	Coffee	A	6	28.758690	-1.535920	1684
		B	6	28.752580	-1.533580	1682
		C	6	28.768310	-1.527890	1682
JACKSON	Coffee	A	6	28.757220	-1.534140	1687
		B	6	28.773030	-1.530890	1684
		C	6	28.776170	-1.530000	1786
RABC15	Coffee	A	6	28.765940	-1.528030	1703
		B	6	28.769530	-1.531720	1707
		C	6	28.772170	-1.531030	1706
FHIA17	Banana	A	6	28.795610	-1.322690	1727
		B	6	28.796170	-1.324110	1730
		C	6	28.796920	-1.324190	1726
INJAGI	Banana	A	6	28.796670	-1.324640	1725
		B	6	28.797440	-1.324860	1727
		C	6	28.797280	-1.325720	1723
MPOROGOMA	Banana	A		28.796030	-1.322640	1726
		B	6	28.796830	-1.322920	1723
		C	6	28.796810	-1.323610	1726

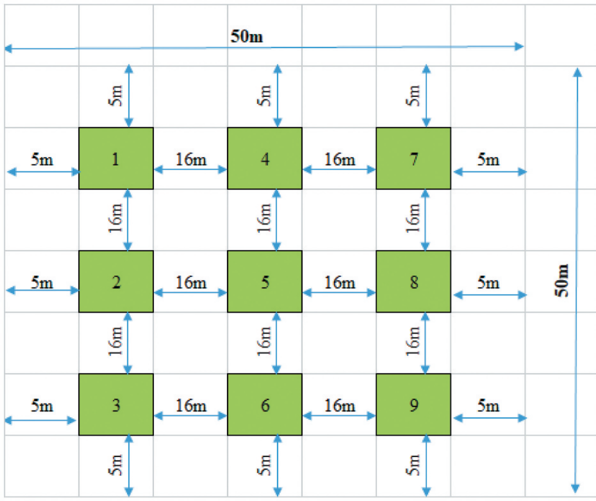

Figure 2. Sampling scheme for soil-litter arthropods and soil cores in each replicate at the Arboretum of Ruhande and Rubona agricultural research station. The size of each plot was 50 x 50m, sampling points were placed in $1m^2$ (indicated in green colour), the distance from the edge was 5m, and the distance between sampling points was 16m.

each sampling point and taken to the laboratory. To extract specimens of soil-litter arthropods from collected soil and litter, a 60-watt bulb placed at 10cm above the funnel for a period of 24 hours was used to heat the samples. The bottom of each apparatus was filled with 20ml of 75% ethanol to catch biota as they dropped from the funnel. Then, the specimens were conserved separately in plastic containers half-filled with 20ml of 75% ethanol (Manhães et al. 2013).

Collected soil-litter arthropods of each sampling technique and land use were taken separately to the laboratory of biology, College of Education, University of Rwanda. Each sample was analysed independently from others, and classified to the family level (Wang, Tong, and Wu 2014). The classification was firstly done morphologically under Olympus SZH10 microscope, and then confirmed by the use of dichotomous keys in the literature (Mignon, Haubruge, and Francis 2016; Biaggini et al. 2007). Names of families of soil-litter arthropods were confirmed after comparing our specimens with those stored at the Royal Belgian Institute of Natural Sciences (RBINS). Samples are housed in the centre of excellence in biodiversity and natural resources management, College of Science and Technology, University of Rwanda.

2.4. Soil data collection and laboratory analysis

In May 2018, nine soil cores (10cm x 10cm, 0-10cm soil layer depth) were collected at each sampling point. Samples from the same replicate were bulked together to give one representative sample (Sayad et al. 2012), put in a plastic bag and taken to the laboratory of soil and plant analyses, College of Agriculture, Animal Science and Veterinary Medicine, University of Rwanda. Each sample was then analysed separately. Prior to laboratory analysis, soil samples were sieved and air-dried for 48 hours (Nsabimana et al. 2009) at 35 - 40°C (Mallarino 2018). Soil pH was measured by taking soil-water suspension in the ratio 1:2, where 20ml of distilled water were added to 10g of soil in a beaker. The content was stirred with a glass rod intermittently, then the suspension was stabilized for half an hour. The levels of pH in the solution were taken by the use of portable RS232 pH meter (Station 1998).

Soil texture was determined by using the hydrometric method, where the organic matter was decomposed by hydrogen peroxide and dispersed with sodium hexameta-phosphate (Yeshaneh 2015). Soil organic carbon was calculated by dissolving 1g of soil in 500ml of distilled water. To this solution, 10ml of potassium dichromate solution and 20ml of concentrated sulfuric acid were added. The mixture was stabilized for 30 minutes, and then diluted with 200ml of distilled water. Furthermore, 10ml of 85% ortho-phosphoric acid and 1ml of diphenylalanine were added, and the solution was titrated with 0.5N ferrous sulphate until a turbid blue colour changed to brilliant green (Dutta and Agrawal 2002). Total nitrogen was calculated by using the colorimetric method through ultraviolet visible spectrophotometer (Joel et al. 2015), while the available phosphorus was calculated by spectrophotometry at 884nm wavelength (Sarker et al. 2014).

2.5. Data analysis

Abundance and diversity of soil-litter arthropods

The mean abundance of the families of soil-litter arthropods was calculated for each land use in Excel 2016. Later, the mean abundance was used to calculate the Shannon index of diversity (H'), and evenness (E') using the Paleontological Statistics (PAST) 3.8 software. The main purpose was to provide more information on the diversity of families of soil-litter arthropods for each land use (Ashford et al. 2013). In addition, data were analysed using Kruskal-Wallis analysis of variance in PAST 3.8. For each land use, variations in abundance were visualized by the bar graphs, standard deviations and significance using Excel 2016. Additionally, the general univariate linear model analysis of variance was performed through Tukey honestly significant difference for multiple comparison between land uses using the Statistical Package for the Social Sciences (SPSS) 25 software. Findings were given in a table, and significant differences were indicated by letters according to the P values (Doléc and Chessel 1994).

Soil physicochemical characteristics

In relation to soil physicochemical properties, variations per land use were analysed based on plot means, and then by Kruskal-Wallis analysis of variance to assess significant differences between the mean values in plots used for exotic and native tree species, and in plots used for coffee and banana plantations (Kassa et al. 2017). In addition, significant differences for each soil physicochemical parameter per land use were analysed using Tukey honestly significant difference for multiple comparison. Significant differences were indicated by letters based on P values. Statistical tests were performed using Excel 2016, PAST 3.8, and SPSS 25.

Relationships between soil-litter arthropods and soil physicochemical properties

To analyse the relationships between soil-litter arthropod families and soil properties, we calculated a Pearson correlation matrix between soil-litter arthropods and soil physicochemical properties pairwise for each land use system using native, exotic, coffee and banana plantations as co-variables, with a significance threshold of $P < 0.05$ (de Filho et al. 2016). The relationships between the assemblage composition of soil-litter arthropod families and soil physicochemical parameters under each land use were elucidated by the canonical correspondence analysis (CCA). Statistical analyses were done in PAST 3.8 and SPSS 25.

Results

Abundance and diversity of soil-litter arthropods

A total of 3176 individuals of soil-litter arthropods comprising 13 orders and 23 families were identified. Responses to land use by different arthropod families were mixed and family dependent. Greater abundance of soil-litter arthropods was found in soil and litter collected under native tree species and banana plantations than those collected under exotic tree species and coffee plantations (Table 2, Figure 3). The analysis of variance for the overall abundance of soil-litter arthropods indicated significant differences in abundance across all land uses (χ^2 = 49.8, $P < 0.001$). Significant differences were also found between plots occupied by exotic and native tree species (χ^2 = 37.4, $P < 0.001$), and between plots occupied by coffee and banana plantations (χ^2 = 38.9.0, $P < 0.001$). However, no differences were witnessed between plots of native tree species and plots occupied by banana plantations. Furthermore, significant differences were found in soil-litter arthropod diversity (χ^2 = 17.1, $P < 0.001$; Table 2) and evenness (χ^2 = 13.7, $P < 0.001$; Table 2) across all land-

Table 2. Overall abundance and diversity (mean, standard deviation and significance) of identified families of soil-litter arthropods in the soil-litter collected in plots of exotic and native tree species and in coffee and banana plantations.

		Abundance of soil-litter arthropods (mean, standard deviation and significance				
Order	Families	Banana	Coffee	Native	Exotic	Total
Geophilomorpha	Geophilidae	17.6 ± 0.0^a	12.2 ± 0.1^b	16.5 ± 0.8^a	12.2 ± 0.0^b	14.6 ± 0.2
Scolopendromorpha	Scolopendridae	10.6 ± 0.2^b	7.0 ± 0.3^b	15.6 ± 0.8^a	8.2 ± 0.5^b	10.4 ± 0.5
Tetramerocerata	Pauropodidae	14.8 ± 0.3^b	10.4 ± 0.3^b	19.0 ± 1.0^a	14.2 ± 0.2^b	14.6 ± 0.5
Symphyla	Scutigerellidae	11.5 ± 0.1^a	6.0 ± 0.3^b	14.7 ± 0.8^a	8.2 ± 0.4^b	10.1 ± 0.4
Julida	Julidae	12.7 ± 0.5^a	8.2 ± 0.1^b	20.2 ± 0.3^a	15.7 ± 0.1^a	14.1 ± 0.3
Trombidiformes	Trombidiidae	15.3 ± 0.0^a	6.9 ± 0.2^b	24.3 ± 0.9^a	13.5 ± 2.1^a	15.0 ± 0.8
Trombidiformes	Trombiculidae	12.0 ± 0.1^a	8.4 ± 0.2^b	15.5 ± 0.7^a	7.8 ± 0.4^b	10.9 ± 0.4
Protura	Eosontomidae	13.3 ± 0.2^a	9.4 ± 0.0^b	19.7 ± 1.8^a	15.2 ± 0.6^a	14.4 ± 0.7
Diplura	Campodeidae	13.8 ± 0.1^b	10.4 ± 0.2^b	20.1 ± 1.2^a	12.1 ± 0.4^b	14.1 ± 0.5
Diplura	Japygidae	15.0 ± 0.5^a	11.2 ± 0.7^b	15.3 ± 0.4^a	11.3 ± 0.5^b	14.2 ± 0.4
Isopoda	Porcellionidae	12.3 ± 0.1^a	7.9 ± 0.0^b	19.8 ± 0.5^a	8.3 ± 0.5^b	12.1 ± 0.3
Entomobryomorpha	Isotomidae	19.0 ± 0.0^a	10.0 ± 0.0^b	18.9 ± 0.6^a	12.2 ± 0.6^a	14.0 ± 0.4
Entomobryomorpha	Entomobryidae	11.1 ± 0.1^b	11.6 ± 0.7^b	26.1 ± 0.4^a	15.2 ± 0.4^a	16.1 ± 0.4
Isoptera	Termitidae	16.4 ± 0.1^a	12.3 ± 0.0^a	15.6 ± 0.9^a	9.7 ± 0.4^b	13.5 ± 0.4
Isoptera	Rhinotermitidae	16.3 ± 0.1^a	15.2 ± 0.1^a	12.2 ± 0.4^b	8.2 ± 0.2^b	12.2 ± 0.2
Coleoptera	Carabidae	10.6 ± 1.5^a	5.4 ± 0.2^b	10.2 ± 0.7^a	7.1 ± 0.2^b	8.3 ± 0.7
Coleoptera	Chrysomelidae	10.8 ± 0.1^a	5.4 ± 0.2^b	10.6 ± 0.0^a	7.2 ± 0.8^b	8.5 ± 0.3
Coleoptera	Staphylinidae	10.1 ± 0.4^a	5.9 ± 0.5^b	10.3 ± 0.5^a	7.2 ± 0.4^b	8.4 ± 0.5
Coleoptera	Scarabaeidae	10.4 ± 0.0^a	5.1 ± 0.0^b	10.7 ± 0.0^a	7.3 ± 0.1^b	8.4 ± 0.0
Coleoptera	Elateridae	10.6 ± 0.2^a	5.1 ± 0.1^b	10.8 ± 0.1^a	9.0 ± 0.0^a	8.9 ± 0.1
Coleoptera	Histeridae	11.6 ± 0.1^a	5.2 ± 0.0^b	11.7 ± 0.1^a	9.2 ± 0.4^a	9.4 ± 0.2
Orthoptera	Gryllidae	17.8 ± 0.0^a	12.6 ± 0.6^a	13.5 ± 0.6^a	7.2 ± 0.1^b	12.8 ± 0.3
Hymenoptera	Formicidae	19.3 ± 0.5^a	30.5 ± 1.6^a	35.5 ± 1.6^a	37.8 ± 2.1^a	30.8 ± 1.5
Total		13.6 ± 0.2	9.5 ± 0.3	16.8 ± 0.7	11.5 ± 0.5	12.8 ± 0.4
Shannon diversity (H´)		1.2 ± 1.0^a	0.8 ± 0.3^b	2.5 ± 0.1^a	1.7 ± 1.1^a	1.6 ± 0.6
Evenness (E´)		1.3 ± 0.2^a	1.4 ± 0.2^a	1.2 ± 0.1^a	0.9 ± 0.3^b	1.2 ± 0.8

Different letters indicate significant differences in abundance between four land uses considered in this study, $P < 0.05$. Analyses were performed using Tukey honestly significant difference

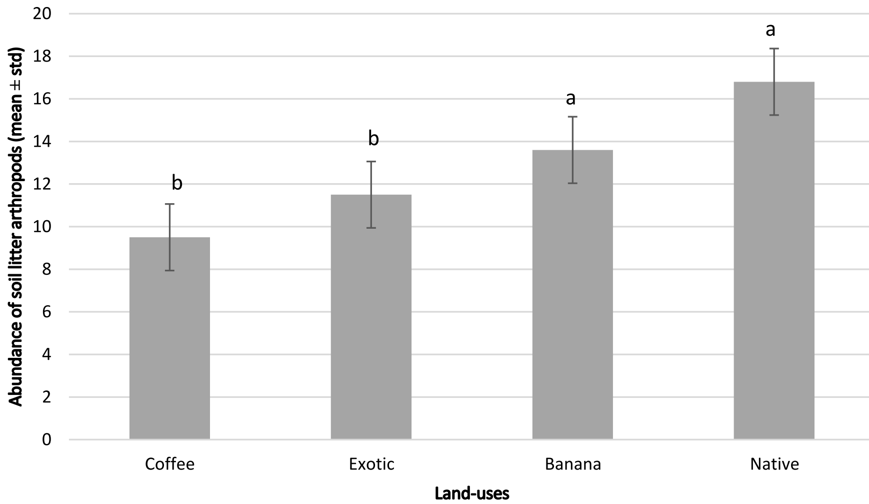

Figure 3. Overall abundance (mean, standard deviation) of soil-litter arthropods per land use. Different letters above line graphs represent significantly different means, P < 0.05. Analyses were performed using Tukey honestly significant difference

uses. Coffee plantations were least diverse in soil-litter arthropods compared to banana plantations, exotic tree species and native tree species. Results also indicate that exotic tree species had the lowest evenness (Table 2).

Soil physicochemical characteristics

Significant differences in the overall soil physicochemical properties were found between soils sampled in plots of exotic and native tree species (χ^2 = 12.8, P < 0.001), and between soils sampled in plots of coffee and banana plantations (χ^2 = 10.0, P < 0.001). However, no significant differences were found in soil physicochemical properties sampled in plots of native tree species and banana plantations. Specifically, significant differences were found in soil pH (χ^2 = 4.1, P < 0.001) across all land uses. The highest levels were recorded in soils sampled in plots of banana plantations and native tree species (Table 3), while low levels were recorded in soils sampled under exotic tree species. Significant differences were also found in the content of soil organic carbon (χ^2 = 5.3, P < 0.001) across all land uses. Particularly, soil organic carbon was significantly higher in soils sampled under plots of exotic and native tree species compared to soils sampled in plots of coffee and banana plantations (Table 3).

Significant differences were also found in soil total nitrogen across all land uses (χ^2 = 0.4, P < 0.001). This parameter had statistical similarities in banana plantations, exotic and native tree species compared to coffee plantations (Table 3). Significant differences were further found in soil available phosphorus (χ^2 = 6.3, P < 0.001). Statistically, available phosphorus had higher levels in soils sampled under coffee and banana plantations than the soils sampled in plots of exotic and native tree species. In addition, statistical differences were found under exotic and native tree species (Table 3). Regarding soil texture, the results indicated that banana plantations, exotic tree species and native tree species were statistically equal in clay, silt and sand.

Relationships between soil-litter arthropods and soil physicochemical properties

The assemblage composition of the families of soil-litter arthropods correlated differently with soil physicochemical properties. The families of Formicidae, Porcellionidae, Trombiculidae, Isotomidae and Entomobryidae showed strong correlations with soil pH, soil organic carbon, soil total nitrogen, silt and clay, mainly in soils beneath native tree species (P < 0.05). These five physicochemical

Table 3. Variations in soil physicochemical properties (mean, standard deviation and significance) under exotic, native, banana and coffee plantations (SOC: Soil Organic Carbon, Tot. N: Total Nitrogen, Av. P: Available Phosphorus). The analysis of variance was performed by the use of Tukey honestly significant differences (P < 0.05).

Land use	Soil pH	SOC (%)	Tot. N (%)	Av. P (mg/Kg)	Clay (%)	Silt (%)	Sand (%)
Exotic	5.3 ± 0.3^b	7.6 ± 2.9^a	0.6 ± 0.3^a	4.0 ± 1.4^a	13.7 ± 2.2^a	16.4 ± 2.1^a	68.9 ± 3.9^b
Native	6.1 ± 0.5^a	6.4 ± 0.2^a	0.5 ± 0.1^a	3.7 ± 0.9^a	14.6 ± 4.4^a	17.5 ± 2.8^a	69.0 ± 0.7^b
Banana	6.1 ± 0.5^a	2.6 ± 0.7^b	0.3 ± 0.2^a	7.7 ± 0.8^b	12.1 ± 1.5^a	11.7 ± 1.5^a	75.7 ± 2.5^b
Coffee	5.8 ± 0.4^b	3.3 ± 0.2^b	0.2 ± 0.1^b	15.5 ± 0.3^c	12.7 ± 2.0^b	11.0 ± 3.0^b	76.3 ± 3.2^a

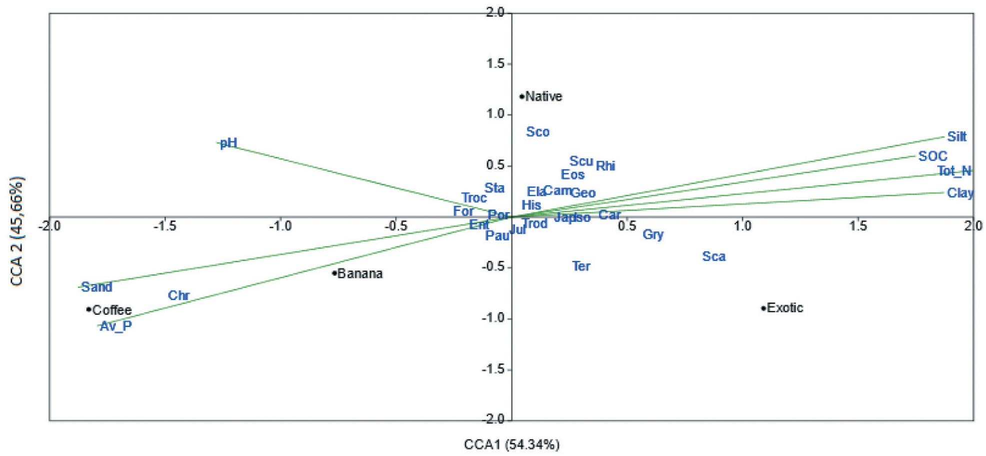

Figure 4. The CCA plot visualising the relationships between soil physicochemical parameters, assemblage composition of the families of soil-litter arthropods and the land use. Av_P: available phosphorus, SOC: soil organic carbon, Tot. N: total nitrogen, Cam: Campodeidae, Car: Carabidae, Chr: Chrysomelidae, Ela: Elateridae, Ent. Entomobryidae, Eos: Eosontomidae, For: Formicidae, Geo: Geophilidae, Gry: Gryllidae, His: Histeridae, Iso: Isotomidae, Jap: Japygidae, Jul: Julidae, Pau: Pauropodidae, Por: Porcellionidae, Rhi: Rhinotermitidae, Sca: Scarabaeidae, Sco: Scolopendridae, Scu: Scutigerellidae, Sta: Staphylinidae, Ter: Termitidae, Troc: Trombiculidae, Trod: Trombidiidae. The relative length of each eigenvector (green lines) is proportional to the relative importance of each displayed physicochemical parameter in determining the community composition in each land use. The orientation of each eigenvector (CCA1 and CCA2) illustrates the axis of maximum change in the value of each physicochemical parameter and abundance of soil-litter arthropod across the land use. The graph was produced from Pearson correlation matrix between the abundance of soil-litter arthropods and soil properties pairwise for each land use system as co-variables, with a significance threshold of $P < 0.05$.

properties had strong positive relationships with the first axis ($P < 0.05$, CCA1), while soil available phosphorus and sand soil texture negatively correlated with the second axis ($P < 0.05$, CCA2). Furthermore, families of soil-litter arthropods differed with the land use and soil physicochemical properties since they were separated in the CCA ordination space (Figure 4).

Discussion

Abundance and diversity of families of soil-litter arthropods

Results of this study indicated that native tree species statistically retain the highest diversity and abundance of the families of soil-litter arthropods compared to exotic tree species, coffee plantations and banana plantations. Research conducted in the Northern Iran indicated that higher abundance and diversity of soil-litter arthropods in native tree species are associated with the plant diversity and plant heterogeneity (Kassa et al. 2017) which provide suitable habitats and nutrients to soil fauna (Bayranvand, Kooch, and Rey 2017). Another related study, also conducted in the Northern Iran, indicated that the abundance and diversity of soil fauna in areas dominated by native tree species might be associated with canopy density which creates microclimates and provides stable environments (Kooch, Tavakoli, and Akbarinia 2018; Kamau et al. 2017) that offer better conditions for the survival of soil-litter biodiversity.

Soil and litter covered by banana plantations had the second highest abundance of soil-litter arthropod families, after native tree species. Statistically, only coffee plantations had significantly lower diversity of arthropod families compared to banana plantations, exotic tree species, and native tree species. Research conducted on edaphic fauna in Brazil indicated that the abundance of soil-litter arthropods in banana plantations is controlled by the use of different types of fertilizers and the disposal of the agricultural remains in soil (Casaril et al. 2019). This was supported by our observations during the field data collection where all plots of banana plantations were well mulched with organic mulches and fertilized twice per year by organic fertilizers. Another study on biodiversity conducted in humid tropical banana plantations indicated that mulching with organic mulches and organic fertilizers favour a wide range of soil-litter biodiversity because they provide shelter and prey (Vargas 2006).

Soil and litter samples from the plots of exotic tree species had less abundance of soil-litter arthropod families, despite the statistical similarity with native tree species and banana plantations in soil-litter arthropod diversity. Effects of exotic tree species on soil biodiversity has been a topic of discussion in different studies. Some concluded that exotic tree species provide a poor habitat for soil fauna (Quine and Humphrey 2010; Vavra, Parks, and Wisdom 2007) due to the less decomposed litter layer, limited soil water content, soil nutrients and plant diversity under the canopy of exotic tree species (Kassa et al. 2017). Another study comparing the diversity and abundance of soil-litter arthropods in Rwanda was not conclusive about negative effects of exotic tree species on soil fauna. Nsabimana (2013) indicated that the abundance of soil-litter arthropods found under exotic tree species was comparable to that found under native tree species. Due to the divergence in previous studies, we cannot conclude anything about the cause of low abundance in the families of soil litter arthropods in exotic tree species found in this study. We suggest more research be conducted in other exotic and native forests of Rwanda and other parts of the globe to verify the relevance of our findings in exotic tree species.

Low abundance and diversity of soil-litter arthropods was found in soils and litter collected in plots of coffee plantations compared to those of native, exotic, and banana plantations. Low abundance and diversity may be associated with land use management. During field data collection we observed that all plots of coffee plantations were fertilized by inorganic fertilizers. Even though the application of fertilizers is essential to enhancing crop yields (Wang et al. 2016), they affect soil properties by changing the species and quantity of plant residues which subsequently change the diversity and composition of soil fauna communities (Reeve et al. 2010). Due to strong association with the availability of soil nutrients, soil-litter arthropods are sensitive to changes in soil physicochemical composition caused by the application of chemical fertilizers (Wang et al. 2016; Zhu and Zhu 2015). Different families (Table 2) showed high abundance in soils and litter collected under coffee plantations. A study conducted on the impact of agroecological practices on greenhouse vegetable production suggests that this could be due to the arthropod's ability to tolerate chemical fertilizers (Ciaccia et al. 2019).

Variations in soil physicochemical properties

Low levels of soil pH were found in soils collected in plots of exotic tree species, compared to the soils collected in plots of native, coffee and banana plantations. Low levels of soil pH in soils collected in plots of exotic tree species were associated with soil acidification by accumulation of basic cations in biomass, and the production of organic acids from litter decomposition (Nsabimana et al. 2008). On the other hand, higher levels of soil pH found in soils collected in plots of native tree species, coffee and banana plantations were attributed to the availability of high exchangeable base cations (Sharma, Mandal, and Venkateswarlu 2012). As for the soil organic carbon, higher levels of it were found in soils collected in plots of native and exotic tree species compared to coffee and banana plantations. Other studies explained higher levels of soil organic carbon in forest plantations to be the result of high decomposition of litter fall from trees and shrubs. Lower levels were ascribed to tillage and weeding activities practiced in coffee and banana plantations (Kassa et al. 2017).

Results of this study indicated that soil total nitrogen was statistically similar between exotic, native and banana plots. The stability of total nitrogen in forest plantations may be due to soil organic matter being released from dead fine roots and mycorrhizal fungi activities in forest plantations (Kassa et al. 2017). However, significant differences in soil total nitrogen were found in soils under coffee and banana plantations. Findings from a study conducted in Western India indicated that significant differences in soil nitrogen might be associated with weeding and mulching management (Sharma, Gopinath, and Osman 2019). This is in congruence with our observations during field data collection. We observed that the majority of coffee were weeded but not well mulched, while banana plantations were mulched with maize, sorghum and banana leaves. These might be the cause of similarities in total nitrogen under exotic and native forest plantations, and the cause of its significant differences between coffee and banana plantations.

Soils collected under plots of coffee plantations were rich in available phosphorus compared to soils collected in plots of native, exotic, and banana plantations. These higher levels of available phosphorus may be the result of chemical fertilizers being applied to increase production (REMA 2014). In addition to higher levels in soil available phosphorus, soils collected in plots of coffee plantations were sandier compared to the soils collected in the other plots, having top soils rich in clay and silt fractions. The richness of clay and silt textures in soils collected under exotic, native and banana plantations was found to be influenced by the presence of canopies of banana leaves, trees and shrubs that cover and protect the surface of soil from leaching and soil erosion (Yeshaneh 2015). The poor canopy of coffee plantations added to the intensive weeding activities favour the rain erosion that washes the top soil rich in silt and clay, and hence increase the sand soil texture.

Relationships between soil litter arthropods and soil physicochemical properties

Soil-litter arthropods respond differently to the land use and to soil physicochemical properties. Research conducted on the contribution of soil-litter arthropods to soil fertility indicated that relationships between soil-litter arthropods, soil physicochemical properties and land use can be explained by the functions of soil-litter arthropods that enhance soil properties (Culliney 2013). The strong correlation between the family of Formicidae (ants) and soil pH found in this study was also found in another review study on the effects of ants on soil properties and processes. Findings of this research indicated that the presence of ants may shift soil pH to a neutral value by increasing its levels in acid soils or by decreasing its levels in basic soils (Frouz and Jilková 2008). In addition, Formicidae are leaf litter decomposers and predators that enrich soils in organic matter. They are soil engineers that facilitate soil aeration, soil mixing with organic matter, porosity, texture and transport of nutrients at different soil horizons (Luke et al. 2014).

Soil pH also strongly correlated with the family of Porcellionidae (isopods). A review study on the use of terrestrial isopods as model organisms in soil ecotoxicology indicated that isopods are litter decomposers that avail organic matter in soil (Gestel, Loureiro, and Zidar 2018). Another study conducted in Columbia indicated the relationship between soil pH and soil organic matter; it reported that soil pH facilitates the decomposition of organic matter, and hence influences the long-term soil organic carbon and nutrient dynamics (Ghimire, Machado, and Bista 2017). A study on the characteristics of soil carbon, nitrogen and phosphorus stoichiometric ratios conducted in China concluded that soil pH plays an important role in controlling soil carbon, nitrogen and phosphorus stoichiometry (Yang et al. 2019). An example of this was indicated by another study conducted in China on the relationships between soil pH and soil organic carbon. It indicated that soil organic carbon would increase more when the soil pH decreased (Jin and Wang 2018). Therefore, the correlation of Porcellionidae and soil pH might be a sign of a balance between soil pH and soil organic carbon.

Furthermore, soil pH strongly correlated with the family of Trombiculidae (Acari). Research conducted on the assessment of soil quality index based on microarthropods in corn cultivation in Northern Italy indicated that Acari participate in the litter breakdown by enhancing the decomposition rates and hence release nutrients in the soil, which in turn stabilize the soil pH (Aspetti et al. 2010). However, this is generalized to all Acari. We suggest that a specific research be conducted on the Trombiculidae family to specify its contribution on soil physicochemical properties.

Strong correlations were also found between silt and clay soil texture, soil organic carbon, soil total nitrogen and the families of Entomobryidae and Isotomidae (Collembola). These findings are in relation with another study conducted in Southern Brazil on the use of Collembola community structure as a tool to assess land use effects on soil quality. Findings of this research indicated that Collembola have an influence on soil microbial ecology, facilitate nutrient cycling, and improve soil fertility by feeding on soil microorganisms, and hence availing in soil the soil organic carbon and soil total nitrogen (de Filho et al. 2016).

Conclusion

Analysis of the abundance of soil-litter arthropod families indicated a decrease in abundance from native tree species to banana plantations, exotic tree species and varieties of coffee plantations. Higher abundance of soil-litter arthropods in plots of native tree species can be justified by the environmental stability, plant diversity and plant heterogeneity, as well as the availability of nutrients under the canopy of native tree species. In banana plantations, higher abundance of the families of soil-litter arthropods can be justified by the management practices, specifically weeding, mulching with organic mulches, and the use of organic fertilizers. Low abundance in exotic tree species was related to the negative effects of exotic tree species such as less decomposed litter layer, soil water content, soil nutrients and plant diversity imposed by exotic tree species. Low abundance in coffee plantations might be related to the weeding activities without mulching and to the application of chemical fertilizers.

The analysis of diversity through Shannon diversity and evenness indicated that banana plantations, exotic tree species and native tree species offer better conditions in terms of the diversity of families of soil-litter arthropods than coffee plantations. In addition, the analysis of soil physicochemical data indicated plots of native tree species and banana plantations offer suitable conditions in soil physicochemical properties. The analysis of the relationships between the land use, soil properties and families of soil-litter arthropods indicated that the soil-litter arthropods correlated and responded differently to the land use and to soil physicochemical properties. However, positive correlations and relationships were mainly found in native tree species rather than in plots of exotic tree species, coffee and banana plantations. We conclude that native tree species play a significant role in the conservation of soil-litter arthropods and maintenance of better soil conditions.

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Disclosure statement

No potential conflict of interest was reported by authors.

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