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Impact of chemical fertilizers on diversity and abundance of soil-litter arthropod communities in coffee and banana plantations in southern Rwanda

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ABSTRACT

Few studies explored effects of chemical fertilizers on diversity and abundance of soillitter arthropods in the tropics. To fill this gap, a study focussed on the abundance of soil-litter arthropods and selected soil physicochemical properties in coffee plantations treated with chemical fertilizers and in plantations of coffee and banana treated with organic fertilizers and organic mulches in southern Rwanda. Each land use was replicated three times. Soil-litter arthropods were collected using pitfall traps and hand collection. They were identified to the family level using dichotomous keys. Soil have been collected using auger and taken to the laboratory for the analysis of soil pH, soil organic carbon, total nitrogen, phosphorus, and cation exchange capacity. Findings indicated a total of 12,945 individuals distributed into 3 classes, 16 orders, 50 families and 92 morphospecies, with higher abundance and diversity in coffee plantations treated with organic fertilizers and organic mulches. Collected soil-litter arthropods were mainly classified in the class Insecta, dominated in numbers by ants (Hymenoptera: Formicidae), while Coleoptera and Hemiptera had more families. However, soil under coffee plantations treated with organic fertilizers and organic mulches was acidic compared with the soil under coffee plantations treated with inorganic fertilizers and banana plantations treated with organic fertilizers and organic mulches. The relationships between soil-litter arthropods and soil physicochemical properties suggest that soil-litter arthropods respond to the land use independently from soil physicochemical properties. We recommend further studies in coffee and other crop plantations in other regions of Rwanda to verify the findings of this study.

1. Introduction

Land use change results in biodiversity loss (Hansen et al., 2004; Tibcherani et al., 2020), through its effects on biodiversity population growth rates (Dobson et al., 2006), species interactions (Komonen et al., 2000), changes in trophic chains and community structure (Forero-Medina and Vieira, 2007). Habitat loss was identified as the greatest threat to biodiversity change at population, community, and ecosystem levels (Barnosky et al., 2011; Watling and Donnelly, 2006). This is of particular importance in agricultural lands (Lal, 2015), where frequent and deep tillage, soil cover change, poor management of organic residues, soil physical degradation, and soil contamination by chemical fertilizers - individually or by interacting with each other - affect soil quality, soil health (Lavelle et al., 2001) and soil biodiversity (Gagnarli et al., 2021). These changes disturb regulatory processes of soil fauna that underpin soil ecological services (Wagg et al., 2014).

Chemical fertilizers used in agriculture contain large concentrations of nutrients needed for plant growth (Mushtaq et al., 2018; Singh et al., 2018) and continues to be an essential tool to increase soil fertility and crop productivity (Bhatti et al., 2017). Yet, many countries aim at high crop production and neglect the environmental effects of chemical fertilizers on the soil fauna. Chemical fertilizers are source of heavy metals such as cadmium (Cd), arsenic (As), mercury (Hg), nickel (Ni), lead (Pb), and copper (Cu). They are also a source of natural radionuclides of the

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uranium, namely U^{238}, U^{232}, and U^{210} (FAO, 2009; Sönmez et al., 2007). The accumulated heavy metals and radionuclides in the soil are further absorbed by plants and transferred to consumers through food chains (Pahalvi et al., 2021). In addition, long-term use of chemical fertilizers leads to the decline in soil organic matter content and increases soil acidity (Dar et al., 2016). Furthermore, long term use of chemical fertilizers hardens the soil, reduce soil fertility, pollutes water and soil, lessen important nutrients of soil and minerals, thereby bringing hazards to the environment (Pahalvi et al., 2021).

In Rwanda, agriculture sector is the main economic activity hosting 69% of the working population, with 26.8% depending on cropping farming only (GoR, 2022). The use of chemical fertilizers is motivated by the will of the Government to shift from a household agriculture to a private sector-led and knowledge-based economy and from subsistence-based to the market-oriented agriculture (Miklyaev et al., 2021). The government subsidizes chemical fertilizers, and improved seeds to farmers grouped into farming cooperatives. Subsidized chemical fertilizers are used only on a government approved list of crops to reinforce agriculture through land use consolidation (Golooba-Mutebi, 2014). Approved crops include cassava (Family: Euphorbiaceae), Irish potatoes (Family: Solanaceae), maize (Family: Poaceae), beans (Family: Fabaceae) and varieties of coffee.

In Rwanda, used fertilizers are based on commodity NPKs, and soil studies have been conducted to meet soil conditions, chemical fertilizers, and crop-specific needs such as soil types (IFDC, 2018). In this regard, Di-ammonium phosphate (DAP) is mainly used to fertilize maize, wheat, and beans, while nitrogen-phosphorus-potassium (NPK) 17–17-17 is mainly used to fertilize rice and potatoes. Inorganic fertilizers used in coffee include either NPK (20−10−10) applied at 400 g per tree per year, or NPK (17–17-17) applied at 120 g per tree per year and urea (46% of N) applied at 75 g per tree per year. These are applied two times in a year (March and September) at a half dose to reduce potentials for leaching loss (Nizeyimana et al., 2013).

Besides cassava, Irish potatoes, maize, and beans that are mainly sold at Rwanda local markets, coffee is a major exported product generating good income for the country. It is ranked first among the crops grown with chemical fertilizers to boost the productivity and represents about 7% of total export value compared to 20% of the total agriculture export value. Recently, the shift from household and subsistence-based agriculture to a private and market-oriented agriculture increased the Gross Domestic Product (GDP) from 418.14 billion in 2006 to 570 billion of Rwandan Francs in 2019 and accounted to 26% of the overall GDP in 2020 (REMA, 2021). In this regard, all income generated from coffee exported alone was 62,761 thousand USD compared with rice (14,000 USD) and other cereals (25,867 USD) in 2018 only (RCE [Rwanda Coffee Export], 2018). Despite the economic improvements, agriculture contributed to >67% of the total greenhouse gas emission due to the application of urea in Rwanda (REMA, 2021).

In relation with chemical fertilizers and soil biodiversity, a recent study has indicated that intensive use of chemical fertilizer may affect soil fauna and their ecological functions (Ojo et al., 2015). However, soil-litter arthropods such as ants (Hymenoptera: Formicidae), termites (Isoptera), Coleoptera (adults and larvae), Arachnida, Diplopoda, Chilopoda, Myriapoda, and Isopoda (Fragoso et al., 1999) have an influence on soil formation, soil water infiltration and nutrient cycling (Brussaard et al., 2007; Lavelle et al., 2006). They function as plant-litter decomposers and ecosystem engineers that contribute to the availability of soil nutrients and to the improvement of soil structures (Bagyaraj et al., 2016). They recycle soil nutrients, improve agricultural productivity, plant growth, biological and physicochemical soil conditions (Culliney, 2013). Different groups of soil arthropods have been found to be related to certain abiotic factors mainly soil moisture, temperature, and organic matter, while the land use change from conventional to organic farming led to a higher arthropod biodiversity (Ghiglieno et al., 2020).

Effects of chemical fertilizers on soil-litter arthropods are less documented. In low and high elevation forests of Puerto Rico, the abundance of litter arthropods increased in the wet forest fertilized plots due to the accumulated litter from the vegetation (Yang et al., 2007). Another study conducted in a Texas pine plantation reported that arthropod species richness increased following nitrogen and phosphorus fertilization, even though Shannon diversity indices did not (Bird et al., 2000). Effects of chemical fertilizers on soil-litter arthropod diversity and abundance in different agroecosystems is still far from being understood, especially in agricultural lands in tropical regions. Particularly, little is known about how chemical fertilizers applied in coffee and banana plantations, affect soil-litter arthropods. More studies are needed to advance soil biodiversity conservation so that they may maintain their soil ecological functions.

This motivated us to fill the gap by conducting research on effects of chemical fertilizers on the diversity and abundance of soil-litter arthropods in coffee and banana plantations in Southern Rwanda. The study aimed at assessing the impacts of chemical fertilizers on diversity and abundance of soil-litter arthropods and on selected soil physicochemical properties in coffee and banana plantations. The key question that guided the study was: Is there significant differences in soil physicochemical properties and in diversity and abundance of soil-litter arthropods under (1) coffee treated with chemical fertilizers, (2) coffee and banana treated with organic fertilizers and organic mulches? We have hypothesized that there are significant differences in soil properties, diversity, and abundance of soil-litter arthropods under (1) coffee treated with chemical fertilizers, (2) coffee and banana treated with organic fertilizers and organic mulches.

2. Martials and methods

2.1. Study sites

The study was conducted in Southern Rwanda, Huye district, at Rubona located in Rusatira sector and at Kigoma hill located in Kigoma sector (Fig. 1). Geographically, Rubona is located at $2^{0}29'$S and $29^{0}46'$E at 1750 m elevation, while Kigoma is located at $2^{\circ}28'$S, and $29^{\circ}38'$E at 1707 m elevation. The soil type at Rubona is combisol characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminium oxides. At Kigoma, the soil is Oxisol, dominated by Iron III (Fe^{3+}) and Aluminium (Al^{3+}) oxides (Verdoodt and van Ranst, 2006). Further, the sites are dominated by the same annual precipitation controlled by two rain seasons: short rain season (generally from September to January) and long rain season (February to May) alternating with two dry seasons, specifically, short dry season (generally from January to February) and long dry season (generally from June to September) every year (Nsengimana et al., 2021). The average annual rainfall is 3015 mm while the annual average temperature is 24 °C, ranging from 22 °C in May to 26 °C in September. Hence, the sites have been selected because they are in the area generally dominated by the same annual precipitation, temperature, and almost the same altitude.

Historically, Rubona is known as the first center for agricultural research in Rwanda since 1930s and covers around 675 ha. It is now managed by Rwanda Agricultural Board (RAB), and it is used for livestock and agricultural research on crop plantations including varieties of coffee and banana plantations (Nsengimana et al., 2021). Kigoma coffee is planted on the surface area of 9 ha and is managed by Rogers Family Coffee company. The land was occupied by *Eucalyptus* tree species until 2019, the time by which it has been transformed into coffee plantations by Rogers Family Coffee company. It is one of the largest lands used for coffee plantations not treated with chemical fertilizers in southern Rwanda.

2.2. Experimental design and sampling

At Rubona, data have been collected in coffee plantations treated with chemical fertilizers and in banana plantations treated with organic fertilizers and organic mulches, while at Kigoma, sampling was done in

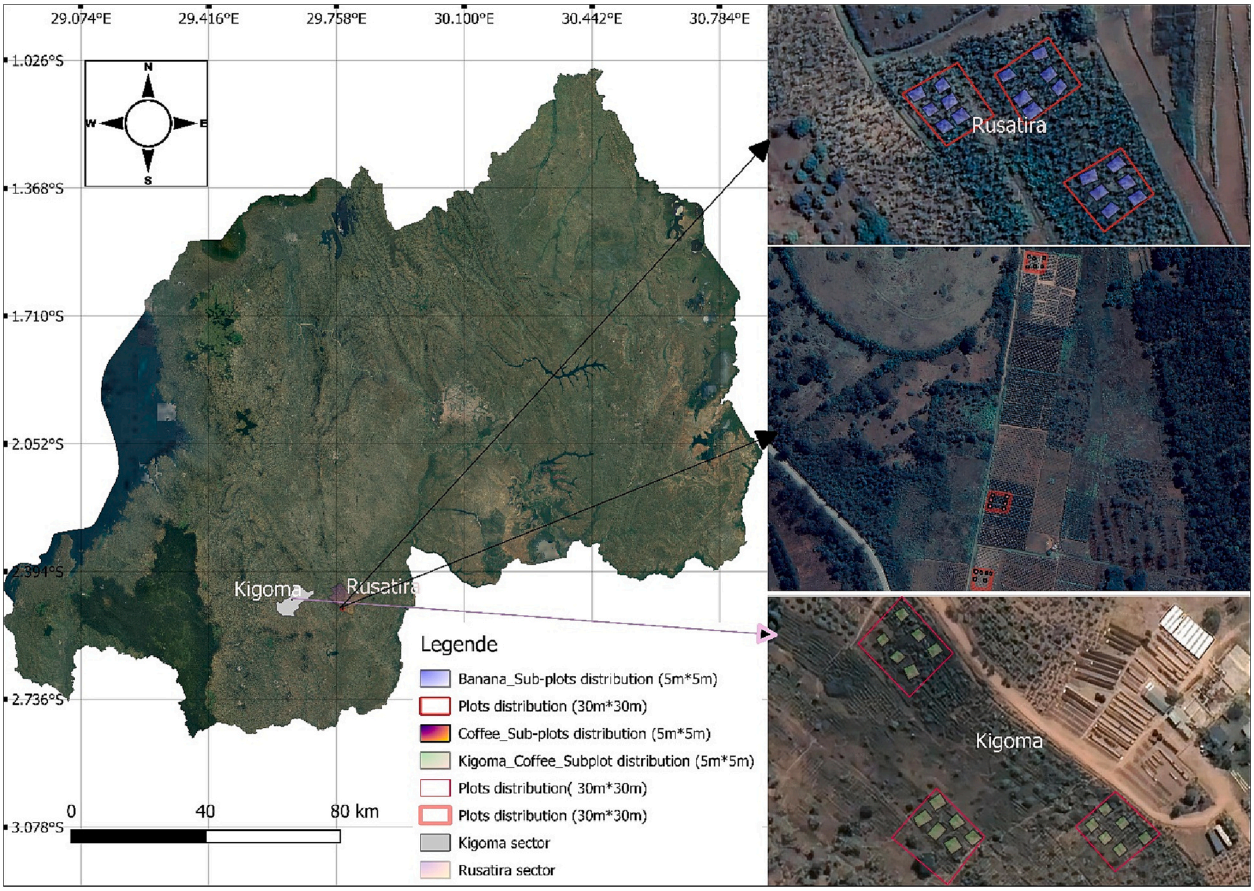

Fig. 1. Location of Rusatira and Kigoma in Huye district, location of plots in each sector and location of each sub-plots in the plot. At Rusatira plots are located at Rubona research centre centre, at Kigoma, plots are located at Kigoma hill.

coffee treated with organic fertilizers and organic mulches. Each coffee and banana plantation type was subdivided into plots of 30 × 30 m and replicated three times (Fig. 1). Within each replicate, six subplots separated by 5 m have been established and used for sampling soil-litter arthropods and soil cores for the analysis of soil physicochemical properties. Borders of 5 m from the edge were left outside of the sampling plot to avoid edge effects (Nsengimana et al., 2021), and a 10 m minimum distance was maintained between two plots to avoid autocorrelation.

2.3. Arthropod collection and identification

Pitfall traps and hand sampling were used for sampling soil-litter arthropods in each land use. Data were collected between May (end of the rain season) and June (starting of the rain period) in 2021 to avoid effects of rain and dry seasons on the diversity and abundance of soil-litter arthropods. Nine pitfall traps were placed in each sub-plot (Vasconcellos et al., 2013). The pitfall trap was made of a transparent plastic bottle (6 cm in diameter and 10 cm in depth) buried in a soil pit and partly filled with 25 ml of 75% ethanol. To prevent rainwater, leaves, and debris from entering the trap, each trap was covered with a piece of 100 cm^2 cardboard lid. Each trap was set after the removal of the leaf-litter layer, and it was maintained in place for 24 h to maximize chances of collecting day and night active soil-litter arthropods (Nsengimana et al., 2021). Furthermore, to maximize chances of collecting high abundance and diversity of soil-litter arthropods, data were sampled by hand collection, where soil-litter arthropods were collected in $1m^2$ by using pickup forceps in 10 cm soil depth and searched in the leaf-litter layer for 30 min (Sayad et al., 2012). Collected specimens were conserved in 25 ml of 75% ethanol (Wang et al., 2016)

Further, collected soil-litter arthropods from each sampling technique and land use type were taken to the laboratory of the Centre of Excellence in Biodiversity and Natural Resource Management (CoEB). Each sample was analyzed independently from others, and all specimens in each sample were classified to the order and family levels (Wang et al., 2016). The classification was firstly done morphologically under the microscope, and confirmed by using recent dichotomous keys (Mignon et al., 2016; Biaggini et al., 2007) and existing identified specimens in the zoological collection of the CoEB. When the name of a genus and species could be found from the dichotomous keys, they were noted and reported, otherwise, the morphospecies description of each specimen was provided to differentiate specimen types of the same family.

2.4. Soil data collection and laboratory analysis

Soil physicochemical properties from Kigoma were obtained from Rogers Family Coffee Company. At Rubona, nine soil cores (10 cm × 10 cm, 10 cm depth) were collected in each replicate and pooled to obtain one representative sample (Sayad et al., 2012). In total, 27 samples (3 samples from each land use) have been collected and taken to the laboratory for soil analyses based in the College of Animal and Veterinary Medicine, University of Rwanda. Each sample was analyzed for pH water, soil organic carbon, total nitrogen, total phosphorus, and cation exchange capacity. Prior to laboratory analysis, soil samples were sieved and dried for 48 h (Nsabimana et al., 2008) at 35-40 °C (Mallarino, 2018). Soil pH was measured by taking soil-water suspension in 1:2 ratio, where 20 ml of distilled water were added to 10 grammes of soil in a beaker. The content was stirred intermittently with a glass rod, and the suspension was stabilized for half an hour (Nsengimana et al., 2021).

Soil pH was measured by using an RS232 pH meter. Data were recorded in excel sheet per sampling point.

Further, soil organic carbon was measured by dissolving 1 g of sieved soil in 500 ml of distilled water and adding 10 ml of potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml of concentrated sulfuric acid ($H_2SO_{4\ conc}$). The mixture was stabilized for 30 min, the time after which it was diluted with 200 ml of distilled water. Furthermore, 10 ml of 85% ortho-phosphoric acid (H_3PO_4) and 1 ml of diphenylalanine ($C_{12}H_{11}N$) were added to the solution, which was later titrated with 0.5 N ferrous sulphate ($FeSO_4$) solution until a turbid blue colour changed to brilliant green colour (Dutta and Agrawal, 2002). The mass of solid materials was measured and converted to 1gramme over 1 kg. Furthermore, the cation exchange capacity (CEC) was measured following Kjeldahl distillation method (Chapman, 1965) after oscillating exchange and vacuum. In this regard, the acidic and neutral soils were treated with ammonium acetate ($NH_4CH_3CO_2$), while the calcareous soil was treated with ammonium chloride and ammonium acetate. Cations were quickly exchanged and cleaned by shaking and using suction filtration, then ammonium ions were measured to calculate the value of the cation exchange capacity (Yi-fei et al., 2019).

The levels of total nitrogen and phosphorus were then measure by using Kjeldahl method for digestion and ultraviolet (UV) colorimeter methods (Okalebo et al., 2002). A solution composed of 0.5 grammes of dried soils sieved at 0.5 mm was mixed with 1.5 grammes of potassium sulphate (K_2SO_4), 5 grammes of iron sulphate ($FeSO_4$), 10 grammes of copper sulphate ($CuSO_4$), 1 g of selenium (Se) and 20 ml of 98% of $H_2SO_{4\ conc}$. The mixture was mineralized at 300 °C for 2 h until the appearance of a green colour. Then, the solution was diluted with distilled water at 1:9 ratio. The absorbency was measured 10 h later at 650 nm, when the blue colour got stable.

2.5. Data analysis

The mean abundance of the families of soil-litter arthropods was calculated for each treatment, and later used to calculate the Shannon index of diversity, and the evenness. The purpose was to provide more information on the diversity of the families of soil-litter arthropods sampled in each treatment (Ashford et al., 2013). Data were also analyzed using the one-way ANOVA for multiple samples in excel 365 software. For each treatment, variations in abundance were indicated on bar graphs, together with standard deviations, and significant difference *P* values (Nsengimana et al., 2021). Then, the general univariate linear model analysis of variance was calculated using Tukey honestly significant difference for multiple comparison between treatments by using PAST 3.14 software. Findings were given in a table of abundance, where significant differences were indicated by different letters following the obtained statistical P values (Doléc and Chessel, 1994).

Variations in soil physicochemical properties per treatment were analyzed in plot means, and by Kruskal-Wallis ANOVA to assess significant differences between the mean values in (1) plots of coffee plantations treated with organic fertilizers and organic mulches, (2) plots of coffee plantations treated with chemical fertilizers, and (3) plots of banana plantations treated with organic fertilizers and organic mulches (Kassa et al., 2017). Significant differences for each soil parameter per treatment type were analyzed using Turkey honestly significant differences for multiple comparison. Significant differences were indicated by letters based on P values in PAST software. Finally, the relationships between the abundance of soil-litter arthropod families and soil properties were calculated using a Pearson correlation matrix between the abundance of soil-litter arthropods and soil physicochemical properties pairwise, by using treatments of coffee and banana plantations as covariables at $P = 0.05$ (de Filho et al., 2016). Families restricted to one land use have been removed in the analysis to avoid biases. The relationships between the abundance of the families of soil-litter arthropod and soil physicochemical parameters in each treatment were visualized by a correspondence analysis (CA), in XLSTAT, 2022 software uploaded in office 365.

3. Results

3.1. Diversity and abundance of soil-litter arthropods per land use type and management

A total of 12,945 individuals of soil-litter arthropods was identified. High abundance was found in coffee plantations treated with organic fertilizers and organic mulches (39.7%, $N = 5141$) compared with coffee plantations treated with chemical fertilizers (30.9%, $N = 4004$) and with banana plantations treated with organic fertilizers and organic mulches (29.4%, $N = 3800$). Further, results have indicated that many sampled soil-litter arthropods (63.1%, $N = 8170$) were collected by pitfall traps (coffee plantations treated with organic fertilizers: 22.9%, $N = 2974$; coffee plantations treated with chemical fertilizers and organic mulches: 20.7%, $N = 2685$; banana plantations treated with organic fertilizers and organic mulches: 19.4%, $N = 2511$) relative to hand sampling technique (36.9%, $N = 4775$ distributed as follows: coffee plantations treated with chemical fertilizers: 14.1%, $N = 1861$; coffee plantations treated with organic fertilizers and organic mulches: 13.8% %, $N = 1794$; banana plantations treated with organic fertilizers and organic mulches: 8.6%, $N = 1120$).

Collected soil-litter arthropods were classified into 4 classes, 16 orders, 50 families and 92 morphospecies (Appendix 1). Higher abundance was found in the class Insecta (93,6%; $N = 12{,}121$) with 13 orders and 47 families compared to Diplopoda (9.5%, $N = 1232$), Arachnida (6.3%; $N = 810$), and Entognata (0.1%, $N = 14$). Arachnida and Entognata each had one order and 2 families, while Diplopoda had one order and one family. The class Insecta was dominated by ants (Hymenoptera: Formicidae: 68.2%, $N = 8265$), while Coleoptera (30.0%, $N = 15$), Hemiptera (24.0%, N = 12) and Orthoptera (8.0%, N = 4) had more families compared to other identified orders. These families had high abundance in coffee plantations treated with organic fertilizers and organic mulches compared with coffee plantations treated with chemical fertilizers and banana plantations treated with organic fertilizers and organic mulches (Fig. 2).

Statistically, significant differences in abundance of soil-litter arthropods were found between coffee plantations treated with chemical fertilizers and coffee plantations treated with organic fertilizers and organic mulches ($\chi^2 = 3.4$, $P < 0.5$), coffee plantations treated with chemical fertilizers and banana plantations treated with organic fertilizers and organic mulches ($\chi^2 = 2.3$, $P < 0.5$), and between coffee and banana plantations both treated with organic fertilizers and organic mulches ($\chi^2 = 1.3$, $P < 0.5$). Statistically, significant differences were also found in diversity indices. Higher diversity was found in soil-litter arthropods collected in coffee plantations treated with organic fertilizers and organic mulches ($H' = 0.9 \pm 1.1$, $E' = 0.6 \pm 0.4$) compared to the coffee plantations treated with chemical fertilizers ($H' = 0.7 \pm 1.1$, $E' = 0.5 \pm 0.1$) and banana plantations treated with organic fertilizers and organic mulches ($H' = 0.8 \pm 1.2$, $E' = 0.5 \pm 1.1$).

3.2. Effects of land use type and management on selected soil properties

Concerning soil parameters, significant differences were found in properties of soils sampled under coffee plantations treated with chemical fertilizers and coffee plantations treated with organic fertilizers and organic mulches ($\chi^2 = 4.4$, $P < 0.5$), coffee plantations treated with chemical fertilizers and banana plantations treated with organic fertilizers and organic mulches ($\chi^2 = 3.3$, $P < 0.5$) and between coffee and banana plantations both treated with organic fertilizers and organic mulches ($\chi^2 = 2.8$, $P < 0.5$). Data have also revealed that soils under banana plantations are less acidic, had higher levels of cation exchange capacity and total nitrogen. The levels of soil total phosphorus were beyond the required quantity in coffee treated with chemical fertilizers and banana plantations treated with organic fertilizers and organic

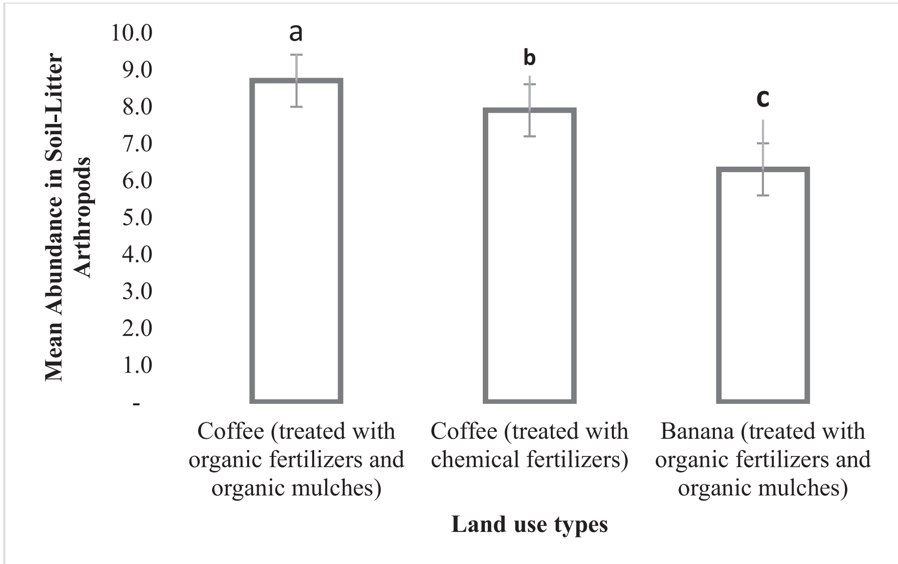

Fig. 2. Overall abundance (mean, standard deviation) of soil-litter arthropods per land use. Letters above line graphs represent significantly different means, $P < 0.05$ (a > b > c). Analyses were performed using Tukey honestly significant differences.

mulches. Furthermore, total nitrogen was beyond required ranges in coffee treated with chemical fertilizers and banana treated with organic fertilizers and organic mulches (Table 1).

3.3. *Relationships between soil physicochemical properties and soil-litter arthropods*

The analysis of the relationships between the abundance of soil-litter arthropods and soil physicochemical properties indicated significant differences in relationships between soil-litter arthropods, soil physicochemical properties, coffee, and banana plantation types ($\chi^2 = 79.0$, $P < 0.05$, df = 60). In this regard, soil-litter arthropods respond to the land use independently to soil physicochemical properties. The location of each family of soil-litter arthropod and soil physicochemical properties (Fig. 3) is proportional to the relative importance of each displayed physicochemical parameter in determining the community composition in coffee plantations treated with chemical fertilizers and in coffee and banana plantations treated with organic fertilizers and organic mulches. Further, the orientation of factors (F1 = 83.48%; F2 = 16.52%) illustrates the axis of maximum change in the values of each soil parameter and abundance of soil-litter arthropods in coffee plantations treated with chemical fertilizers and in coffee and banana plantations both treated with organic fertilizers and organic mulches.

The symmetric plot indicated that the families of Salticidae and Pholcidae (Araneae), Japygidae (Diplura), Termitidae (Isoptera), Blattidae (Blattodea), Muscidae (Diptera), Pentatomidae (Hemiptera), Coccinellidae and Paederinae (Coleoptera) showed a positive correlation ($P < 0.05$) in coffee treated with organic fertilizers and organic mulches (Fig. 3). Further, a negative correlation ($P < 0.05$) was found between the families of Formicidae (Hymenoptera), Rhinotermitidae (Isoptera), Scarabaeidae, Scydmaenidae, and Tenebrionidae (Coleoptera) while a positive correlation ($P < 0.05$) was found between the families of Lygaeidae (Hemiptera), Staphylinidae, Carabidae, Curculionidae (Coleoptera) and Gryllidae (Orthoptera) with cation exchange capacity mainly in banana plantations treated with organic fertilizers and organic mulches. Furthermore, the families of Reduviidae, Coreidae, and Cydnidae (Hemiptera), Acrididae (Orthoptera), Gomphodesmidae (Polydesmida), and Blatellidae (Blattodea) correlated with soil total nitrogen, soil pH, soil organic carbon and soil total phosphorus in coffee treated with chemical fertilizers. These families differed with land uses as they were separated in correspondence analysis ordination space and form their distinctive group (Fig. 3).

Table 1
Variations in soil properties (mean, standard deviation, statistical significance, and ranges in soil properties (SOC: Soil Organic Carbon, Tot N: Total Nitrogen, Tot P: Total Phosphorus, and CEC: Cation Exchange Capacity) under coffee and banana treated with chemical and organic fertilizers (*: adequate - the quantity is in the required range, **: inadequate – the quantity is either low or high of the required range, The analysis of variance was calculated by the use of Tukey honestly significant differences at $P < 0.05$).

Land Use	pH water	SOC (g/Kg)	Tot N (g/Kg)	Total P (mg/kg)	CEC (mmol/kg)
Coffee (Rubona)	5.8 ± 0.4 $^{a, *}$	32.6 ± 1.3 $^{a, *}$	3.0 ± 0.3 $^{a, **}$	15.8 ± 10.3 $^{b, **}$	80.0 ± 0.0 ^{a,*}
Coffee (Kigoma)	5.5 ± 0.0 $^{a, *}$	19.1 ± 1.0 $^{b, *}$	1.8 ± 0.0 $^{b, *}$	0.7 ± 0.0 $^{a, **}$	76.6 ± 0.4 $^{a, *}$
Banana (Rubona)	6.1 ± 0.5 $^{a, *}$	25.7 ± 0.7 $^{a, *}$	4.6 ± 0.1 $^{a, **}$	13.7 ± 8.0 $^{b, **}$	119.0 ± 0.0 ^{a,*}

4. Discussion

4.1. *Diversity and abundance of soil-litter arthropods per land use type and management*

High abundance and diversity of soil-litter arthropods were found in coffee plantations treated with organic fertilizers and organic mulches compared with coffee plantations treated with chemical fertilizers, and banana plantations treated with organic fertilizers and organic mulches. A recent study on chemical fertilizers and their impact on soil health and soil quality has indicated that constant use of chemical fertilizers may result in the decrease of useful soil organisms (Pahlvi et al., 2021). This has been confirmed by a study on effects of chemical fertilizers on soil microbial growth and populations which has indicated low microbe populations in the fields treated with chemical fertilizers mainly due to the decrease in soil organic matter (Ojo et al., 2015). Another study on effects of organic fertilizers on soil microorganism has indicated that organic fertilizers favor the growth of microbial populations and their functions (Lazcano et al., 2021). With reference on these studies on soil microorganisms, we conclude that low abundance and diversity of soil-litter arthropods in coffee plantations treated with chemical fertilizers might be associated with the continuous use of chemical fertilizers. This however can be biased as soil-litter arthropods found in coffee

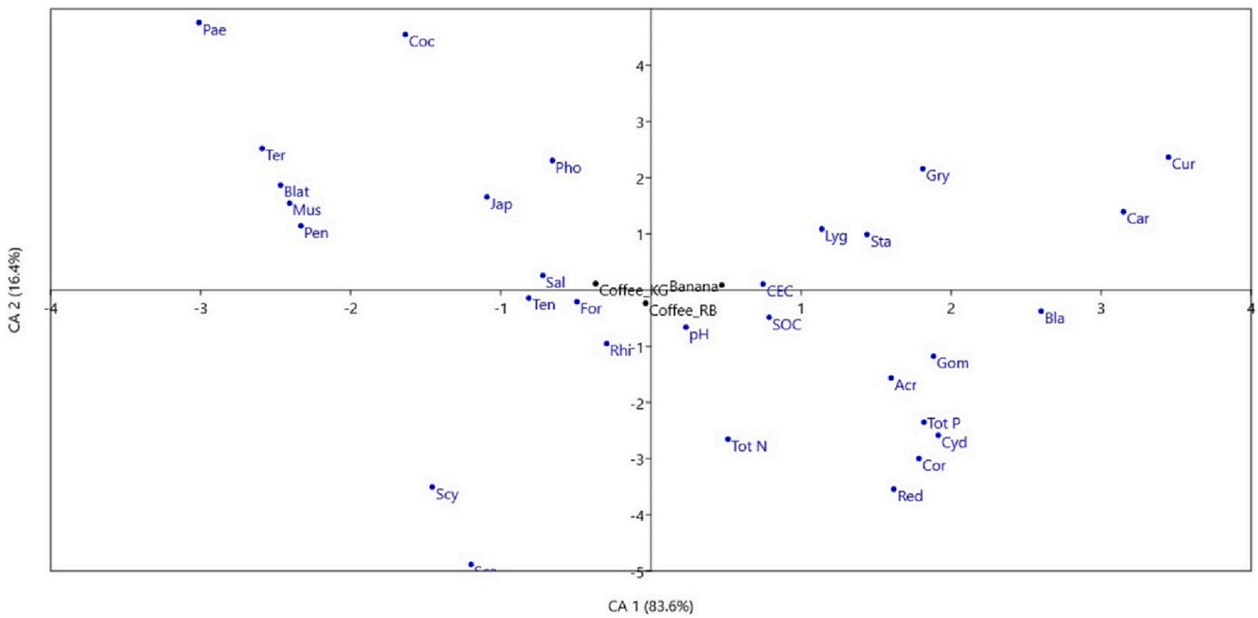

Fig. 3. The correspondence analysis (CA) visualizing the relationship between soil physicochemical properties, composition of the families of soil-litter arthropods and the land use. The graph was produced from Pearson correlation matrix between abundance of soil-litter arthropods and soil physicochemical properties pairwise for each land use system as co-variables with a significant threshold of $P < 0.05$. Coffee_KG: coffee treated with organic fertilizers and organic mulches, Coffee_RB: coffee treated with chemical fertilizers, CEC: cation exchange capacity, SOC: soil organic carbon, Tot N: total nitrogen, Tot P: total phosphorus, Sal: Salticidae, Jap: Japygidae, Pho: Pholcidae, Coc: Coccinellidae, Pae: Paederinae, Ter: Termitidae, Blat: Blattidae, Mus: Muscidae, Pen: Pentatimidae, Sca: Scarabaeidae, Scy: Scymaenidae, Rhi: Rhinotermitidae, Ten: Tenebrionidae, For: Formicidae, Lyg: Lygagenidae, Sta: Staphylinidae, Gry: Gryllidae, Car: Carabidae, Cur: Curculionidae, Red: Rediviidae, Cor: Coreidae, Cyd: Cydnidae, Acr: Acrididae, Gon: Gomphodesmidae, Bla: Blatellidae. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

plantations treated with chemical fertilizers might have developed tolerance ability to chemical fertilizers applied in the area (Ciaccia et al., 2019).

Low abundance of soil-litter arthropods was found in banana plantations treated with organic fertilizers and organic mulches. This was in contradiction with another recent study in the same banana plantation which indicated high abundance and diversity of soil-litter arthropods (Nsengimana et al., 2021) due to the continuous use of organic fertilizers and organic mulching practices, providing suitable habitat and prey to soil-litter arthropods (Vargas, 2006). Low abundance and diversity in the present study are associated with disturbances in the plots of banana plantations, as during the field data collection, we have observed that plots of banana plantations have been cleared during weeding activities and the organic mulches which could serve as the habitat and source of food for soil-litter arthropods have been disturbed while adding new mulches.

4.2. *Effects of organic mulches, chemical and organic fertilizers on selected soil properties*

Results of this study have also indicated that coffee plantations treated with organic fertilizer and organic mulches have high acid soil levels compared with coffee plantations treated with chemical fertilizers and banana plantations treated with organic fertilizers and organic mulches. This might be related to the historical background of the area where these coffee plantations treated with organic fertilizers and organic mulches are planted. The land has been used for *Eucalyptus* plantations for a long time before becoming a land for coffee plantation in 2019. This may take longer time to move out effects of *Eucalyptus* tree species. In this regard, the *Eucalyptus* like other exotic tree species is blamed to increase soil acidification by the production of organic acids from litter decomposition (Nsabimana et al., 2008).

On the other hand, the banana plantation had less acidic soils due to the application of organic fertilizers and organic mulches (Dębska et al., 2016) contributing to the availability of high exchangeable base cations in soil. These cations are moving from soil to negatively charged organic colloids from organic fertilizers and organic mulches at the soil surface (Sharma et al., 2012). Advantages of using mulches and organic fertilizers are extended to the conservation of soil moisture, minimizing soil compaction and soil erosion, regulation of soil temperature, improvements in soil fertility, mitigation of soil salt stress. In addition, they contribute to plant growth, plant development, improve crop yield, reduce diseases, control the weed populations, remediate heavy metals, and lower soil pH (Iqbal et al., 2020). Further, organic mulches and organic fertilizers are appreciated for their low cost compared with organic fertilizers.

However, differences in soil organic carbon, total nitrogen, total phosphorus and cation exchange capacity in coffee and banana plantations treated with organic fertilizers and organic mulches and coffee plantations treated with chemical fertilizers may be due not only to the use of chemical fertilizers that increase these nutrients in the soil, but also to agricultural practices in banana plantations and previous land use now occupied by coffee plantations treated with organic fertilizers and organic mulches. A study has indicated that soil organic carbon is mainly influenced by the decomposition rate of the litter and shrubs (Kassa et al., 2017).

Further, low levels in soil organic carbon under banana plantations can be associated with weeding practices which disturbed the surface soil and organic mulches, while low levels in coffee plantations treated with organic fertilizers and organic mulches might be associated with effects of *Eucalyptus* tree species that have been in the area long time ago and could have depleted soil nutrients, decreased available water resources and suppressed ground vegetation by the secretion of allopathic chemicals (Jagger and Pender, 2003). Higher levels of total phosphorus and total nitrogen in coffee plantations treated with chemical fertilizers was associated to higher inputs of inorganic fertilizers in the soil (REMA, 2014), while low levels in cation exchange capacity in coffee plantations treated with organic fertilizers and organic mulches was enhanced by the accumulation of hydrogen ion from organic acids (Hertemink, 2003), and variations in exchangeable base cations (Kassa et al., 2017).

4.3. Relationships between soil physicochemical properties and soil-litter arthropods

The correlation between families of soil-litter arthropods specifically for the families of Salticidae and Pholcidae (Araneae), Japygidae (Diplura), Termitidae (Isoptera), Blattidae (Blattodea), Muscidae (Diptera), Pentatomidae (Hemiptera), Coccinellidae and Paederinae (Coleoptera) in coffee plantations treated with organic fertilizers and organic mulches were found in this study. Japygidae are generally omnivorous and feed on both living and decaying vegetation and/or animals. Predatory activities have been also observed for this family (Koch, 2009). Further, some species of Termitidae raise soil pH, and contribute to the increase of soil organic carbon (Donovan et al., 2001). We conclude that the mode of feeding of Japygidae and Termitidae enhances the decomposition processes in soils which enriches the soil in nutrients (Grazia et al., 2015). On the other hand, even though Araneae are bioindicators of environment change (Maleque et al., 2009), while Coccinelidae are predators (Biranvand et al., 2018), nothing is known about the contribution of Salticidae, Pholcidae, Coccinelidae and Paederinae families to soil properties. Maybe they do it through predation on the prey that has an impact on soil properties, or their presence might be associated to other characteristics not measured by this study such as the vegetation types under coffee plantations treated with organic fertilizers and organic mulches or parts of coffee plantations.

Further, a positive correlation was found between Formicidae, Rhinotermiridae, Scarabaeidae, Scydmaenidae, and Tenebrionidae families and form a separate group, not related to any land use. For Formicidae and Rhinotermiridae families the correlation might be associated with their mode of life and adaptations that allowed them to tolerate chemical fertilizers. Formicidae have high ability to respond to changing environments (Majer, 1983), while Rhinotermiridae are pest of insects feeding on wood. Both Formicidae and Rhinotermitidae are good leaf-litter decomposers and create galleries in the soil (Lainé and Wright, 2003) that increase soil aeration and facilitate water infiltration. Members of the family of Scarabaeidae mainly fed on growing plant roots and/or leaves (Briatnica, 2020), while members of Tenebrionidae family are generalist omnivores that fed on decaying leaves, rotting wood, fresh plant matters, dead insects, and fungi (Bousquet et al., 2018) allowing them to survive environmental conditions imposed by the land use. More studies are needed to verify if the feeding mode and the ecological function of the individuals making these families are the ones driving their adaptation to the lands treated with chemical fertilizers.

A positive correlation was also found between cation exchange capacity and the families of Lygaeidae, Staphylinidae, Carabidae, Curculionidae and Gryllidae mainly in banana plantations treated with organic fertilizers and organic mulches. The occurrence of these families might be associated to the presence of mulches in banana plantations despite their disturbance by weeding practices. Members of the Lygaeidae are pests of agricultural plants and other vegetation (Capinera, 2020). Most Staphylinidae species prefer moist habitats associated with soil or decaying organic matter and may consume maggot eggs and larvae, mites, and springtails, while some others may eat insect eggs or small insects on foliage. Some others feed on the eggs and maggots of flies (Bohac, 1999). Carabidae consume soil dwelling insects including caterpillars, wireworms, maggots, ants, aphids, and slugs, and several of them may also eat seeds of weeds. Their prey preferences can change throughout their life cycle based on nutritional needs or change in the resources or environment (Liebmanand and Gallandt, 1997). Curculionidae occur all over the world, where they feed on all types of plants (Rolf et al., 2007), while Gryllidae are omnivorous and can accept a wide range of organic food stuffs. Some species are completely herbivorous feeding on flowers, fruits, and leaves. Some others are predators depending on eggs of other invertebrates, larvae, and pupae. Furthermore, others are scavengers depending on different organic remains, decaying plants, seedlings, and fungi (Naskrecki, 2013). The correlation might be associated with shared mode of life of these insects.

The families of Reduviidae, Coreidae, Cydnidae, Acrididae, Gomphodesmidae, and Blatellidae correlated with total nitrogen, soil pH, soil organic carbon and total phosphorus and total nitrogen in coffee treated with chemical fertilizers. Reduviidae are predators, while Coreidae are plant feeders which can enrich soil in nutrients (Doughty et al., 2016). Cydnidae take liquid from the plant phloem vessels and often feed on plant roots (Henry, 2009), Acrididae feed on plant foliage and grasses, even though they can take a variety of plants as source of food (Capinera et al., 2012) and Gomphodesmidae are leaf-litter decomposers. Members of these families enrich soil in nutrients; hence their mode of life allows them to survive different levels of soil pH, soil total phosphorus, soil total nitrogen and soil organic carbon regardless of the vegetation type, even though this might be confirmed by a separate detailed study.

4.4. Conclusion and recommendations

This study indicated high diversity and abundance of soil-litter arthropods in coffee plantations treated with organic fertilizers and organic mulches compared to coffee plantations treated with chemical fertilizers and banana plantations treated with organic fertilizers and organic mulches. Further it shows statistically significant differences in selected soil physicochemical properties and has indicated that soil-litter arthropods respond to the land use independently from soil physicochemical properties. We conclude that differences in soil-litter arthropods were associated with effects of organic and chemical fertilizers, farming management and land use history of the studied areas. However, other factors such as plant species interactions may have an implication on the diversity and abundance of soil-litter arthropods.

4.5. Limitation of the study and future research directions

Considering the current use of chemical fertilizers in Rwanda, the study should be extended to other crops such as maize, rice and Irish potatoes for example. Further, more agroecological zones could be studied to verify effects of agroecological parameters on the diversity and abundance of soil-litter arthropods and on soil physicochemical properties in addition to the use of chemical and organic fertilizers. Furthermore, other biological parameters such as soil microbiology could be studied. However, limitations in funding could not allow us to do so. We recommend future studies to be conducted in other agricultural plants treated with chemical fertilizers in different agroecological zones of Rwanda to verify findings of this study and to include effects of geological and altitudinal factors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crsust.2023.100215.

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