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Soil Macroinvertebrates and Soil Carbon Stock Ecosystem Services Across Managed Agroecosystem

Teresia Njeri[1*], Peter Njoroge Mwangi[1] Mary Wanjiku Gikungu[2]

[1]Department of Botany, Jomo Kenyatta University of Agriculture and Technology.
[2]Department of Invertebrates, National Museums of Kenya,
Teresia Njeri (https://orcid.org/0000-0002-2063-0259)[1*],
Peter Njoroge Mwangi (https://orcid.org/0009-0004-3226-6003)[1]
Mary Wanjiku Gikungu (orcid.org/0000-0002-4552-9325)[2]

*Corresponding email: twanyoro@gmail.com

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ABSTRACT

Soil macroinvertebrates in agroecosystems facilitate the soil biogeochemical processes which influence carbon stock ecosystem services and atmospheric circulations. Moreover, agronomic practices such as minimum tillage, influence the soil macroinvertebrate species abundance and richness. Currently, there is an increased interest in conservative agronomic practices that increase carbon stock ecosystem services to mitigate climate change. This study assessed the abundance and diversity of soil macroinvertebrates species and the quantity of soil carbon stocks ecosystem services across the conservative and non-conservative practices in tea, coffee and banana farms. The Tropical Soil Biology and Fertility Institute (TSBF) soil sampling procedure was used to collect data on macroinvertebrates across the two farming practices. Termitidae, lumbricidae and formicidae were the dominant families sampled in the agroecosystems. The farms that practiced conservation agriculture reported higher quantities of soil macroinvertebrate species richness and abundance. The conservation banana farm ($t_{166}=5.85$, $p<0.05$) coffee farms ($t_{166}=6.75$, $p<0.05$) and tea farm ($t_{166}=9.25$, $p<0.05$). The association between soil carbon and soil macroinvertebrates was positive in the banana farm ($r=0.224$) but negative in the coffee ($r = -0.104$, $p>0.05$) and tea ($r = -0.243$, $p=0.025$) farm. Conservation agricultural practices such as use of plant residues, farmyard manure and animal waste enriched the soil and attracted macroinvertebrates. Long term studies and increased conservation agricultural practices are recommended as a means of creating diverse agroecosystems which are similar to natural areas and rich in carbon stock ecosystem services.

Key words: Climate change, Macroinvertebrates, Carbon stocks, Agroecosystems, Ecosystem services.

INTRODUCTION

Soil as a physical resource influences the flow of many ecosystem services which supports agricultural activities (Binkley and Fisher 2019, Matei, Matei and Mocanu 2020). Soil is a physical resource that supports essential processes such as nutrient recycling and soil formation, which support agricultural production systems (Kulmatiski , *et al.* 2017). Soil functions facilitate accumulation and stabilization of carbon thereby regulating the atmospheric carbon (Filser, et al. 2016).

Soil invertebrates have important roles in handling organic material inputs in the soil and regulate resource distribution (Bennett, *et al.* 2017, Fujii , et al. 2018, Asaye and Solomon 2021). They are recognized for roles in nutrient recycles that connects lithospheric and atmospheric processes. They fragment and move organic residue within and between soil layers thereby influencing the soil carbon (Dempsey, Fisk and Fahey 2011). They constitute over 20% of earth's living organisms and facilitate communities' succession and diversity (Guerra, *et al.* 2021, Lavelle, *et al.* 2022).

Soil invertebrates are categorized into three groups including microfauna, mesofauna and macrofauna (Lavelle, et al. 2022, Zagatto, *et al.* 2020). The smallest micro-invertebrates comprise of prokaryotes, nematodes and protozoa while the medium sized mesofauna are composed of collembolans, springtails, mites, and oribatids (Darby and Neher 2016). The largest macroinvertebrates dwell in nests and burrows and includes ants, termites, snails, earthworms and crabs (Kamau, *et al.* 2017, Lavelle, *et al.* 2022).

The soil organic carbon ecosystem services form the biggest terrestrial carbon pool, containing up to three times the amount of carbon in the atmosphere (Tang, Yang and Markus 2022, Jörn, et al. 2014). They are therefore important in the global carbon cycle and energy balance (Navarro-Pedreño, Almendro-Candel and Zorpas 2021). Consequently, safeguarding the ecosystem services is a key strategy in mitigating climate change (Rumpel, *et al.* 2020). The quantity of these ecosystem services in the soil is also an indicator of the wellbeing and productivity of the soil (Zhao*, et al.* 2015).

Soil macroinvertebrates are vital components of agricultural ecosystems, supporting processes that sustain high crop production (Velasquez and Lavelle, 2019, Loranger-Merciris, *et al.* 2023). They are significant determinants of carbon stock ecosystem services dynamics through roles in waste breakdown and mineralization (Sutherlin 2021). Despite their evident value, intensified agricultural activities such as use of pesticides and herbicides constrain their growth (Chabbi, *et al.* 2017). Their reduced diversity impairs essential carbon regulation functions (Karungi, *et al.* 2018, Benito and Syamsu 2019).

There is paucity of information on the interactions between soil macroinvertebrates and soil carbon stock ecosystem services in differently managed agricultural ecosystems. In this study, we hypothesized that conservation agricultural practices encouraged higher abundance and diversity of soil macroinvertebrates as well as high quantity of soil carbon stock ecosystem services.

The main objective of the study was to determine the abundance and diversity of soil macroinvertebrates and soil carbon stock ecosystem services across the conservation and non-conservation tea (*Camellia sinensis*) (L)Kuntze, coffee (*Coffee arabica*) L. and banana (*Musa acuminata* Colla .) farms.

METHODOLOGY

The study was conducted during the wet (April–June) and dry season (July–September), 2021 in the Irati river basin, Muranga county. The area, which is under continuous utilization, falls within the upper midlands and lower midland agro-ecological zones of the Aberdares Ranges. The area is dominated by small scale cash crop farms which were derived from biodiversity rich montane forest ecosystems about 70 years ago. In the river basin, the dominant cropping systems include *Camellia sinensis*, *Coffee arabica* and *Musa spp*.

Soils include andosols and nitisols which have moderate to high fertility (Sombroek , Braun and van der 1980). The elevation is between 1790m and 2170m above sea level. The annual rainfall ranges between 1500 –1800mm, most of it falling during the long rainy season between March and May. Conservation agricultural practices such as minimum tillage, permanent plant cover, organic fertilizer, agroforestry, non-use of pesticides and crop diversification are common, however, with varying percentages of use. Accordingly, the study categorized the farms into conservation and non-conservation agroecosystems. Conservation practices included minimum tillage, permanent soil cover, organic fertilizer, agroforestry, non-use of pesticides and crop diversification. The conservation farms practiced at least five conservation agricultural practices while the non-conservation farms practiced agroforestry and use of inorganic fertilizer only.

Three major cropping systems including banana, tea, and coffee were identified by direct surveying of the study area. Ten plots per cropping system were established for sampling and the Tropical Soil Biology and Fertility Institute (TSBF) procedure was used for sampling (Anderson and Ingram 1993). Soils were dug out and all macrofauna encountered on litter and in the soil were hand sorted and identified to family level and returned to the soil. The unidentified macroinvertebrates were preserved in 70% alcohol and transported to the Kenya Forest Research Institute laboratory for identification to the species level. The study also used wet pitfall traps with a diameter of 30cm and a height of 45cm. The containers were filled with water and a drop of unscented and undyed soapy water was added to break the surface tension.

In the tea and coffee cropping systems, sampling plots measuring 10m x10m were set at a 500m interval. In the banana cropping systems, the sampling plots measured 5m x 5m because banana pseudo-stems tend to grow close together. Soil samples were extracted from the four corners and the centre of the sample plots within the cultivation depth of 0–30 cm, at three depth intervals; 0–10cm, 10cm – 20cm, and 20cm – 30cm using a hand-held soil sampler. The soil samples were manipulated to break the soil aggregates and to remove any plant residue.

The soil samples from different parts of the sample plots were mixed thoroughly to obtain composite samples for each depth. In the laboratory the samples were oven-dried at 45^0C for 2 days then ground and strained by 2 mm sieve (Gelderman and Mollarino 1998). The total organic carbon concentration was determined by the wet oxidation method (Walkley and Black 1934) and multiplying by a 1.33 factor (Rosell, Gasparoni and Galantini 2000).

The mean total organic carbon concentration and bulk density were used to calculate the soil organic carbon. The results were extrapolated to generate soil organic carbon in tonnes per hectare, according to Murphy et al., (2003) formulae:

$$SOC\ (t)/ha = C\ (\%) \times BD\ (g/cm3) \times D\ (m) \times 10000$$

Where;

C% in the carbon concentration,

BD is the bulk density

D is sampling depth.

The data collected were analysed using IBM SPSS Statistics for Windows Version. 20. 0 Armonk NY: IBM Corp.

RESULTS

The macroinvertebrates surveyed in the banana, tea and coffee cropping systems were identified to the family level (Figure 1). The most common soil macroinvertebrates were in the family termitidae followed by family lumbricidae and formicidae. The soil macroinvertebrates relative abundance was highest in the banana cropping system (45.8%) and lowest in the coffee cropping system (21.3%). The mean was significant across the cropping types *($F_{2, 298}$=15.53, p<0.05).*

Figure 1: Red legged millipede

Figure 2: Brown spider

Figure 3: White ant

Figure 4: Water beetle

Figure 5: Blue ant

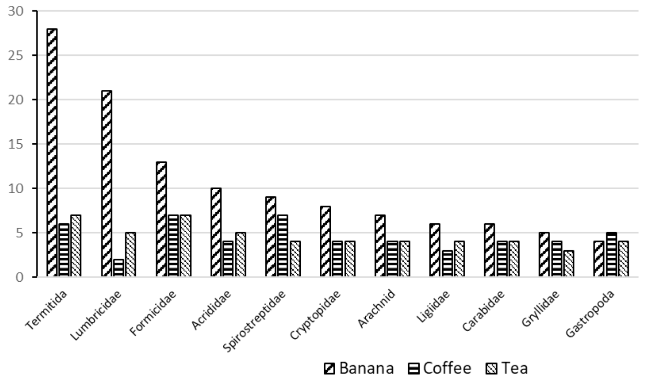

Figure 6: Density /m2 of different invertebrates recorded in different cropping systems

The conservation farms had higher abundance of soil macroinvertebrates than the non-conservation farms (Table 1). The means were significant across farming systems in the banana farm ($t_{166}=5.85,\ p<0.05$) coffee farms ($t_{166}=6.75,\ p<0.05$) and tea farm ($t_{166}=9.25,\ p<0.05$).

Table 1: Descriptive statistics for invertebrates across cropping systems and farming practices.

Cropping systems	Farming Practices	N	Mean	Std. Deviation	Std. Error Mean
Banana	Conservation Agriculture	100	54	14.06	1.41
	Non-Conservation Agriculture	100	39	13.35	1.35
Coffee	Conservation Agriculture	100	27	12.67	1.27
	Non-Conservation Agriculture	100	16	5.4	0.54
Tea	Conservation Agriculture	100	41	12.32	1.23
	Non-Conservation Agriculture	100	25	10.53	1.05

The 0 –10 cm depth had the highest relative abundance (91.5%) while 21-30 cm depth had the lowest relative abundance (1.7%). The mean was significant across the soil depth *($F2, 298=98.3, p<0.05$).* The Shannon Diversity Index species evenness was highest in the 0-10cm depth with an index of 1.97.

Table 2: Soli carbon stock ecosystem services (t/ha) in the different cropping systems.

Soil Depth	BANANA Mean	SD	COFFEE Mean	SD	TEA Mean	SD
0-10cm	21.32	5.83	10.79	5.09	18.82	17.51
10-20cm	19.32	6.07	6.91	5.40	17.02	17.40
20-30cm	20.34	7.67	6.40	3.20	11.22	4.53

The soil carbon stocks in the cropping systems are relatively uniform from one depth to another (Table 2). The associations between the soil carbon stock ecosystem services and the abundance of soil macroinvertebrates were negative in the coffee (r = -0.104, p>0.05) and tea (r = -0.243, p=0.025) cropping systems (Fig 7). In the banana cropping system the association was positive (r = 0.224, p =0.025) (Fig 8a and 8b).

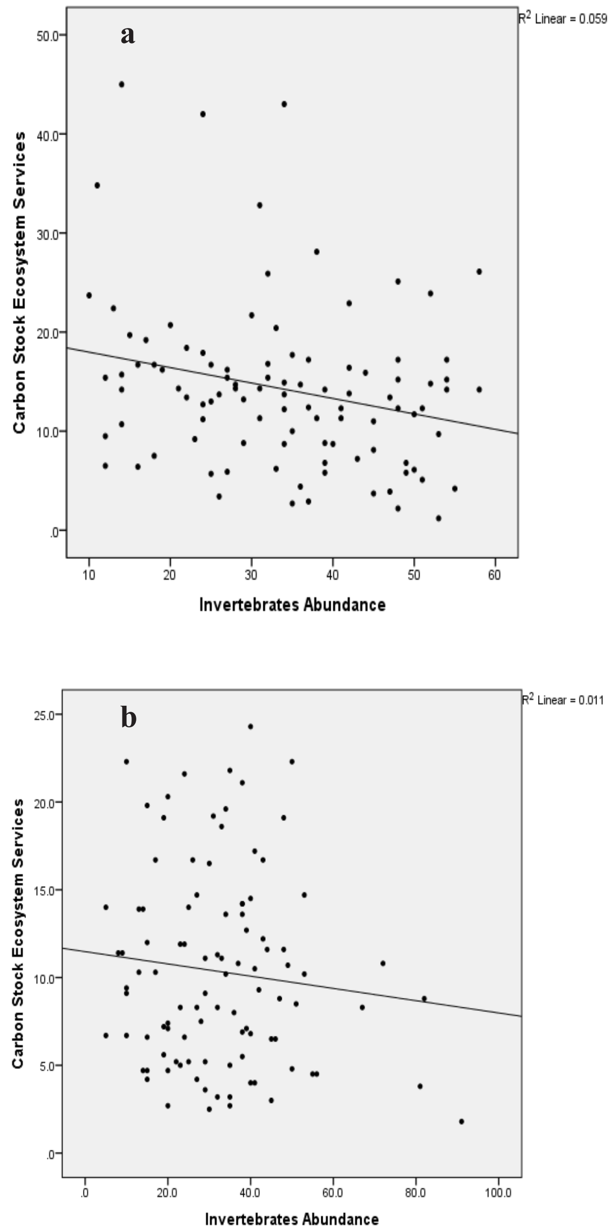

Figure 7: Correlations between the soil carbon stock ecosystem services and soil macroinvertebrates in the a) Tea and b) Coffee cropping system

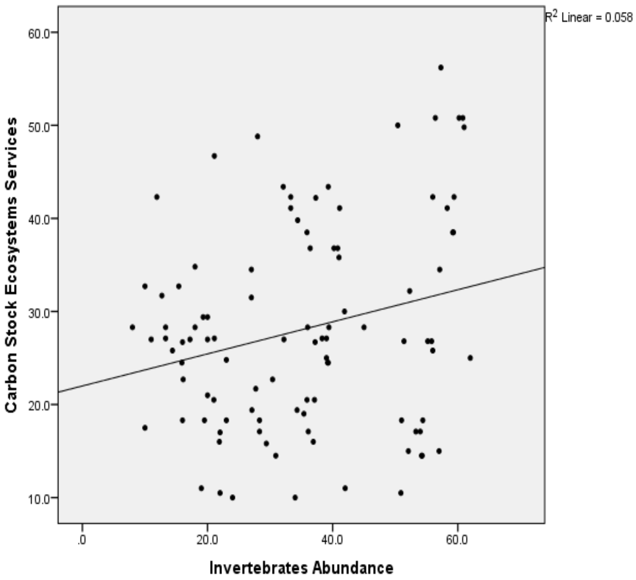

Figure 8: Correlations between the soil carbon stock ecosystem services and soil macroinvertebrates in the Banana cropping system

DISCUSSION AND CONCLUSION

The reported macroinvertebrates abundance is lower than what was reported by (Marichal, et al. 2014) and (Angelli , et al. 2020) for different landscapes and ecosystems. The study area was a pure agricultural landscape and at the time of the study, was under use for production of banana, tea and coffee. Agricultural ecosystems tend to have low abundance of macroinvertebrates (Sanchez-Bayo and Wyckhuys 2019), probably due to agricultural practices such as use of agrochemicals.

The banana cropping system was associated with a high soil macroinvertebrates species abundance and density compared to the tea and coffee. High abundance and density of soil macroinvertebrates occur in high plant productivity areas (Angelli , et al. 2020). The banana growth habits are attributed to increased plant productivity and therefore high soil macroinvertebrates abundance and density. The quantity of soil organic carbon followed a similar pattern where they decreased from banana farm through tea farm to the coffee farm.Unlike coffee and tea, banana farming does not involve the application of any agrochemicals.

The study shows that soil organic carbon and soil macroinvertebrates in the different farms have a positive correlation as was reported by Santorufo, *et al.* (2012). The agricultural soils benefit from carbon enrichment through application of organic fertilizers including plant residues, farmyard manure and animal waste. Soil macroinvertebrates are attracted to organic rich soils due to availability of diverse food resources (Ayuke, Zida and Lelei 2019).

The study reported high soil macroinvertebrate density and abundance in the 0–10 cm soil depth and a decrease along the soil depth (10cm–20cm and 20cm–30cm). The findings are consistent with the findings by (Mengistu, *et al.* 2018). The surface soils are favored by most soil macroinvertebrates due the presence of large amounts of litter, plant residue and humus.

The soil organic carbon decreased along the soil depth, with the 0–10cm depth having the highest soil organic carbon and the lowest being found in the 20cm–30cm depth. This pattern of decrease in soil carbon stocks with depth is also reported by other studies in agricultural ecosystems (Cheesman, *et al.* 2016) and in other ecosystems. This is partly because tillage improves soil aeration and consequently decomposition of organic material which have high concentration at surface.

The study recommends further studies to monitor macroinvertebrates on a long-term basis. This will help identify keystone, foundation and indicator soil macroinvertebrate species for monitoring the ecological soundness of agroecosystems. The long-term studies combined with expanded conservation agricultural practices will create agroecosystems rich in macroinvertebrate and carbon stock ecosystem services.

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