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ORIGINAL ARTICLE

Effect of Application of Different Combinations of Organic and Chemical Fertilizers on Soil Fauna in Marginal Oil Palm Fields in the Low Country Wet Zone of Sri Lanka

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Abstract

This study at *Talgaswella* Estate, *Elpitiya* Plantations PLC, in the low country wet zone of Sri Lanka, examined the impact of various combinations of organic and chemical fertilizers on soil fauna and pH in marginal oil palm fields. Using a randomized complete block design, eleven treatments ranging from absolute control to 100% inorganic and organic fertilizers and their combinations were tested in field plots, replicated three times. The aim was to understand how soil biota, particularly earthworms, responds to different fertilizer regimes and soil pH, highlighting the interaction between fertilizers and soil biodiversity, which influences long-term soil fertility and productivity. The fertilization strategy combined organic fertilizers like poultry litter (PL), empty fruit bunch (EFB), and palm oil mill effluent (POME) with inorganic fertilizers such as ammonium sulphate (AS), muriate of potash (MOP), and *Eppawala* rock phosphate (ERP) to meet the NPK needs of oil palm. Soil fauna, including earthworms, centipedes, millipedes, and beetles, were assessed over a one-week period every six months from May 2022 to March 2024 using field traps, covering both day and night. Two and a half years of post-treatment, earthworms were collected from two depth ranges using excavation techniques, while other fauna were collected from the topsoil. The study revealed that earthworm populations thrived in treatments with organic inputs, especially T_6 (50% CF + 50% OF [10% PL + 90% POME]), T_7 (75% CF + 25% OF [20% PL + 80% EFB]), and T_8 (75% CF + 25% OF [10% PL + 90% EFB]), supported by stable pH levels. Chemical fertilizers, like T_2, showed lower, though not significant, earthworm populations. Millipede populations were stable, with T_{11} (100% organic fertilizer) showing significant increases. In conclusion, organic fertilizer treatments, particularly T_{11}, significantly promoted fauna diversity, emphasizing the importance of balanced fertilizer regimes for soil health and biodiversity.

Keywords: *Empty Fruit Bunch (EFB), Oil Palm, Organic Fertilizer (OF), Palm oil mill effluent (POME)*

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1. Introduction

The oil palm comprises two species: *Elaeis guineensis*, native to Africa, and *Elaeis oleifera*, native to South and Central America. Both species are perennial tropical trees belong to the Arecaceae family are cultivated for edible oil production (Dissanayake and Palihakkara 2024). Palm oil finds applications in cooking, processed foods, as a butter substitute, in biodiesel, and in cosmetics (Hasanthi and Palihakkara 2020). Oil palm was introduced to Sri Lanka as a commercial plantation crop approximately 50 years ago, initially established in the Galle District as a rain-fed perennial cash crop. Renowned for its high oil yield and substantial annual dry matter production, the oil palm significantly depletes soil nutrients. The provision of adequate macro and micronutrients is essential for normal growth and development (Dissanayake and Palihakkara 2019).

The optimal pH range for oil palm cultivation is between 4.5 and 6.5. Deviations from this range can result in nutrient deficiencies or toxicities, adversely affecting growth and overall yield (Goh et al. 2016). Soils with high cation exchange capacity values (10 to 30 cmol kg^{-1}) are advantageous for nutrient retention (Wong et al. 2020). Thriving oil palm plantations typically have 2% to 5% organic matter content, which enhances soil fertility and microbial activity (Tao et al. 2016; Zainuddin et al. 2022). The oil palm thrives in well-drained soils with moderate water-holding capacity (20%–40%) (Gerard et al. 2017). Adequate soil porosity promotes root development and ensures an ample oxygen supply to the roots, which is crucial for healthy plant growth. The optimal bulk density ranges from 1.0 to 1.4 g cm^{-1} indicating well-aerated soils that facilitate root expansion and nutrient uptake (Gerard et al. 2017).

Fertilizers, both chemical and organic, are crucial for optimal crop production. Organic fertilizers have been used since the earliest days of agriculture. Extensive research has been conducted on the ecological interactions between oil palm cultivation and soil fauna, with a particular focus on how applying empty fruit bunches (EFB) affects soil biodiversity and fauna dynamics (Bessou et al. 2017) Research in Indonesia shows that applying empty fruit bunches (EFB) significantly enhances soil quality and biodiversity. Empty fruit bunches application increases macro-fauna and soil organic carbon levels, with a surge in ants, coleopterans, and bacteria-feeder nematodes, followed by recovery of earthworms, centipedes, and millipedes (Caliman et al. 2001).

The decomposition phase of EFB further enhances macro-fauna and nemato-fauna densities, demonstrating the intricate relationship between soil physico-chemical attributes and biological diversity (Carron et al. 2015a, 2015b). Metagenomic analyses reveal diversified soil bacterial species, enhancing soil fertility and highlighting positive impacts of EFB on soil microbial communities. Techniques like the bait-lamina strip method demonstrate increased soil fauna feeding activity during EFB decomposition (Carron et al. 2015a). We hypothesized that the complex ecological interactions between oil palm cultivation practices and soil fauna dynamics highlight the potential benefits of EFB application on soil biodiversity and fertility in oil palm plantations. This research aimed to explore the possibility of replacing inorganic fertilizers with organic alternatives and their effects on yield and the environment, particularly soil fauna. These findings might provide solutions to recycle EFB for improving soil fertility and underscore the importance of holistic approaches in optimizing co-product treatments and field management practices in oil palm cultivation.

2. Materials and Methods

This experiment was carried out at Talgaswella Estate, Elpitiya Plantations PLC (6.2555989 N, 80.2773739 E), within the WL_{1a} agro-ecological zone (Dissanayake and Palihakkara., 2019).

2.1 Experimental Layout

Experimental design followed a Randomized Complete Block Design with eleven treatments (T_1 to T_{11}) in three replicates. Treatments were formulated based on the annual nitrogen requirement of an oil palm plant, which is 0.63 kg plant per year (Table 1). Organic materials were added in varying quantities to different treatments to supply the required nitrogen (N), potassium (K), and phosphorus (P) for the palm (Table 1).

2.2 Fauna Counting

Soil fauna, including earthworms, centipedes, millipedes, and beetles, were counted using field traps over a one-week period, encompassing both day and night sessions at the conclusion of yearly cycles. This sampling methodology ensured a comprehensive assessment of soil fauna population dynamics, accounting for variations in activity levels across diurnal and nocturnal cycles.

From the beginning of the research in 2020 and from May 2022 to March 2024, fauna was collected from multiple replicate plots using excavation techniques and traps with a harmless irritant. A standardized 100 cm × 100 cm template delineated sampling areas in two randomly selected spots per treatment, across 33 plots comprising six plants each, covering all treatments and replicates.

For earthworm counting, sampling areas in two depth ranges (0–10 cm and 10–25 cm) were excavated using shovels. In designated areas, in addition to trapped fauna, the top organic layer was removed prior to sampling, and millipedes and beetles found there were collected. Soil samples were manually sifted, and the fauna were placed in plastic bags with cool water, shielded from direct sunlight. After excavating the 0–10 cm and 10–25 cm layers, a mustard solution (1 tablespoon of dry, ground mustard per litre of water) was poured into the soil and left for 20 minutes (Lawrence and Bowers., 2002) to bring deep-burrowing fauna to the surface. This mustard solution, a known non-toxic irritant, facilitated the collection of elusive species. Earthworms, centipedes, millipedes, and beetles were temporarily preserved on ice before being transferred to the laboratory and then preserved in a 10% formalin solution (Smith et al., 2008).

The recorded counts of soil fauna were meticulously organized and catalogued, establishing a robust dataset for subsequent identification and interpretation.

2.3 Data Analysis

Data were analysed using Kruskal-Wallis one-way non-parametric ANOVA for interpretation and the mean rank of each variable were separated using a post hoc Statistical method.

Table 1: The structured treatments to incorporate a combination of both chemical and organic fertilizers

Treatment	Description of Chemical and Organic Fertilizer Combination
T_1	Neither chemical nor organic fertilizer
T_2	100% Chemical Fertilizer (CF) (SA -3kg, MOP - 2.5 kg, ERP - 3Kg)
T_3	50% CF + 50% Organic Fertilizer (OF) (20% PL+ 80%EFB)
T_4	50% CF + 50% OF (10% PL + 90% EFB)
T_5	50% CF + 50% OF (20% PL + 80% POME)
T_6	50% CF + 50% OF (10% PL + 90% POME)
T_7	75% CF + 25% OF (20% PL + 80% EFB)
T_8	75% CF +25% OF (10% PL + 90% EFB)
T_9	75% CF + 25% OF (20% PL + 80% POME)
T_{10}	75% CF +25% OF (10% PL + 90 %POME)
T_{11}	100% Organic Fertilizer (PL - 7.5 Kg, EFB - 20.3 kg, POME - 13kg)

(SA -Sulphate of Ammonia, MOP - Muriate of Potash, ERP -Eppawala Rock Phosphate CF- Chemical Fertilizer, EFB- Empty Fruit Bunches, POME – Palm Oil Mill Effluent, PL – Poultry Litter, OF-Organic Fertilizer)

3. Results and Discussion

The study compared the periodic variation of soil fauna (Fig. 1) over time. The impact of two fertilizer regimes was compared: the total chemical fertilizers applied per tree per year, which included 3 kg of Sulphate of Ammonia, 2.5 kg of Muriate of Potash, 3 kg of Eppawala Rock Phosphate, and the total organic fertilizer used per tree per year, which consisted of 7.5 kg of poultry litter, 20.3 kg of empty fruit bunches, and 13 kg of palm oil mill effluent to provide balance nutrient requirements for all the treatments accordingly (Table 1).

3.1 Earthworms count

During the two-year observation period, treatments with consistently high earthworm counts (T_6, T_7, and T_8), exhibited relatively high counts and stable pH levels indicating a relationship between pH and earthworm population (Table 2). This aligns with previous studies showing that earthworms can be variably sensitive to soil pH. For instance, species like *Lumbricus terrestris* and *Aporrectodea caliginosa* thrived better in soils with pH as low as 5.4 and 5.2-5.4, respectively (Edwards and Arancon 2022, Anoop and Garg 2011). In contrast, T_2, despite showing an increase in pH, had a minimal earthworm count. In addition, T_3 to T_{11} did not show any significant difference ($P > 0.05$) in earthworm counts between of the two treatments. This suggests that while trends are possible, the presences of earthworms were not solely dependent on the soil pH but could be subjected to the responses from other environmental factors such as rain fall and relative humidity (Jänsch et al. 2005).

Table 2 indicates that all treatments did not significantly differ in their effect on earthworm counts. This consistency in earthworm populations across treatments, despite some variability, reflects the ability of earthworms to tolerate a wide range of soil pH (Eijsackers 2011). This study further established that the optimal pH condition for the majority of earthworm species was found to be in a range between 5 to 6. This finding is aligned to observations by of Edwards and Arancon, (2022), in which the highest increment in earthworm population was observed when the pH shifted from 5.1 to 5.9. Conversely, a decline in earthworm population occurred when the pH levels dropped below 5.5, highlighting the sensitivity of earthworms to pH variations.

Overall, results of this study underscore the importance of pH management in soil ecosystems on account of earthworms. Understanding the preferences and tolerances of different earthworm species to pH variations is crucial for soil management practices, agricultural productivity, and ecosystem health.

Table 2: Comparison of pH variation and earthworm counts during the experimental period.

Treatments	In 2023 May			In 2024 March		
	pH	**Earthworm count** 0–10 cm	**Earthworm count** 10–25 cm	**pH**	**Earthworm count** 0–10 cm	**Earthworm count** 10–25 cm
$\mathbf{T_1}$	5.3	1^a	1^a	6.1	1^a	1^a
$\mathbf{T_2}$	5.3	0^a	1^a	6.1	1^a	0^a
$\mathbf{T_3}$	5.1	3^a	2^a	5.9	4^a	4^a
$\mathbf{T_4}$	4.9	4^a	3^a	5.8	4^a	4^a
$\mathbf{T_5}$	4.8	4^a	4^a	5.7	4^a	5^a
$\mathbf{T_6}$	4.5	5^a	5^a	5.5	5^a	5^a
$\mathbf{T_7}$	5.2	5^a	5^a	5.7	5^a	5^a
$\mathbf{T_8}$	4.9	5^a	4^a	5.6	4^a	5^a
$\mathbf{T_9}$	4.8	5^a	4^a	5.7	4^a	4^a
$\mathbf{T_{10}}$	5.0	5^a	4^a	5.5	4^a	4^a
$\mathbf{T_{11}}$	4.8	5^a	4^a	5.7	5^a	4^a

The values do not show statistical significance at the P = 0.05 level.

Initially, most treatments had no earthworms, except T_1, T_9, and T_{11}, which each had only one count (Table 2). After the first year, T_1 had zero earthworms, while T_{10} and T_{11} recorded the highest counts at five each. In the second year, T_2 had the lowest count of one, while T_6 and T_7 had the highest counts of 10. Despite these differences, the non-significance of these suggests the influence of other factors on earthworm populations at the given site.

These results align with existing research on the interaction between earthworms and various fertilizers. Earthworms, *E. fetida* and *E. eugeniae,* are essential in managing organic waste and can thrive on a diversity of organic materials, including livestock excrement, agricultural residues, oil palm waste, and sewage sludge (Bhat et al. 2018). The high nutrient content and the added non-toxic nature of palm oil mill effluent (POME) make it suitable for land application, enhancing possibility of waste management through composting and vermi-composting (Syirat et al. 2014; Bulugahapitiya et al. 2024).

Studies have shown that earthworms, particularly *E. fetida*, performs well with substrates like empty fruit bunches (EFB) and POME, which effectively decompose to produce organic matter with low carbon-to-nitrogen (C/N) ratios, thereby increasing nutrient availability (Hayawin et al. 2014). Organic fertilizers have been found to positively affect earthworm activity and abundance, underscoring the importance of organic inputs for soil health and biodiversity. Conversely, inorganic fertilizers such as urea can negatively impact earthworm populations, particularly that of *E. foetida* (Rai et al. 2014).

The highest increase in earthworm population in this study, was a 50% rise, occurred in the treatment combination of 50% chemical and 50% organic fertilizers (T_3). This suggests the role of organic inputs in influencing the natural earthworm populations, supporting the observed trends that organic inputs promote better earthworm activity and overall soil health.

3.2 Centipede counts

Distinct trends in centipede population dynamics were observed across various experimental treatments during the two-year period (Table 3). However, none of them were statistically significant ($P > 0.05$). Overall, centipede populations remained stable or showed slight increases among treatments, with treatment T_{11} exhibiting a notable increase in its centipede counts from the first to the second year.

Table3: Centipede counts after treatment application, from October 2021 to May 2023

Treatments	Initial average Centipedes count	First year count	Second year count
T_1	0^a	1^a	1^a
T_2	0^a	0^a	1^a
T_3	1^a	1^a	1^a
T_4	0^a	0^a	1^a
T_5	1^a	2^a	0^a
T_6	0^a	0^a	1^a
T_7	1^a	0^a	1^a
T_8	0^a	0^a	1^a
T_9	1^a	0^a	1^a
T_{10}	1^a	0^a	1^a
T_{11}	1^a	1^a	3^a

The values do not show statistical significance at the P = 0.05 level.

3.3 Count of Millipedes and Centipedes

During the two-year study period, from October 2021 to May 2023, millipede counts across different treatments (T_1, T_2, T_3, T_5, T_6, T_7, T_8, and T_9) started with an initial average of zero to one millipede, with variations observed in subsequent years (Table 4). Treatment T_4, and T_{10} started with zero millipedes initially, showing an increase in the second year. Treatment T_{11} exhibited the most substantial increase, starting with zero millipedes and reaching three and five millipedes in the first and second years, respectively.

Centipede and millipede populations across treatments remained relatively stable, while treatment T_{11} recorded a notable rise in its counts over the two-year period. Millipede counts varied across treatments, treatment such as T_{11} exhibited a substantial increase from zero to five millipedes, while others either fluctuated or remained stable. Centipede population did not show any significant difference in among the treatments (Table 3).

Table 4: Millipede counts after treatment application, from October 2021 to May 2023

Treatments	Initial average millipedes count	First year count	Second year count
T_1	0^a	1^a	1^b
T_2	0^a	0^a	0^b
T_3	0^a	1^a	1^b
T_4	0^a	0^a	2^b
T_5	1^a	1^a	1^b
T_6	0^a	1^a	2^b
T_7	1^a	2^a	2^b
T_8	1^a	1^a	2^b
T9	1^a	3^a	2^b
T_{10}	0^a	1^a	3^b
T_{11}	0^a	3^a	5^a

*In each column, values followed by the same letter are not significantly different at P=0.05

3.4 Counts of Beetles

The beetle population dynamics across various treatments from October 2021 to May 2023 exhibited considerable variability. Initially, several treatments recorded zero beetles, while several recorded one beetle. Over the two-year period of treatments, T_2 showed no change in beetle counts, while T_{11} displayed a significant increase. Other treatments either remained unchanged or exhibited a decline. Treatment T_1, which began with zero beetles, resulted an increase to one beetle by the end of the second year (Table 5). Beetle populations exhibited diverse responses to the different fertilizer treatments, with certain treatments exhibited an increase in beetle number over time. Notably, T_1showed an increase from zero to one beetle by the end of the study.

Table 5: Beetle counts after treatment application, from October 2021 to May 2023

Treatments	Initial average count	First year count	Second year count
T_1	0^a	0^a	1^b
T_2	1^a	0^a	1^b
T_3	0^a	1^a	1^b
T_4	0^a	1^a	1^b
T_5	0^a	1^a	2^b
T_6	0^a	1^a	2^b
T_7	0^a	3^a	2^b
T_8	0^a	2^a	2^b
T_9	0^a	3^a	3^b
T_{10}	1^a	3^a	2^b
T_{11}	0^a	4^a	6^a

* In any column, values followed by similar letters are not significantly different at P=0.05

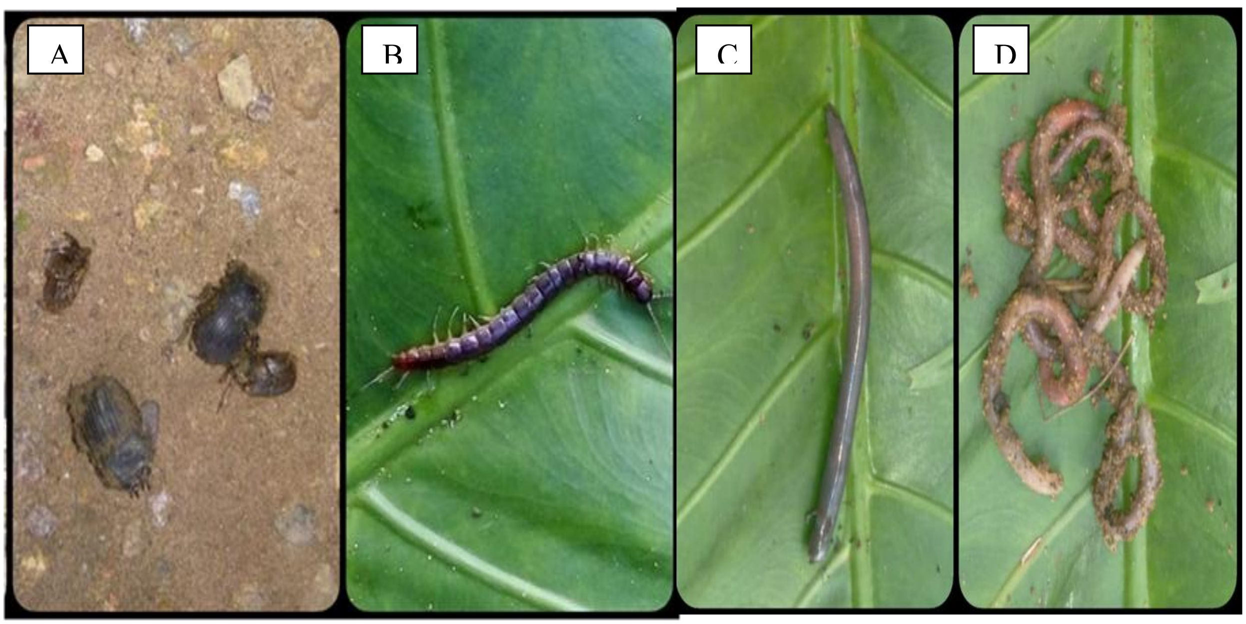

Figure 1: Some fauna species observed during the study: A - Dung Beetle (*Deltochilum valgum)*, B – Centipede (*Scolopendra morstans*), C – Millipede (*Spirobolus formosae*), D – Earthworms (*Eisenia fetida*) Laurence Culot et al. (2013), Tripathi and Sharmae (2005), Wang et al. (2019), Anoop and Garg (2011).

Hole et al. (2005), Laurence Culot.et al. (2013) and Mäder et al. (2002) emphasised the importance of organic inputs in enhancing soil dynamics. Organic matter inputs during organic farming practices stimulate soil processes like ammonification and nitrification, thereby increasing nutrient availability and microbial function (Burger et al. 2003). Organisms like millipedes and centipedes contribute to the breakdown of organic materials, further improving nutrient cycling and soil health (Bagyaraj et al. 2016).

Retaining crop residues and adopting organic farming practices promote below-ground biodiversity and beneficial interactions among soil organisms (Burger et al. 2003). These practices enhance soil structure while supporting macro-fauna like earthworms, which are critical for soil aeration and nutrient cycling. Studies by Sadej et al. (2012) have shown similar positive effects of organic fertilizers on soil quality and beetle populations.

Farmyard manure and bovine liquid manure fortify soil structure, enhance microbial diversity, and provide varied habitats and food sources for beetles (Streever 2007; Pearsons and Tooker 2017). Organic fertilizers enrich soil organic matter, which is vital for the lifecycle stages of beetles that ensure proper development and survival rates of larvae and providing sustenance for adult beetles. This promotes beetle abundance and diversity across agricultural landscapes (Vanmare, 2021; Brown et al., 2001).

In contrast to synthetic fertilizers, which may degrade soil health and biodiversity, organic alternatives offer a sustainable foundation for soil management. Hence, organic manures nurture soil vitality, facilitate nutrient cycling, and support diverse ecosystems, thus bolstering agricultural system resilience and mitigating environmental risks (Thripathi et al. 2020).

4. Conclusions

Based on the comprehensive analysis of soil fauna dynamics under various fertilizer treatments spanning from October 2021 to May 2023, several key conclusions were drawn. Firstly, treatments combined organic and chemical fertilizers: (T_6(75% CF + 25% OF (20% PL + 80% EFB)), T_7(75% CF + 25% OF (20% PL + 80% EFB)), and T_8,(75% CF +25% OF (10% PL + 90% EFB)) consistently supported higher earthworm populations, highlighting the positive impact of organic matter supplementation on the presence of soil fauna. Conversely, treatments relying solely on chemical fertilizers, generally exhibited lower earthworm counts, indicating less favourable habitat conditions.

The use of 100% organic fertilizer (T_{11}), emerged the most effective for increasing faunal diversity while enhancing the soil carbon content. This treatment significantly improved both beetles and millipede populations over the two-year period compared to the rest. The notable increase in centipede numbers underscore the positive impact of organic inputs on supporting diverse soil fauna populations. The treatment [Name] (T_2), which relied solely on 100% chemical fertilizers without any organic supplementation, was less favourable for faunal diversity. Application of 100% chemical fertilizers consistently exhibited lower earthworm counts and minimal increases in centipede and millipede populations compared to the treatments that received organic inputs. Overall, the results of this study provide valuable insights into the ecological dynamics and functioning of the study area's soil ecosystem.

The integration of organic inputs into fertilizer practices has emerged as critical for enhancing and sustaining soil health and biodiversity in sustainable agriculture. These findings underscore the importance of balanced fertilizer regimes, which consider both chemical and organic components to support soil fauna populations while promoting ecosystem resilience over time. Furthermore, research into specific soil fauna preferences and their responses to varying fertilizer compositions could provide deeper insights into optimizing agricultural practices for enhanced soil fertility and ecosystem sustainability.

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